Test Stand Overview

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Review for the HL-LHC AUP Vertical Magnet Test Stand at BNL– August 1-2, 2018

Outline

- History – capabilities and projects
- Upgrades needed for LARP/AUP
- Commissioning
- Mirror Magnet Test
- Test of first long magnet
- Status today
- Risks (Charge 2a, 2b)
- Rick mitigation – FY19 requests to BNL
- Summary

History: Isabelle and SSC

- Isabelle:
  - 4.5 m dipoles, supercritical 4.5 K helium, horizontal test, 5 kA, Magcool (VAX-based) control -- cooldown, test, warmup.
  - Vertical dewars(5), 4.5 K liquid helium, 5 kA
  - Project cancelled in favor of SSC: 1983
- SSC:
  - Vertical test of 4.5 m dipoles (4.5 K liquid, 5k A)
  - Project cancelled: 1993, RHIC begins

RHIC

- 1,740 magnetic elements
- 3.5 T, 10 m dipoles, supercritical helium 5 kA
  - Beams to support magnets traded with DESY for short-sample testing, magnetic field meas equip
- Only 20% of arc dipoles cold tested
  - First 10% of production – test all; thereafter, 10%
- Vertical dewar:
  - Cold masses and short sample
  - DX – IR dipole with stored energy 1.1 MJ (largest)
- Testing complete ~ 1999.

Magnets and short-sample tests for the LHC

- Horizontal -- 22 Magnets:
  - Basis: RHIC arc dipole, but beam pipe is straight
  - Variants:
    - two coils in a single yoke (fields parallel)
    - Two cold masses in a single cryostat
  - Completed: 2005
  - APUL: two additional spares - CD-4 in 2014.

- Vertical: Short-sample tests at 4.5 K for LHC production cable.

Cryo Update and Upgrade (1)

- Update for 4.5 K vertical testing:
  - Funded by BSA (overhead), NP (operating account)
  - Monitor/Control: introduce Labview/National Instruments for remote monitoring of cryo
  - Purchase long-lead-time spare components
  - Replace leaking valves, add controls
  - Rebuild pumps, motors, …

Cryo Update and Upgrade (2)

- Upgrade for AUP testing
  - 1.9 K – Nash-Kinema high-capacity pump (SSC leftover) – write Labview control system, rebuild purchased new pump.
  - 1.9 K – New “top hat” (warm-cold interface) with lambda plate
  - 24 kA power supply: two existing 15 kA supplies in parallel, add fast shutoff (IGBTs), CLIQ, quench protection, Labview controls
    - CLIQ: capacitive-loss induced quench
  - DAQ – Labview, modern instrumentation
  - Magnetic field measurements: adapt BNL analysis to pickup windings (printed circuit) from Fermilab.

BNL contributions to cryo reliability and oven extension

Cost (k$)	Item
$313	Spare long-lead cryo components*
$220	Commission Sullair 500*, Nash-Kinema
$125	Refurbish magnetic field measuring equipment
$250	Extension of reaction oven
$378	Improve cryo reliability (requested)*
$204	Improve crane reliability (requested)*
$1,492	***TOTAL***
	(* reduces project risk)

Extraordinary Project Rate:

For labor the diff is of order ~ 30%

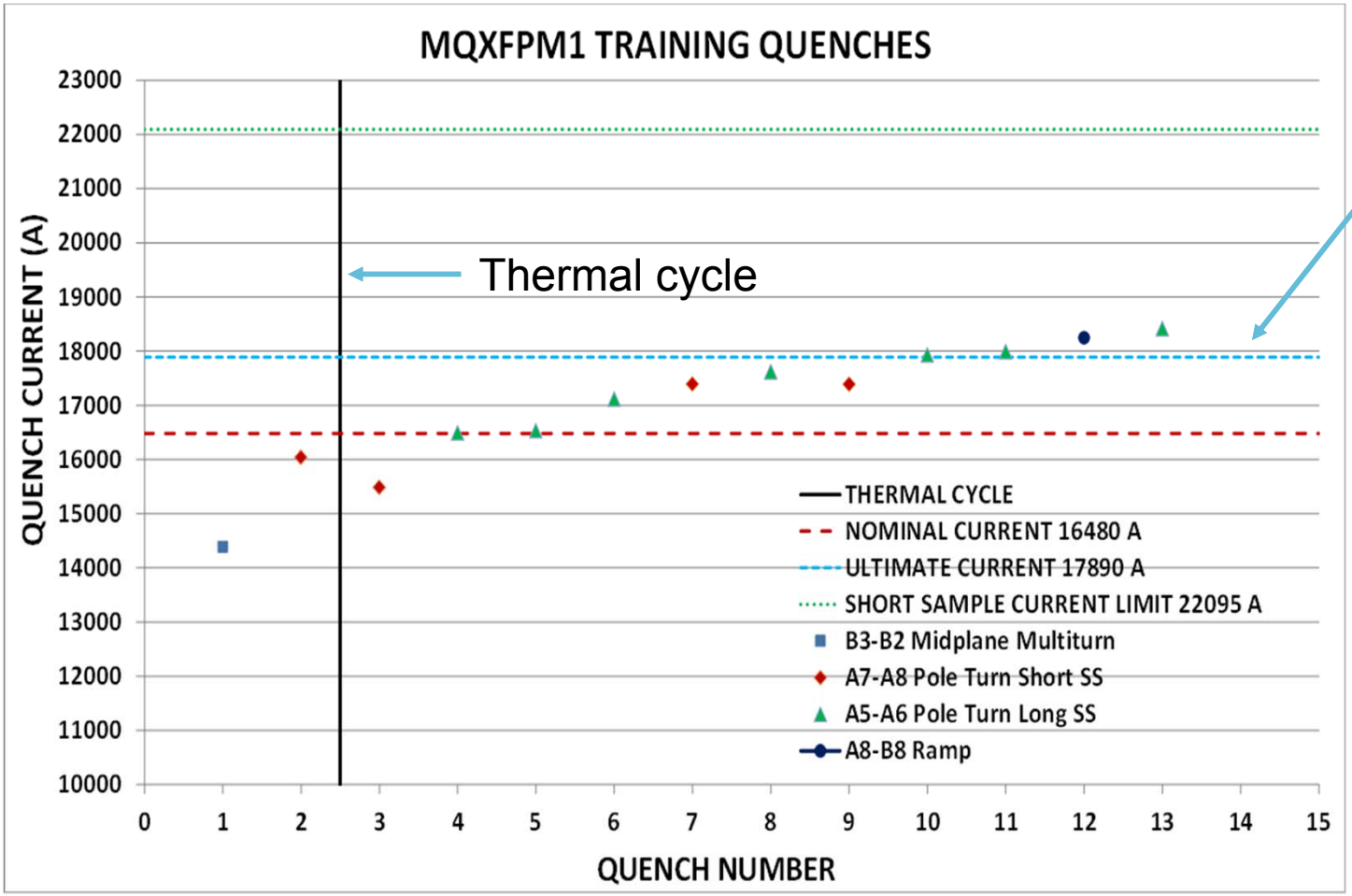
BNL support of 4.5K cryo – leverages upgrade for AUP

Mirror Magnet – Great Success for Magnet & Test Facility

- Mirror Magnet:
  - First long (4.0 m) coil – iron fills remaining ¾ of circle
  - Fields and forces comparable to full magnet
  - Trained well
    - Names: “nominal” = operating; “ultimate” ~8% above nominal
    - AUP requires magnet train above $I_{ultimate}$

- Test Facility:
  - Reached 1.9 K on first cooldown
  - Power supply with IGBT shutoff
  - Quench detection, heaters

Mirror Magnet Test Data

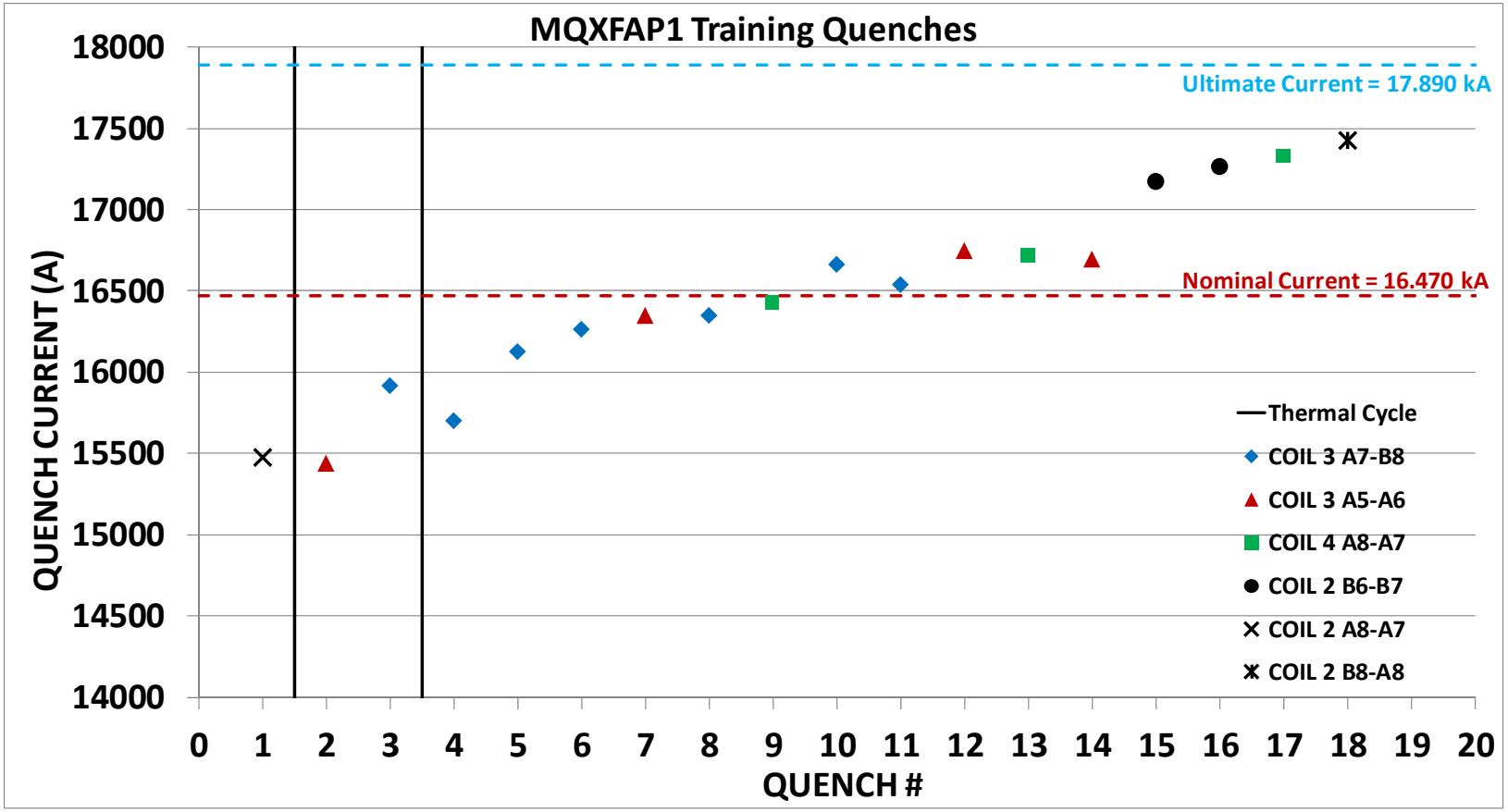


$I_{ultimate}$

Test of First Magnet MQXFAP1

- Major test facility issue: pressure during quench
  - Two cycles of: quench with burst disk rupture → calculate pressure rise, compare to measurements, reduce impedance to venting helium, add instrumentation, clean up cryo system → quench.
  - Third cycle: burst disk did not rupture, 15 quenches made (next slide). Helium vented through pressure relief valves.

Magnet MQXFAP1 - good training



Ground fault after quench 18. The sequence of events that led to the fault will not be repeated. Magnet being repaired (new coil).

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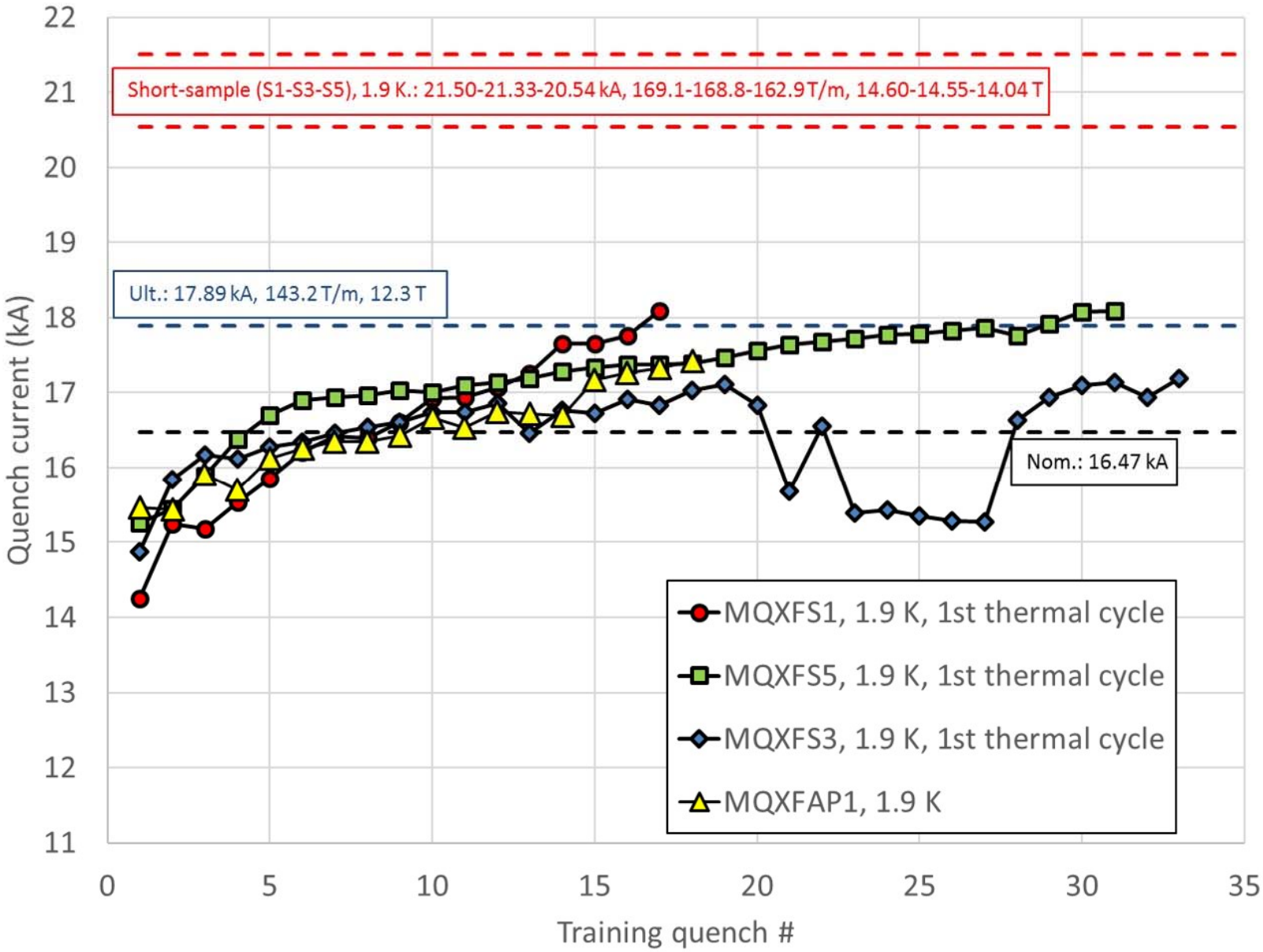

Short-sample (S1-S3-S5), 1.9 K.: 21.50-21.33-20.54 kA, 169.1-168.8-162.9 T/m, 14.60-14.55-14.04 T
Ult.: 17.89 kA, 143.2 T/m, 12.3 T
Nom.: 16.47 kA
MQXFS1, 1.9 K, 1st thermal cycle
MQXFS5, 1.9 K, 1st thermal cycle
MQXFS3, 1.9 K, 1st thermal cycle
MQXFAP1, 1.9 K
Quench current (kA)
Training quench #
22
21
20
19
18
17
16
15
14
13
12
11
0
5
10
15
20
25
30
35

Present Status

- Magnet P2 has just arrived from LBNL.
- Two issues in immediate future:
  - Excessive helium venting – improvement added after test of P1 – add dewar adjacent to test dewar to storage available for venting helium. Estimate that this may reduce venting helium to minor problem. (Additional capacity to be added after test of P2.)
  - Liquefaction capacity insufficient for 3 q/day. Solution: PNNL agreed to transfer ownership of Linde 1610 (almost new, not in use) to BNL. Contract to pack equipment has been issued. There was a safety incident during packing.

Risks: identified, mitigated (Charge 2a) Single-point failure (delay > 3 mo.) (Charge 2b)

- Identification:
  - Initial focus: electrical and cryo separately
  - Identification: long-term experience (e.g., power outages, weather extremes) plus recent experience with Mirror and Magnet P1 tests → risk matrices (next slides)
  - Other sources of risk: cranes

- Mitigation:
  - Buy spare components
  - Preventive maintenance schedule (part of cryo budget)
  - Cranes – preventive maintenance

Top two electrical and cryo risks

- Electrical:
  - IGBTs – 5 weeks down, medium probability, cost of a set of six: $18k, have some spares
  - Soft starts for compressors – 4 weeks down, medium probability, $8k, no spares
- Mechanical:
  - CTI 1st stage HEX – downtime: 2 mo. to replace, 6 mo. to buy, low probability, $125k, no spare. 6 months lead time to purchase. (To mitigate this risk, a pressure pulse bypass was installed 7 years ago. No problem since then.)
  - Mycom He HEX, 1 week down, low probability, $60k, one new spare

Pending request for BNL support (1)

- FY19 support from BNL requested
- Cryo components – focus: spares
  - $378k – details next slide
- Cranes:
  - Three cranes for AUP: 15T, 18T, 30T
  - Cranes part of Cosmotron (~ 1953)
  - These cranes have been very reliable but …
  - Estimates obtained for replacing worn components.
  - $204k
- BNL support decisions late August.

Pending request for BNL support (2)

Cryo Plant Upgrades for Reliable Operation During AUP Magnet Test - June 2018

		Direct Costs				
	Items	MSTC	Tech Labor	Trade Labor	Engineering	Total
1	He Gas Storage Tank farm instrumentation	$3,200	$ 2,267	$ 1,816	$ 1,714	$8,996
2	CTI4000 - rebuild existing engines (2)	$50,000				$50,000
3	CTI4000 - 1st stage heat exchanger	$125,000				$125,000
4	NASH pump rebuild & shaft seal repair	$30,000	$ 3,022	$ -	$ -	$33,022
5	NASH pump Oil level Transmitter	$2,400	$ 1,511	$ -	$ 1,714	$5,625
6	MYCOM Oil level Transmitter	$2,400	$ 1,511	$ -	$ 1,714	$5,625
7	Transfer lines wet expander to storage dewar	$18,000	$ 2,928			$20,928
8	Transfer lines Nitrogen shielded 22' Magcool return header	$18,000	$ 7,556	$ 2,724	$ 4,284	$32,564
9	Solenoid valve current controlled supply	$3,000	$ 1,511	$ -	$ 857	$5,368
10	Pressure and Temperature Sensors for 350 HP and 500 HP Sullair Compressors	$2,500	$ 1,511	$ -	$ 857	$4,868
11	Controls for 350HP and 500HP Sullair Compressor	$5,500	$ 1,511	$ -	$ 2,570	$9,582
12	spare 100hp motor (Nash pump)	$6,000	$ -	$ -	$ -	$6,000
13	Plant large pumpback valve	$12,000	$ 2,928			$14,928
	Totals	**$278,000**	**$26,257**	**$4,540**	**$13,709**	**$322,506**
		7.5% O.H.	No OH	7.5% O.H.	No O.H.	
	O.H.	**$20,850**		**$340**		**$21,190**
	Totals	**$298,850**	**$26,257**	**$4,880**	**$13,709**	**$343,696**
	MPO Oversight					**$34,370**
	Combined Total:					**$378,066**

Summary

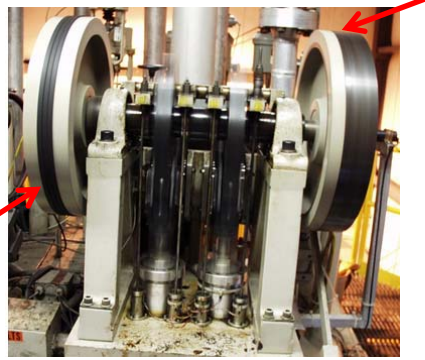
- Testing of the mirror magnet and P1prototype has demonstrated that the principal performance requirements of the cryo test have been met.
- Solutions to handle the remaining tasks – control of helium following a quench and liquefaction capacity for three quenches a day – are at hand.
- We appreciate your advice on the optimal operation of this complex system.

BACKUP SLIDES

CTI Model 4000 Refrigerator/Liquifier

Description:

Primary unit, 320 L/hr. uses (2) reciprocating engine expanders @ 250 RPM



BNL Contribution:

Rebuild expansion engines

New LN_2 heat exchanger,

Doubling # of inline purifiers to four

New diagnostic and control software (LabVIEW).

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Mycom and Sullair 350 Compressors

- *Mycom Compressor (primary unit, 2 stage, 800 hp, 597 KW, 160 g/s)*
  - ✓ *Purchased & received critical spares:*
    - ✓ *new 2nd stage compressor head*
    - ✓ *new 400 hp motor*
    - ✓ *new oil heat exchanger*
    - ✓ *new helium heat exchanger*

- *Sullair 350 Compressor (single stage, 350 hp, 261 KW, 51 g/s)*
  - ✓ *Purchased & received critical spares:*
    - ✓ *new compressor screw*
    - ✓ *new oil pump*

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Sullair 500 - Compressor

Repurpose and move to Magnet Division cryo area
Skid modified to fit into available area

- Electrical panel removed
- Frame cut/shortened/re-welded

4160V transformer relocated

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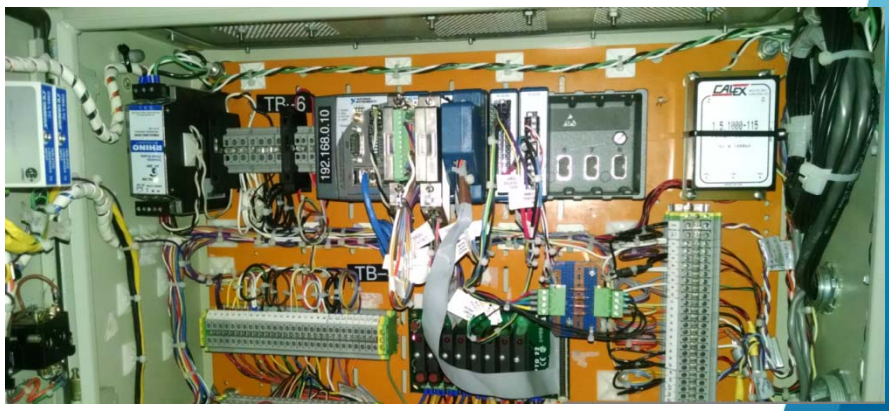
High capacity pump (Nash-Kinema)

Pumps on LHe in heat exchanger - down to 16 mbar for 1.8 K operation

Delivers 2.7 g/s @ 1.8 K
Cooling capacity = 40 W @ 1.8 K

- ✓ ***Purchased new 100 hp Sullair compressor***
- ✓ ***Connected helium exhaust gas line to new 100 hp compressor and inline purifier, to reclaim helium gas (was previously routed to dirty gas facility)***

New control software (Labview), replacing SSC-era controls.



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Cryo risk assessment matrix

SMD Cryo system list of critical spares			6/14/2018		Wanderer, Marone, McKeon		
Item	downtime	sched impact	prob	cost	spares?	lead time	mitigation
Mycom He HEX	1w	1w	0.1	$60k	new	4 mo.	
Mycom Oil HEX	1w	1w	0.05	$15k	new	3 mo.	
Mycom 400 hp motors (2)	1.5w	1.5w	0.07	$20k	used - needs rebuild	1 mo.	
CTI 4000 expansion engines (2)	3-4w	test rate reduced 50%	0.05		spare being rebuilt at BNL		
CTI 4000 O ring seals	2w	0-2w	0.1		new sleeves & O rings made		replace O rings during maint.
CTI 4000 1st stage HEX	2 mo.	2-8 mo.	<1%	$125k	no	6 mo.	pressure pulse bypass installed 7 years ago
Plant pumpback valve	2d	2d	recent failure	$12k	no	6w	buy new - keep used as spare
Notes:							
Probability in 5 years, the duration of AUP							
Cost to repair or replace							
Costs are Direct, w/o labor to install							
Lead time: between order and delivery							
CTI 1st stage HEX: valve to bypass pressure pulse installed 7 years ago							
CTI 1st stage HEX: 2 failures in 30 years							

Electrical Risk Assessment matrix

	Equipment	Type	Down time	Schedule Impact	Probability	Cost of Repair	Available Spares	Critical
1	Power Supply Thyristors	Semiconductor	3 Weeks	severe	very low	$15,000	No Spares	
2	Power Supply IGBTs	Semiconductor	5 Weeks	Severe	Medium	$18,000	Some Spares	Yes
3	Power Supply Thyristor Fuses	Semiconductor	3 weeks	Severe	Very low	$9,000	No Spares	
4	480VAC Power line fuses	Electrical	3 days	Low	Very Low	$2,000	No Spares	
5	Freewheeling Diodes	Semiconductor	1 Week	Low	Low	$5,000	Some Spares	
6	Filter Capacitors	Electrical	3 Days	Low	Very low	$5,000	Some spares	
7	Quench Detector Chassis	Electronics	1 week	low	low	$3,000	No Spare	Yes
8	Quench Detector Modules	Electronics	2 Days	low	low	$2,500	All Spare available	
9	Fast logger Chassis	Electronics	2 Weeks	Moderate	Low	$8,000	No spare	Yes
10	Fast Logger modules	Electronics	2 Days	low	low	$1,500	Some spare available	Yes
11	Slow logger	Electronics	3 days	low	low	$5,000	No spare	
12	Quench Heater power supply	Electronic	4 days	low	low	$4,000	Some spare available	
13	Cryo Valve controller	Electronic	5 days	low	low	$5,000	Some spare available	
14	Nash Pump Controller	Electronic	4 days	low	low	$6,000	Some spare available	
15	Mycom Controller	Electronic	5 days	low	low	$6,000	Some spare available	
16	HUEB Refregerator Controller	Electronic	5 days	low	low	$8,000	Some spare available	
17	Soft Starts for Compressors	Electronic	4 Weeks	Severe	Medium	$8,000	No Spare	