RHIC COLLIDER & CRYOGENICS OPS

Workshop on Cryogenics Operation
FermiLab Oct 25-27 2016

2016

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

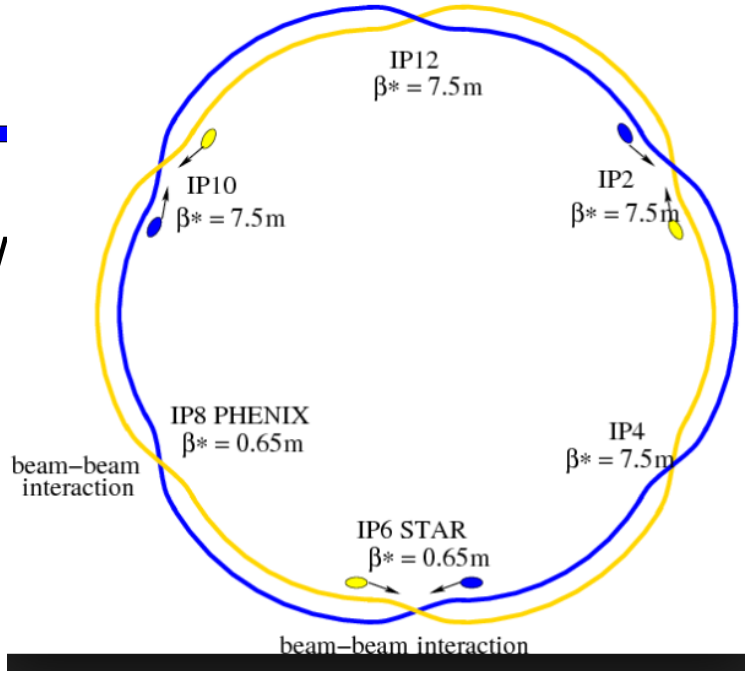
Office of Science
U.S. DEPARTMENT OF ENERGY

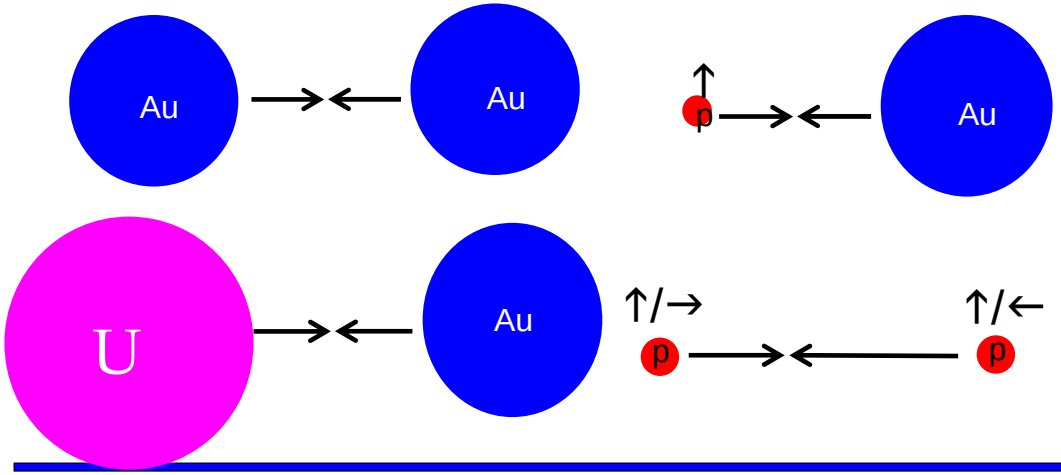
SUMMARY

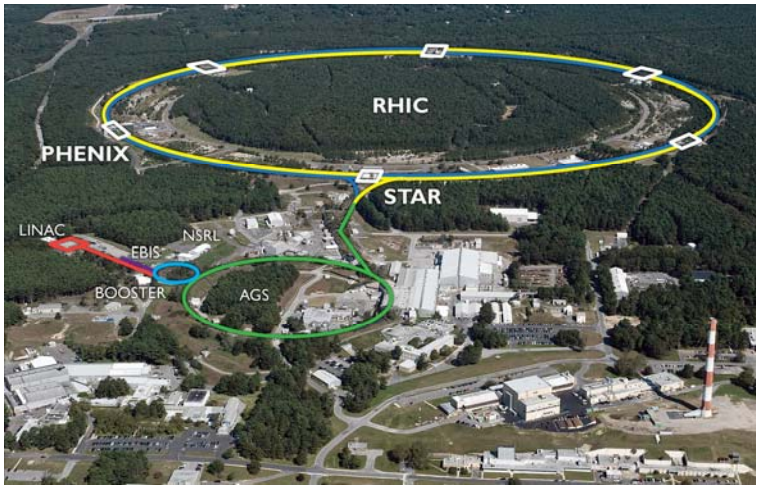
- Collider Overview / Intro
- System summary
- History summary
- Typical RUN/Shutdown
- RHIC Collider availability and Cryo system
- Cryo system history and new systems added for new experiments
- RUN 16: SC Dipole Magnet Protection Diode repair
- Systems slides, operator screens

RHIC COLLIDER OVERVIEW

- 2 separate magnet Rings [Blue/Yellow
- Mixed Species
- Polarized Protons







RHIC COLLIDER OVERVIEW

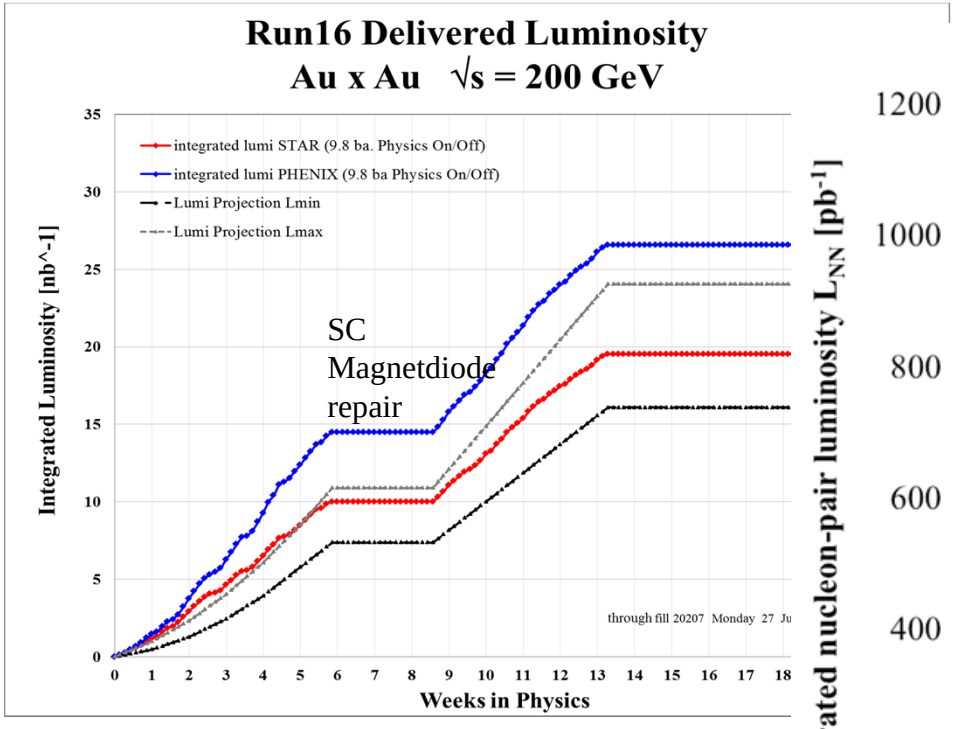
Two magnet rings, each approximately 3.6 km in circumference make up RHIC Collider. There are 1740 superconducting magnets in the machine in 888 cryostats.
The magnet system of the collider consists of superconducting dipole, quadrupole, sextapole, and correction magnets for guiding and focusing the beams through the regular arcs of the machine lattice as well as into collision at the six interaction points. It is designed to allow operation in the energy range 30 to 125 GeV/u. Operation with either equal or unequal ion species in the colliding beams is possible, imposing a ratio of up to 2.5:1 in the magnetic fields of the two rings.

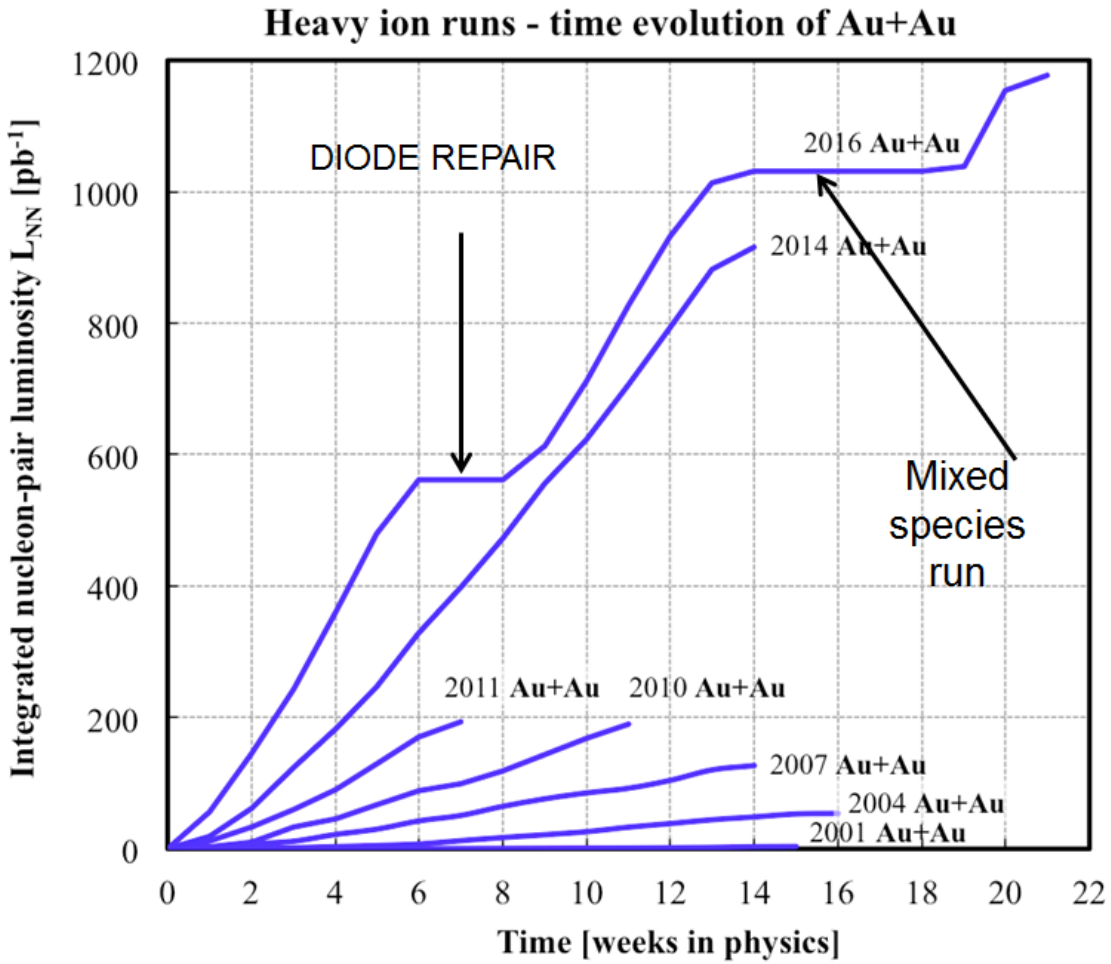
Magnet	Number	Coil Diameter, mm	Length, m
Dipoles			
Arc	264	80	9.45
D5I, D5O	12, 12	80	6.92, 8.71
D6, D8, D9	24, 24, 24	80	2.95, 9.45, 2.95
D0	24	100	3.6
DX	12	180	3.7
Quadrupoles			
Arc	276	80	1.13
Q4, Q5, Q6	24, 24, 24	80	1.83, 1.13, 1.13
Q7, Q8, Q9	24, 24, 24	80	0.95, 1.13, 1.13
Q1, Q2, Q3	24, 24, 24	130	1.44, 3.40, 2.10
Sextupoles			
Arc, Q9	276, 12	80	0.75
Trim Quadrupoles			
Q4, Q5, Q6	24, 24, 24	80	0.75
Correctors			
B, C, D, E, F	96, 132, 78, 78, 36	80	0.5
I, J, K, L, M	12, 12, 24, 12, 12	130	0.5

RHIC RUNS

Run	species
Run-1 CY2000, FY2000 33.6 cryo-weeks	$^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$
Run-2 CY2001/02, FY2001/02 40.7 cryo-weeks	$^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$ polarized p + p
Run-3 CY2002/03, FY2003 30.4 cryo-weeks	$d + {}^{197}Au^{79+}$ polarized p + p
Run-4 CY2003/04, FY2004 26.7 cryo-weeks	$^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$ polarized p + p
Run-5 CY2004/05, FY2005 31.4 cryo-weeks	$^{63}Cu^{29+} + {}^{63}Cu^{29+}$ $^{63}Cu^{29+} + {}^{63}Cu^{29+}$ $^{63}Cu^{29+} + {}^{63}Cu^{29+}$ polarized p + p polarized p + p
Run-6 CY2006, FY2006 21.2 cryo-weeks	polarized p + p polarized p + p
Run-7 CY2006/07, FY2006 18.4 cryo-weeks	$^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$
Run-8 CY2007/08, FY2008 19.0 cryo-weeks	$d + {}^{197}Au^{79+}$ polarized p + p $^{197}Au^{79+} + {}^{197}Au^{79+}$
Run-9 CY2008/09, FY2009 22.0 cryo-weeks	polarized p + p polarized p + p polarized pp2pp
Run-10 CY2009/10, FY2010 27.1cryo-weeks	$^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$
Run-11 CY2010/11, FY2011 24.4 cryo-weeks	polarized p + p $^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$
Run-12 CY2011/12, FY2012 22.9 cryo-weeks	polarized p + p polarized p + p $^{238}U^{92+} + {}^{238}U^{92+}$ $^{63}Cu^{29+} + {}^{197}Au^{79+}$
Run-13 CY2012/13, FY2013 17.0 cryo-weeks	polarized p + p
Run-14 CY2013/14, FY2014 22.0 cryo-weeks	$^{197}Au^{79+} + {}^{197}Au^{79+}$ $^{197}Au^{79+} + {}^{197}Au^{79+}$ $h + {}^{197}Au^{79+}$
Run-15 CY2014/15, FY2015 22.4 cryo-weeks	polarized p + p polarized p + $^{197}Au^{79+}$ polarized p + $^{27}Al^{13+}$
Run-16 CY2015/16, FY2016 23.3 cryo-weeks	$^{197}Au^{79+} + {}^{197}Au^{79+}$ $d + {}^{197}Au^{79+}$ $d + {}^{197}Au^{79+}$ $d + {}^{197}Au^{79+}$ $d + {}^{197}Au^{79+}$

RHIC Heavy Ion Au/Au runs





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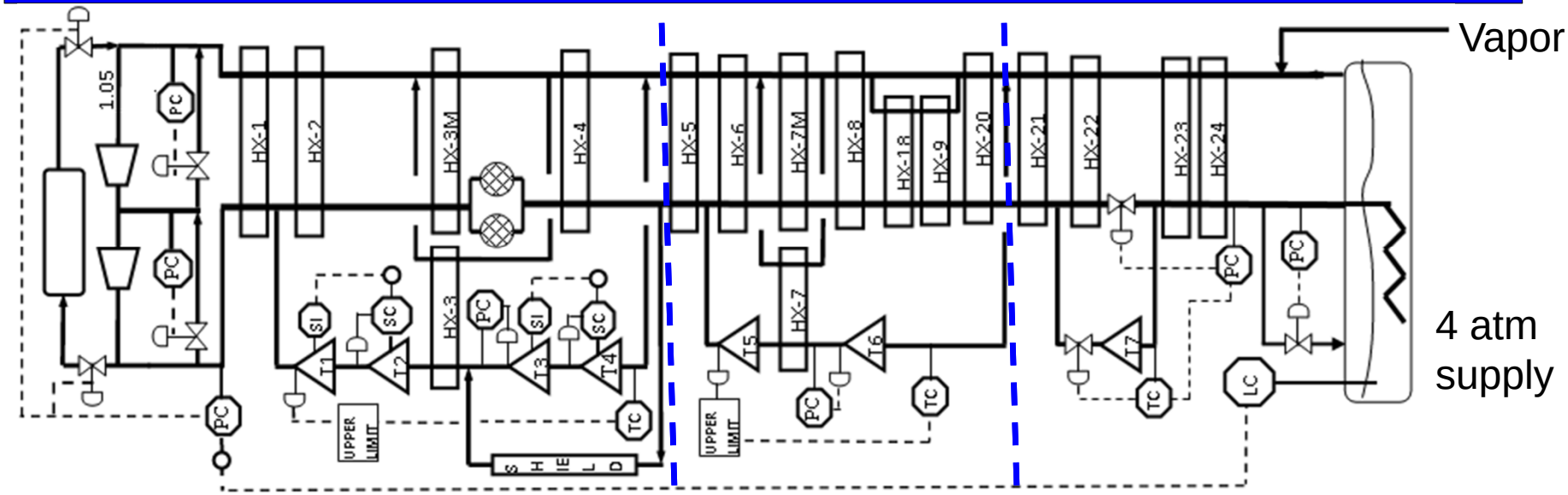
System summary

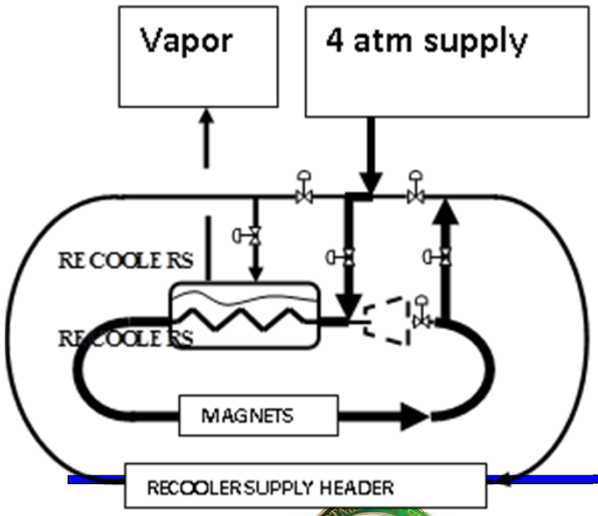
- Built in early 1980's for Isabelle project
- 4500 g/s compressor flow
- 20 x 1st stage + 5 x 2nd stage screw compressors
  - Howden 321mm x 1.65 L/D. 1st: 235 g/s ; 2nd: 900 g/s
- Fine Oil Removal:
- Central Intercooler for 1st stage helium out
- Central Aftercooler for 2nd stage out
- Purifier: LN2 cooled, 80K. 250 g/s
- Utility Compressor: 80 g/s
- Gas storage: 45 tanks, equivalent: 26,000 Gal
- Liquid He storage: 3x 10,000 Gal
- LN2 Storage: 20,000 Gal
- LN2 Storage: 2 x 6000 Gal [Purifier]

- COLDBOX SYSTEM
  - 5 tanks
  - Expander 1 to 4, 160K- 45K: Rotoflow oil bearing turbines
  - Expander 5+6, 45K-10K: Rotoflow oil bearing turbines
  - Expander 7, 4.5K-10K: Linde TGL-45
  - 65K Carbon Beds, Dual
  - Subcooler for 4 bar,4.5K liquid to Collider rings
- Seal gas compressor for Rotoflow expander

- Recommissioned in 1997.
- Running since 2000 to present day

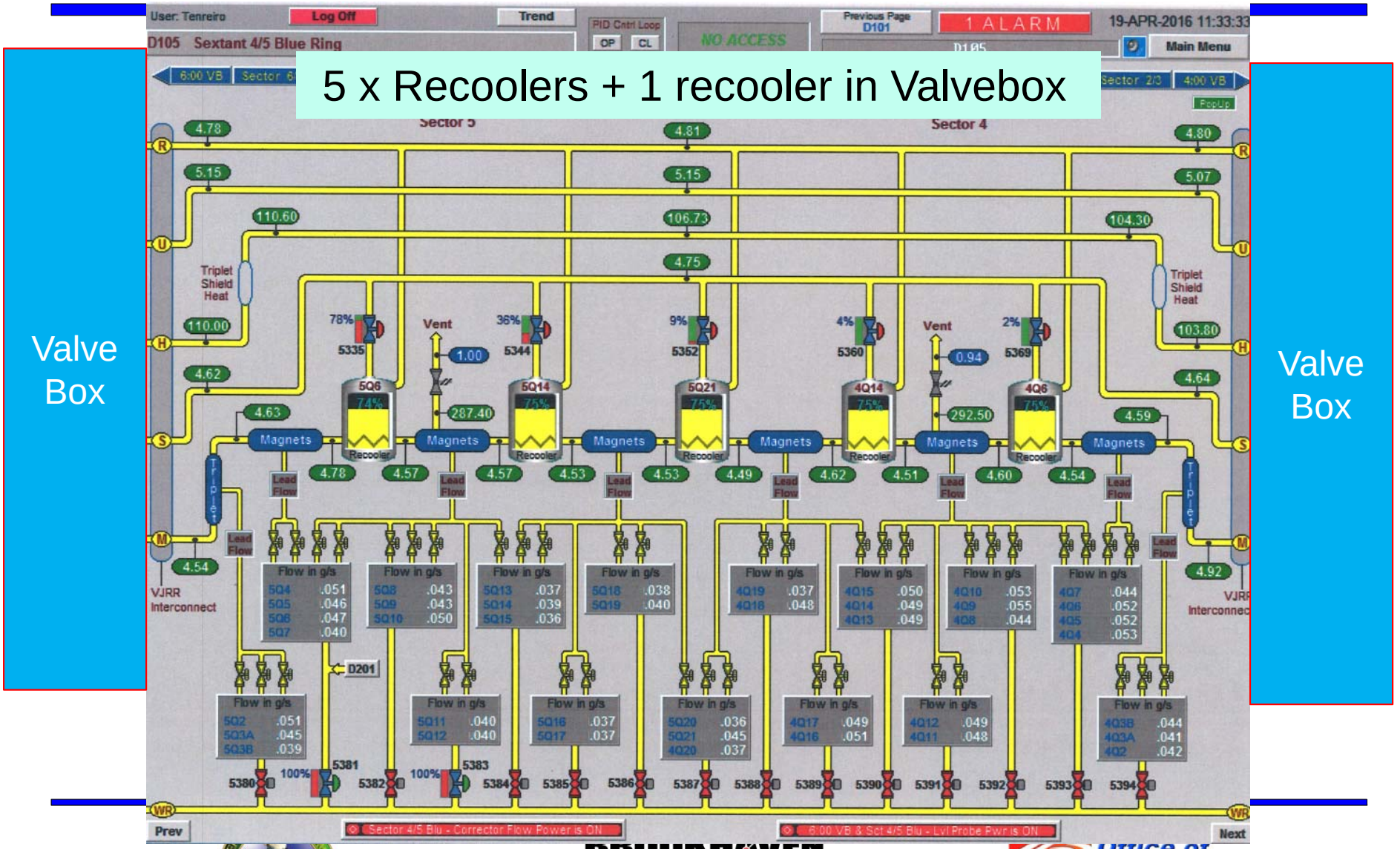
CRYO SYSTEM Simplified Schematic





T7 exit: 4 bar, onto HX-23/24
into Subcooler, exits@4.5K, 4bar onto Collider @IP6 Into Magnet loops [BLUE/Yellow] full 360º through 6 sextants.
Exits, 4.7K, 3.5bar into S-header to recoolers

Typical Sextant



CRYO SYSTEM HISTORY SUMMARY

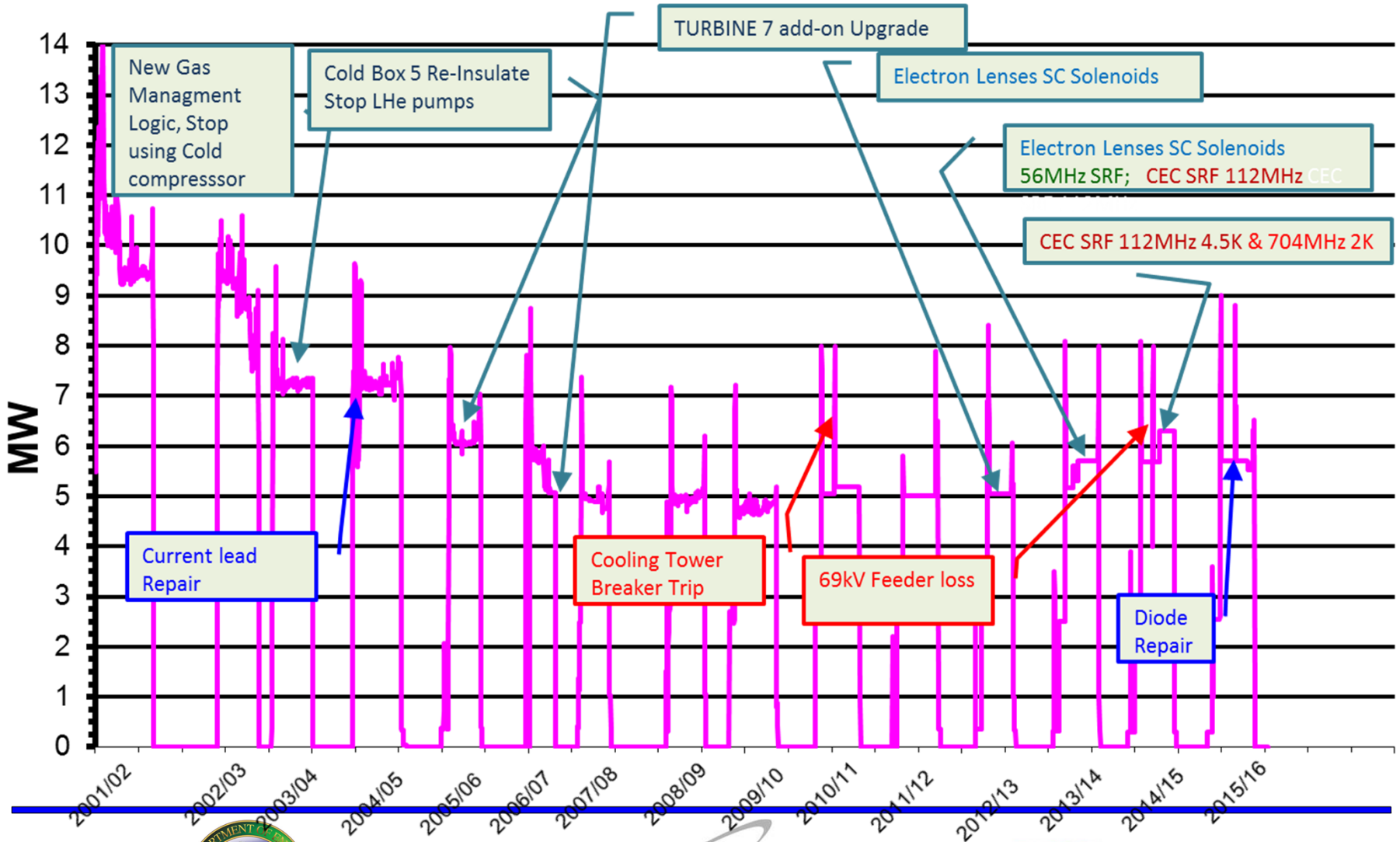
- 2000 RHIC run start
- 2003 Gas management logic change [with JLab]
- 2004 Stop using single stage cold compressor
- 2006 Coldbox 5, re-insulation. Switch from using liquid helium circulators to plant supplly for Magnet flow recooler loops
- 2007 Complete Turbine 7, HX21-24 upgrade [with JLab]
- 2008 Add liquid fill system from LHe truck directly into Coldbox 5 subcooler bath
- 2012 e-lens SC solenoids
- 2013 56MHz Storage cavity
- 2014 CEC 4.5K 112MHz cavity
- 2016 CEC 2K cavity

RHIC CRYO OPS SUMMARY, TYPICAL RUN

- Shutdown during summer, maintenance and new experiments install
- After emptying Collider from helium inventory, let magnets drift to room temperature.
- Liquid helium inventory traded back to Gas supply vendor for redelivery at Start up during 4.5K cooldown wave.
- Room temperature scrub of the magnets helium volume using 80K purifier. 80 g/s through magnet rings
- Warm hipot of the SC magnet loops
- 45K Wave cooldown, 3 weeks
- 4.5K Wave & Fill and soak: ~ 5 days, Liquid inventory redeliveries
- Cold Hipot of SC magnet loops, and DX magnets training if used
- Machine setup
- Physics run: 22 to 30 weeks
- End of Run: LHe Inventory removal 3 days

Power Use History

RHIC Cryogenic System Power Profile



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CRYOLOADING SC Magnet Rings and Experiments

- Refrigeration Load: ~8500W @ 4.5K
- Liquefaction Load Curren leads: 44 g/s
- Shield Loop: 25,000 W, 45K supply, 83K return

RHIC

- e-lenses: ~10 g/s
- 56MHz:
  - Liquefaction Load: 3 g/s, Refrigeration Load: ~ 100 W
  - Low pressure cavity : 5 psig
  - Local small compressor
- Coherent Electron Cooling:
  - 112MHz 4.5K SRF cavity
    - Liquefaction Load: 3 g/s,
  - 704MHz 2K SRF cavity
    - Liquefaction Load: 5 g/s
  - Local small compressor, warm vacuum pumps

See Poster Session

Power Loss

- **Run 11 Cooling Tower trip**
  - Compressor off line ~ 4 hrs
  - Pressurized magnet loops to 250 psig. Collider Reliefs lifted
  - Lost inventory
  - 11 days TOTAL
    - 5 days waiting for inventory delivery
- **Run 14 Lost 69 kV leg to substation**
  - Compressor off line ~1.5hr
  - Waiting for 69kV feeder switch-over
  - 1.5 days to recover
  - No lost of inventory

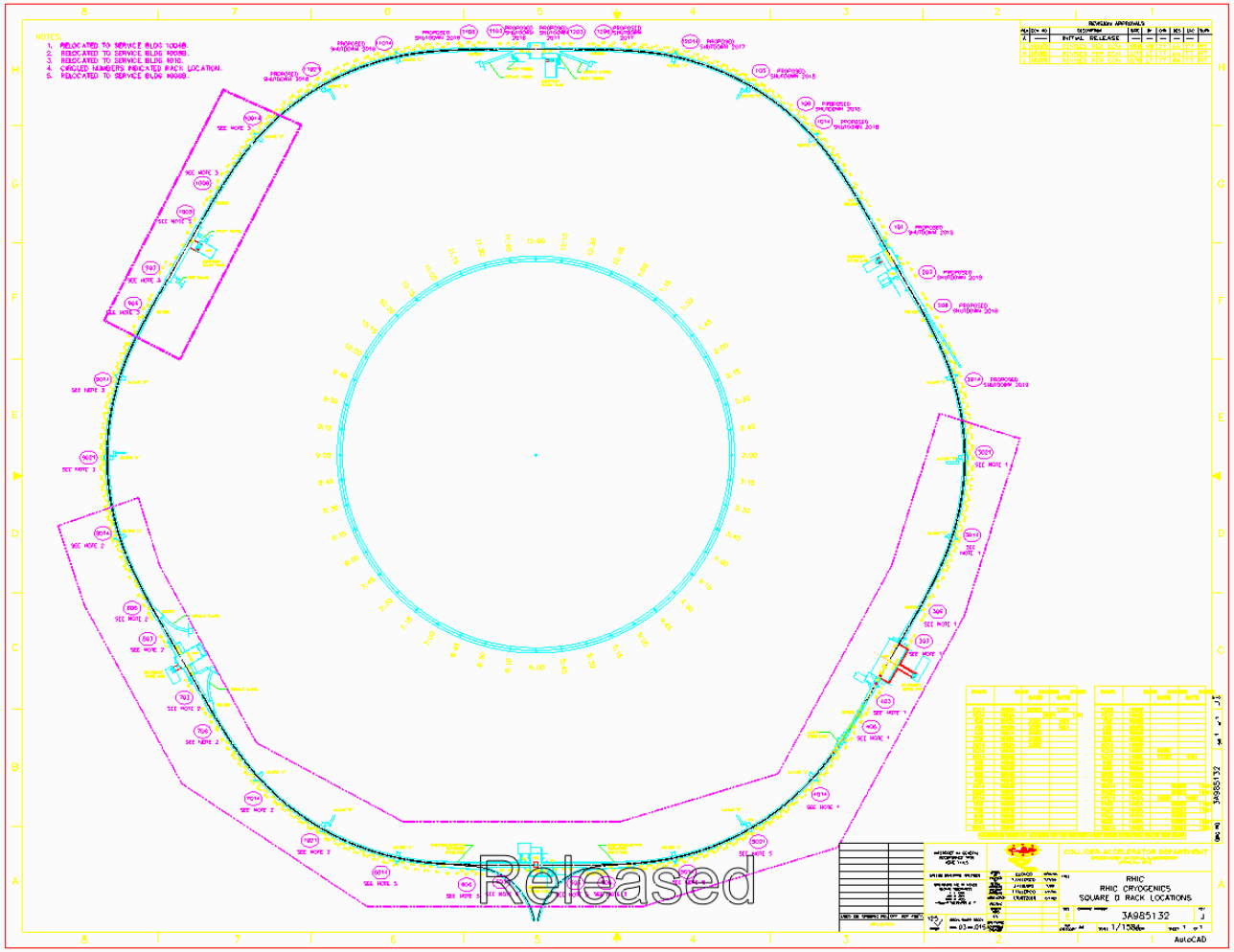
CRYOGENIC SYSTEM

Equipement Failures 2009 to 2016

		BEAMPERMIT
11Q21 Tunnel RACK Resets Run 2016	>60	0
Ring rack PLC AI card, Symax RIM125	35	33
Ring rack PLC chassis Power Supply, Symax S25/35	19	19
Ring rack PLC AO card, Symax ROM122	5	1
Ring rack PLC main CPU, Symax processor	1	1
Current lead Flow Controllers MKS 221, 84 SLPM	12	6
Vacuum Gage Controllers, MKS 937A	9	0
8 channel Temp monitors, Lake Shore 218s	16	0
Pressure Transducer	1	0
RHIC CRYO PLANT PLC I/O card, RTP DO	2	0
RHIC CRYO PLANT PLC I/O card, RTP AI	1	0
Corrector leads thermistors flowmeter, interruptions/failures	27	27
Power Distribution Failure/Trip#1 , Cooling tower #7, 2011	1 hr	12 hours
Power Distribution Failure/Trip#2, Cooling tower #7, 2011	6 hrs	10 days
Power Distribution Failure/Trip#3, Cooling tower #7, 2011	0.5 hr	6 hours
Power Distribution Failure, 69kV downfeed leg, 2015	2.5 hrs	3 days

CRYO CONTROLS TUNNEL RACKS MOVE

Boxed sections are completed move to surface building



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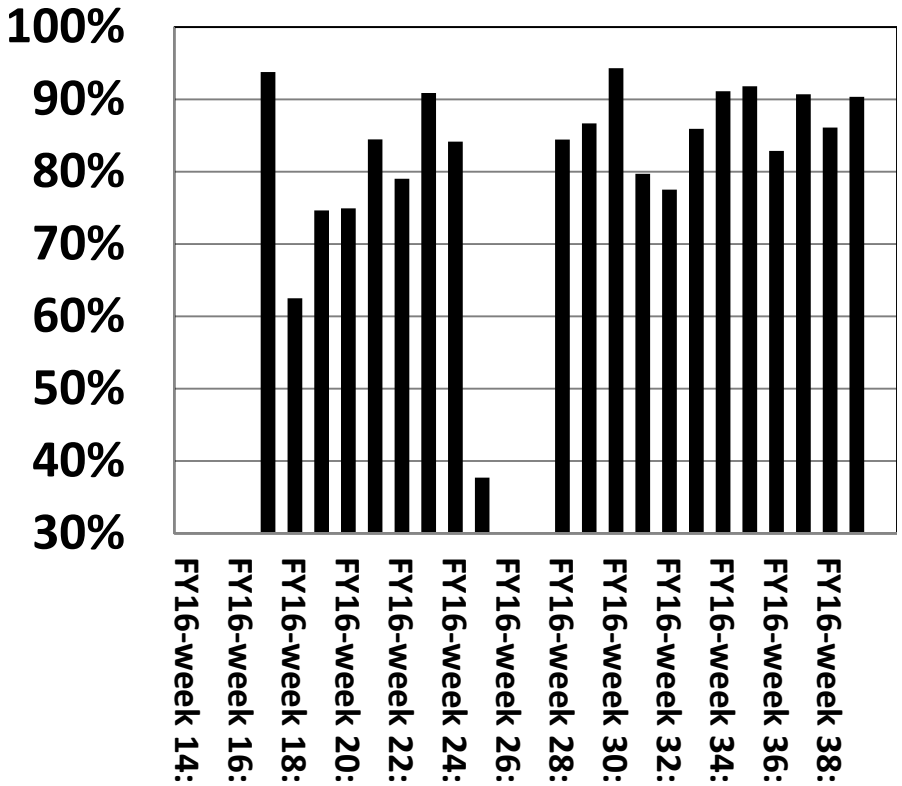
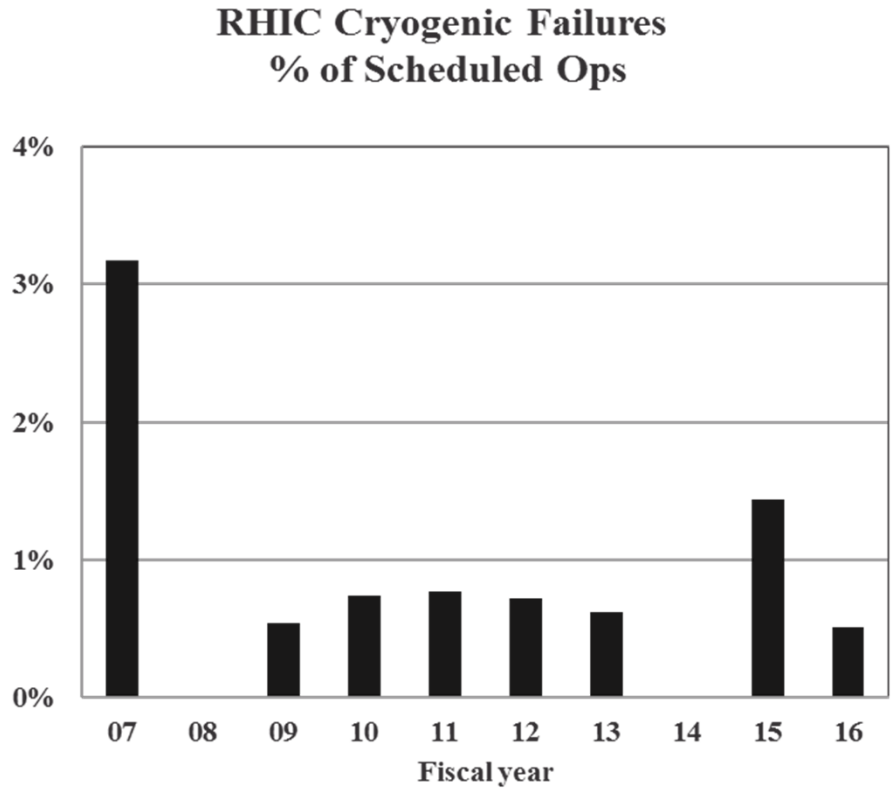
RHIC Run16 availability 83%, Cryo historical





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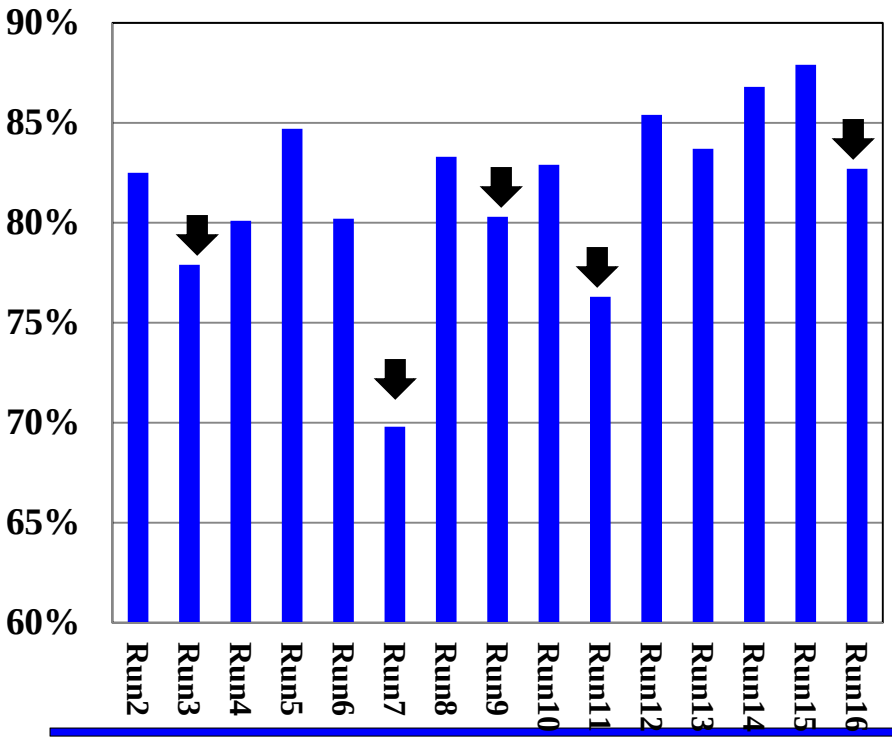
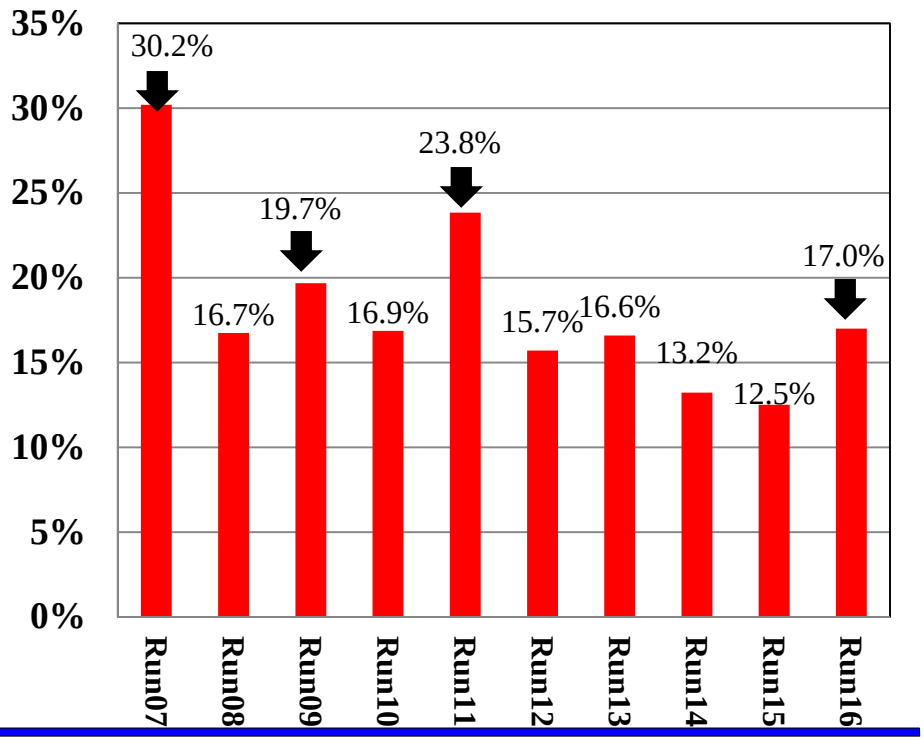
RHIC Availability History

RHIC Availability by Run [%]



Failure as % Scheduled Ops



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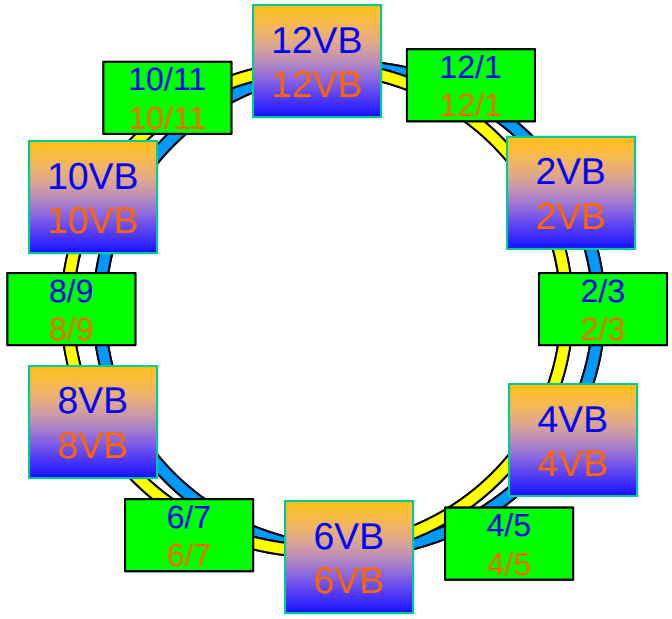
March 2016 SC Magnet Diode replacement during run

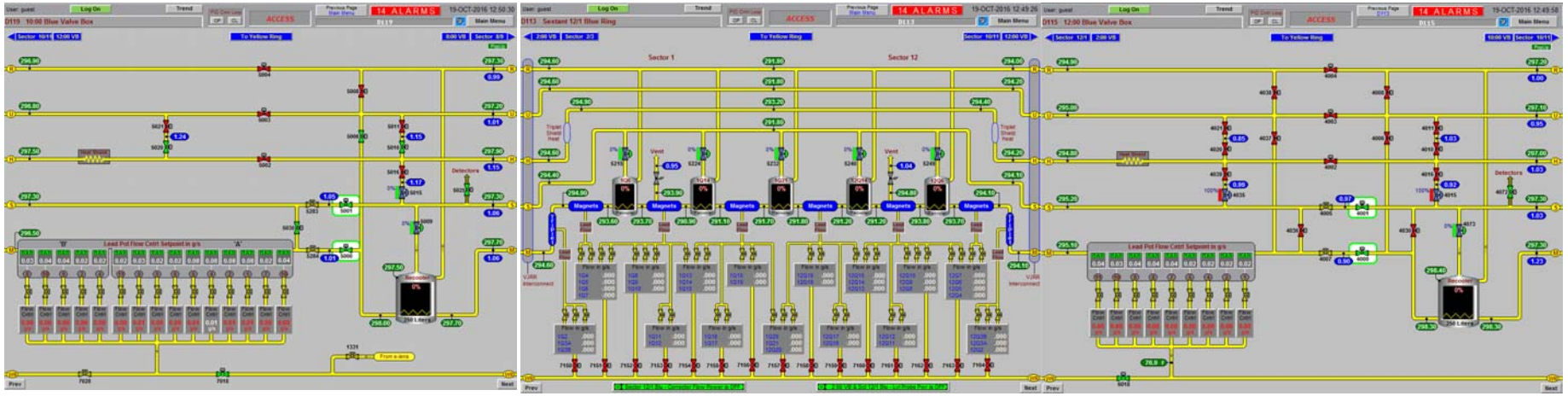
- Quench bypass protection diode on a SC dipole magnet damaged by radiation in sector 10. [approx 900 diodes in the SC magnets rings]
- Beam spray from abort kicker pre-fires
- Lot of beam sprays in sector 10/11

March 2016 SC Magnet Diode replacement during run

- Damaged Bypass Diode in sextant BLUE 10/11
- Remove liquid inventory from sextants:
  - BLUE 6/7, 8/9, 10/11, 12/1
- Warmup of sextant 10/11, 4 days
- Depressurize BLUE 6/7, 8/9, 10/11, 12/1
- LOTO
- Break insulating vacuum
- Cut open dipole cryostat
- Replace diode
- Room temperature High pot
- Close up and weld vacuum boundary and leak check
- Sextant Cooldown wave 5 days



SEXTANT 10/11 ISOLATION, ADJACENT SEXTANT DEPRESSURIZED

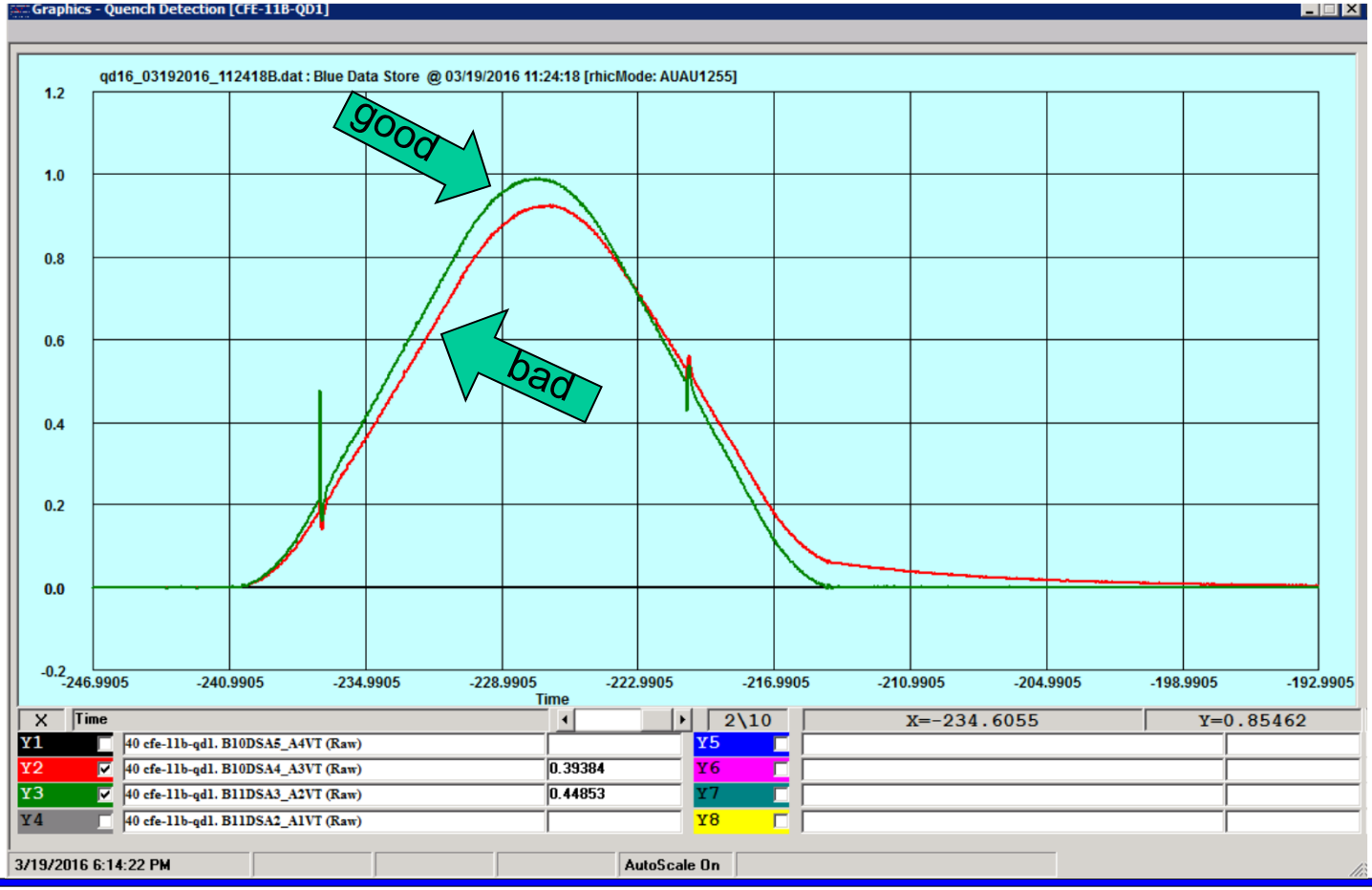


- Each magnet has embedded electric heater to assist warmup

RHIC 16 DIODE REPAIR Diagnosis

Quench Detection System Prevented Ramping

Test after failure at Low Current, 3/19/16



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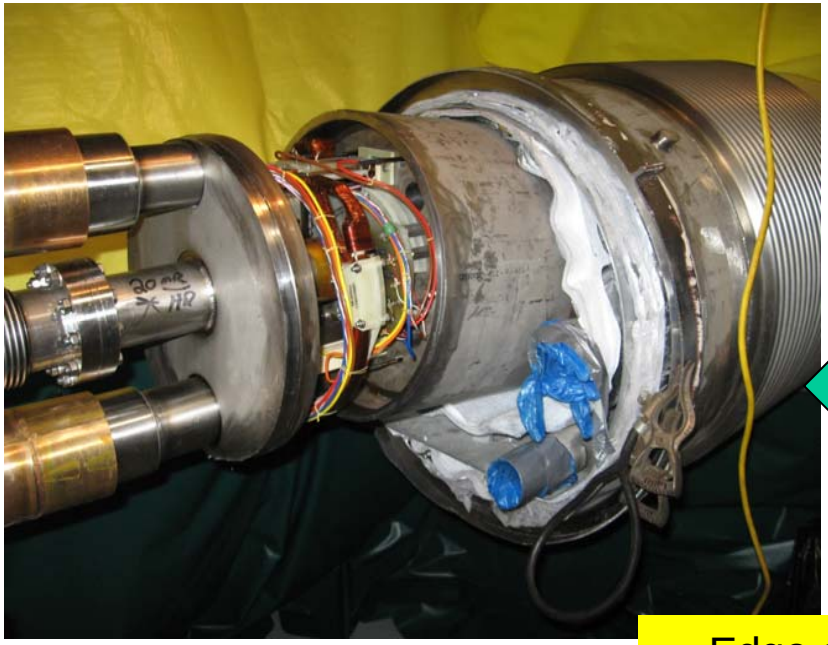
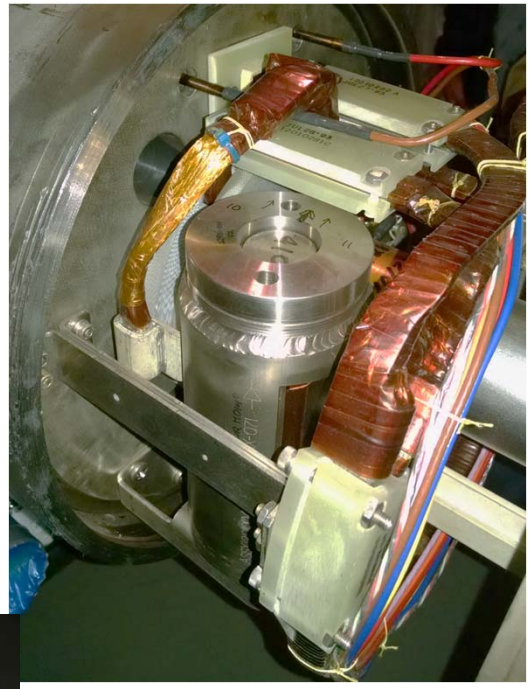
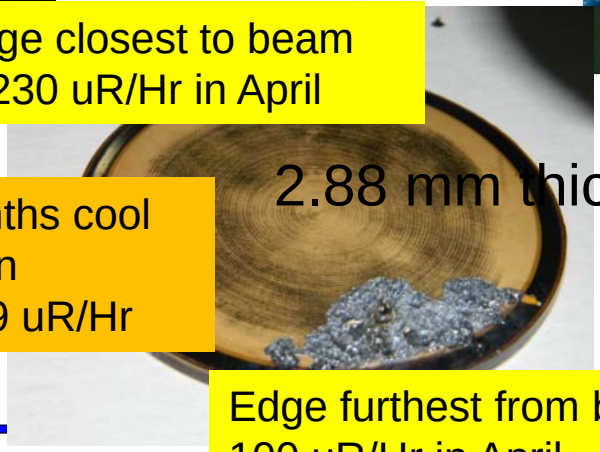
Diode Location End Volume of SC Magnet





Edge closest to beam
230 uR/Hr in April



2.88 mm thick

After 3 months cool down
65 ur & 39 uR/Hr

Edge furthest from beam
100 uR/Hr in April

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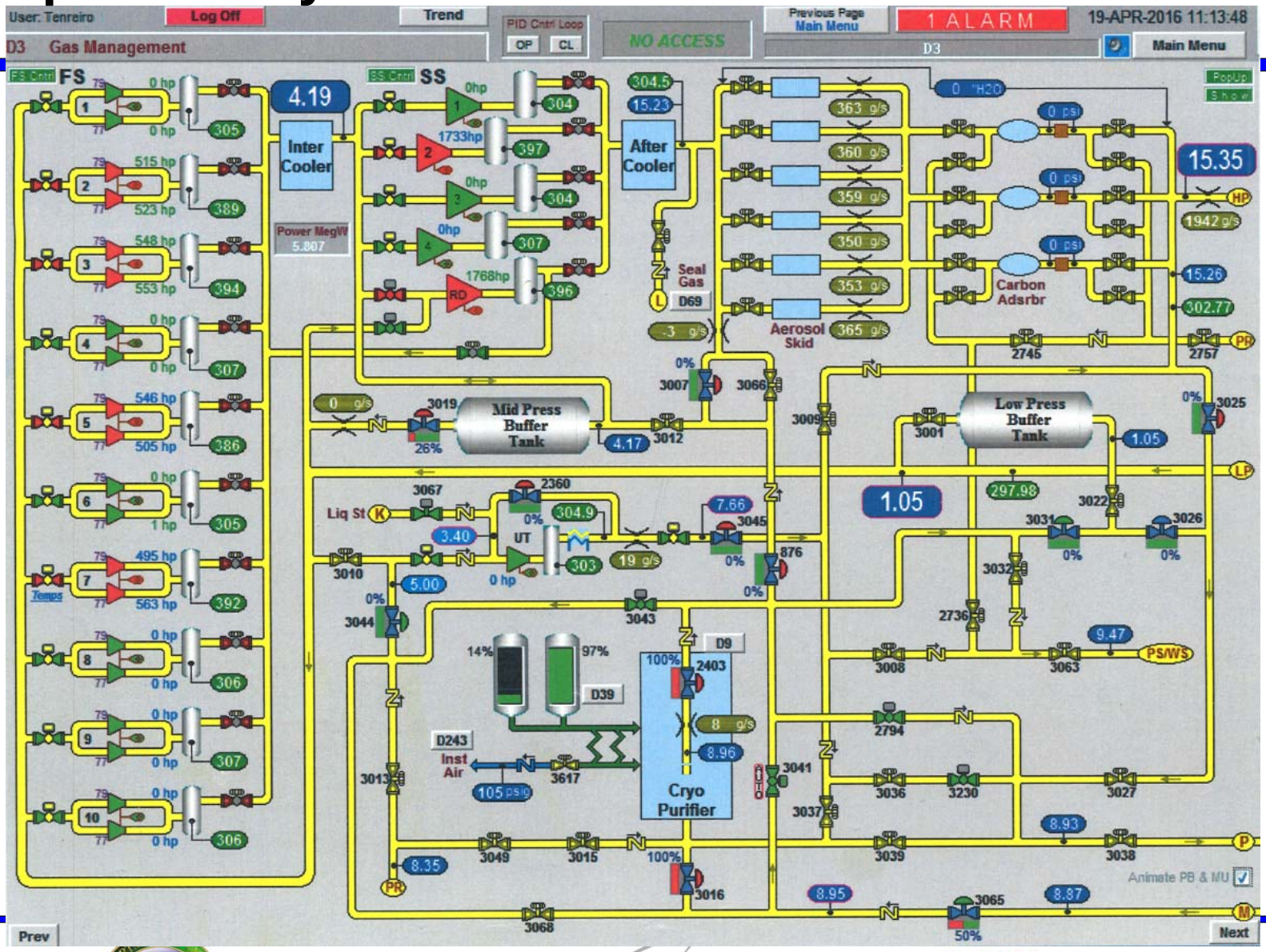
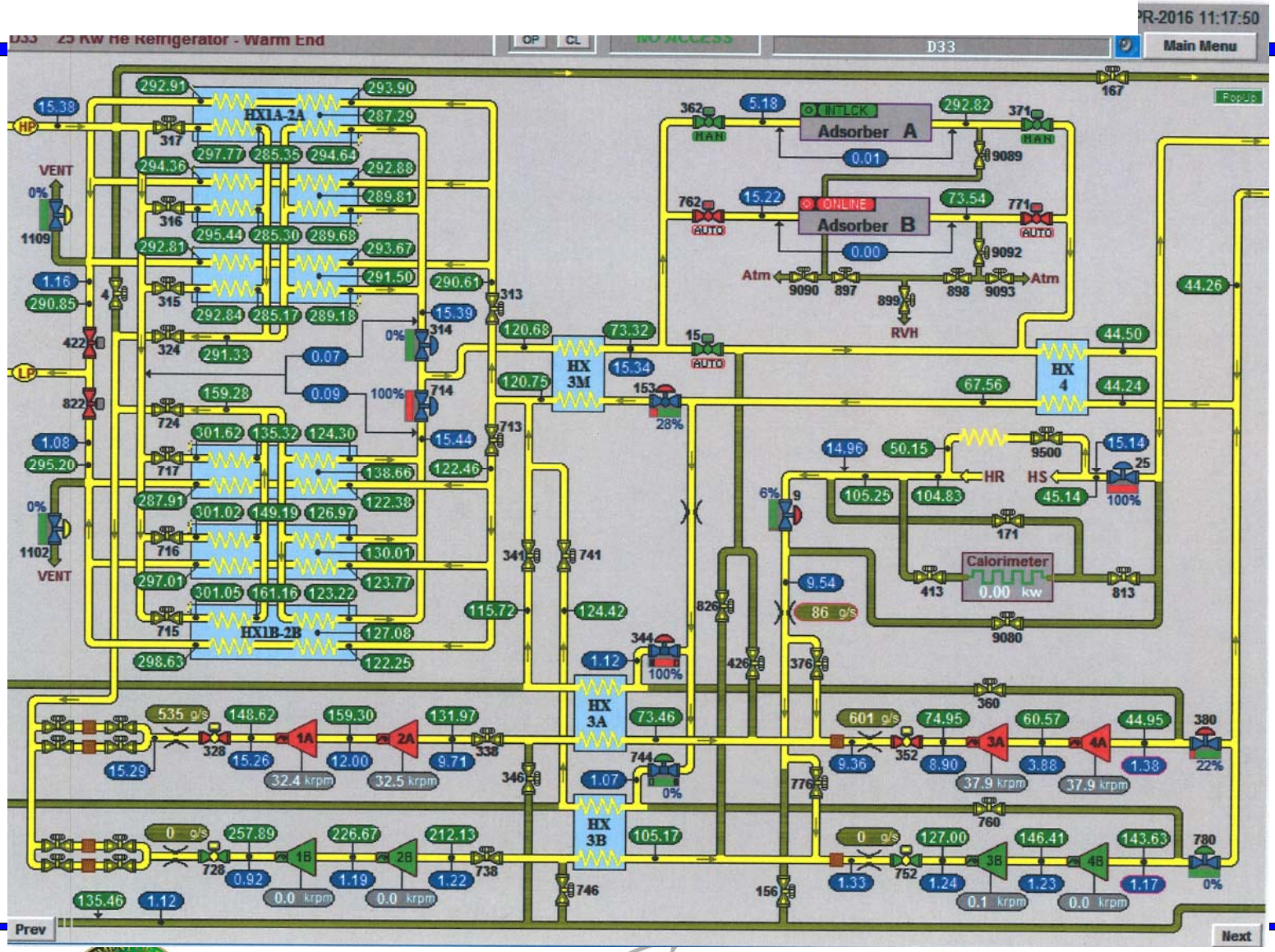
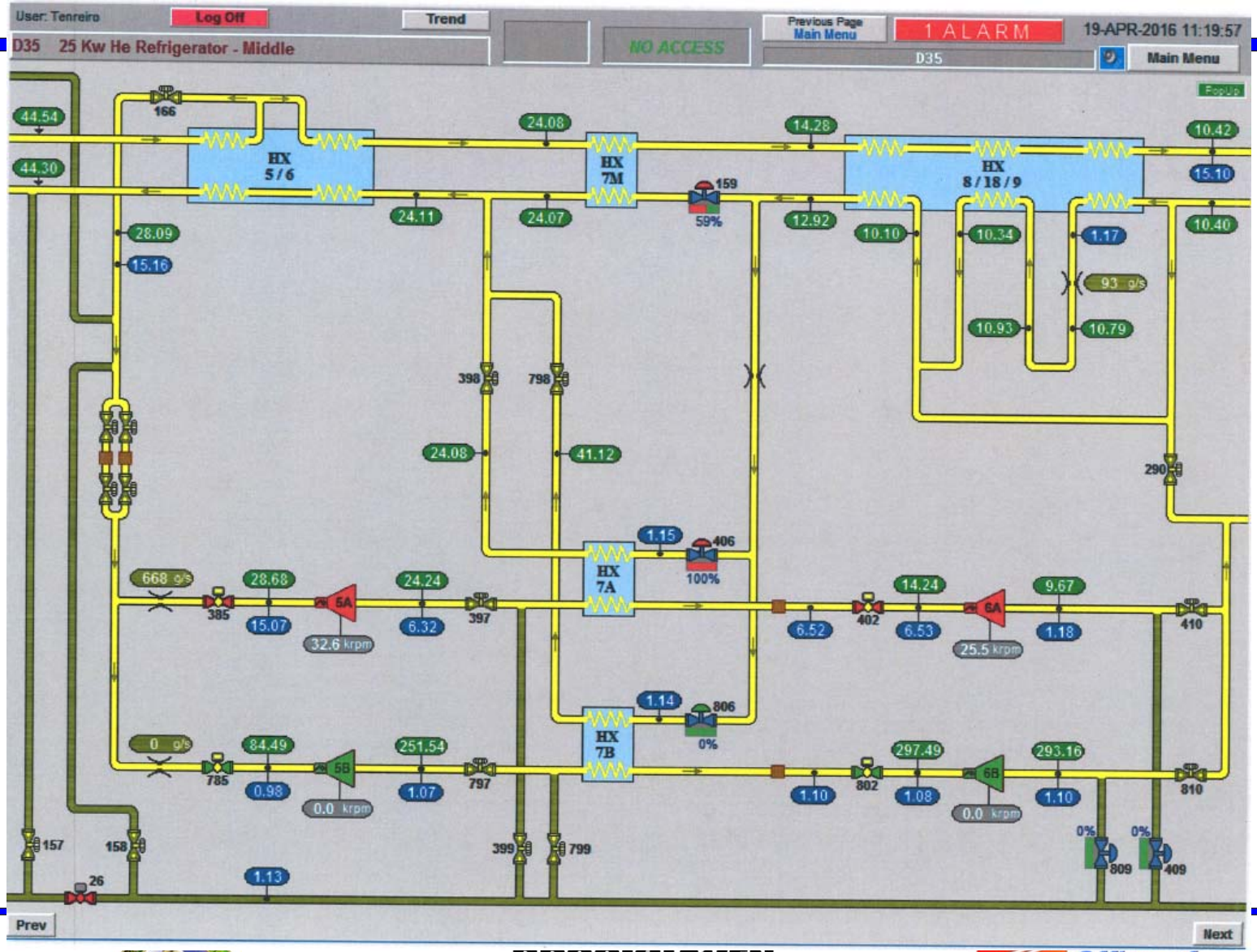
Compressor System



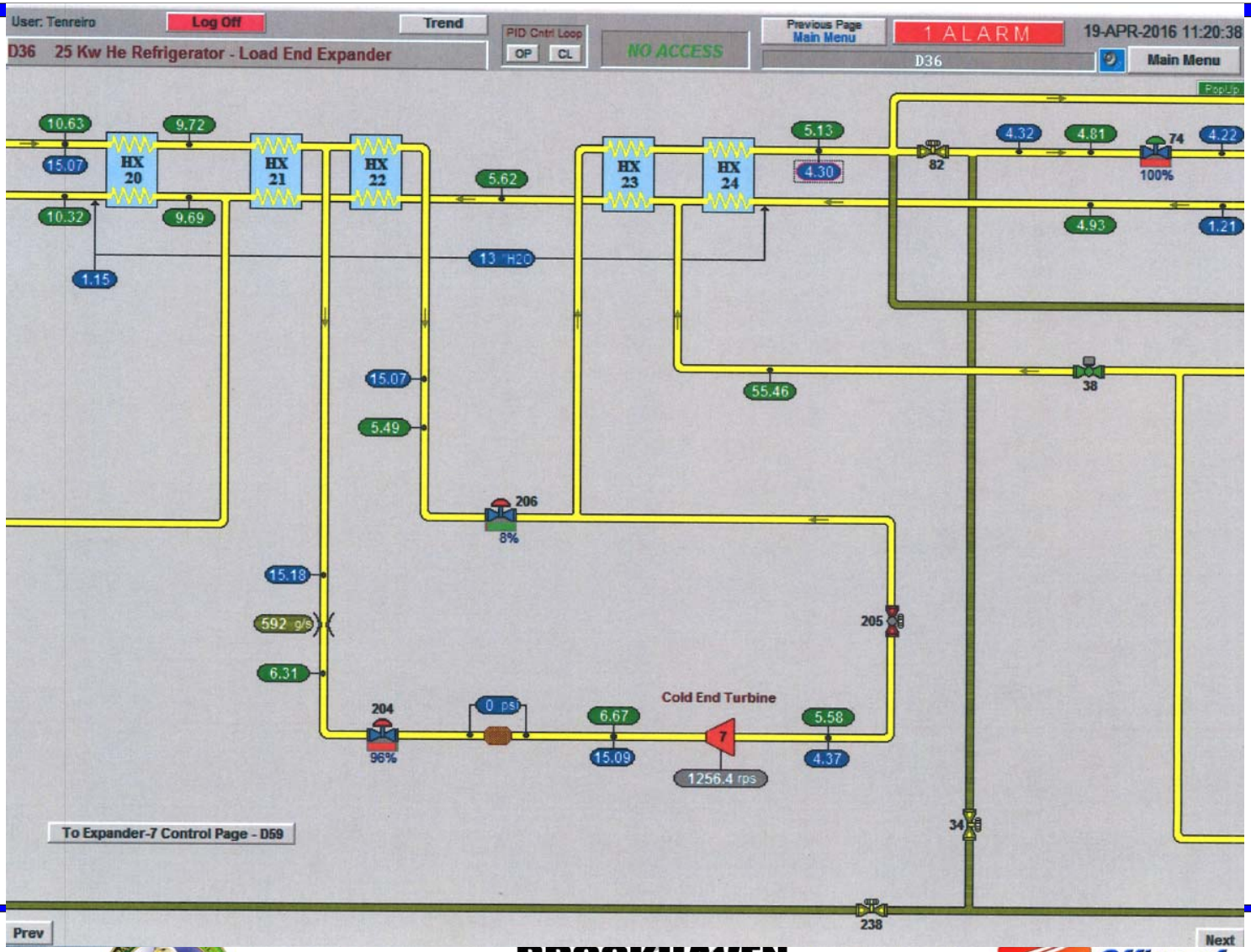
Expander 1 thru 4 (300K to 45K)



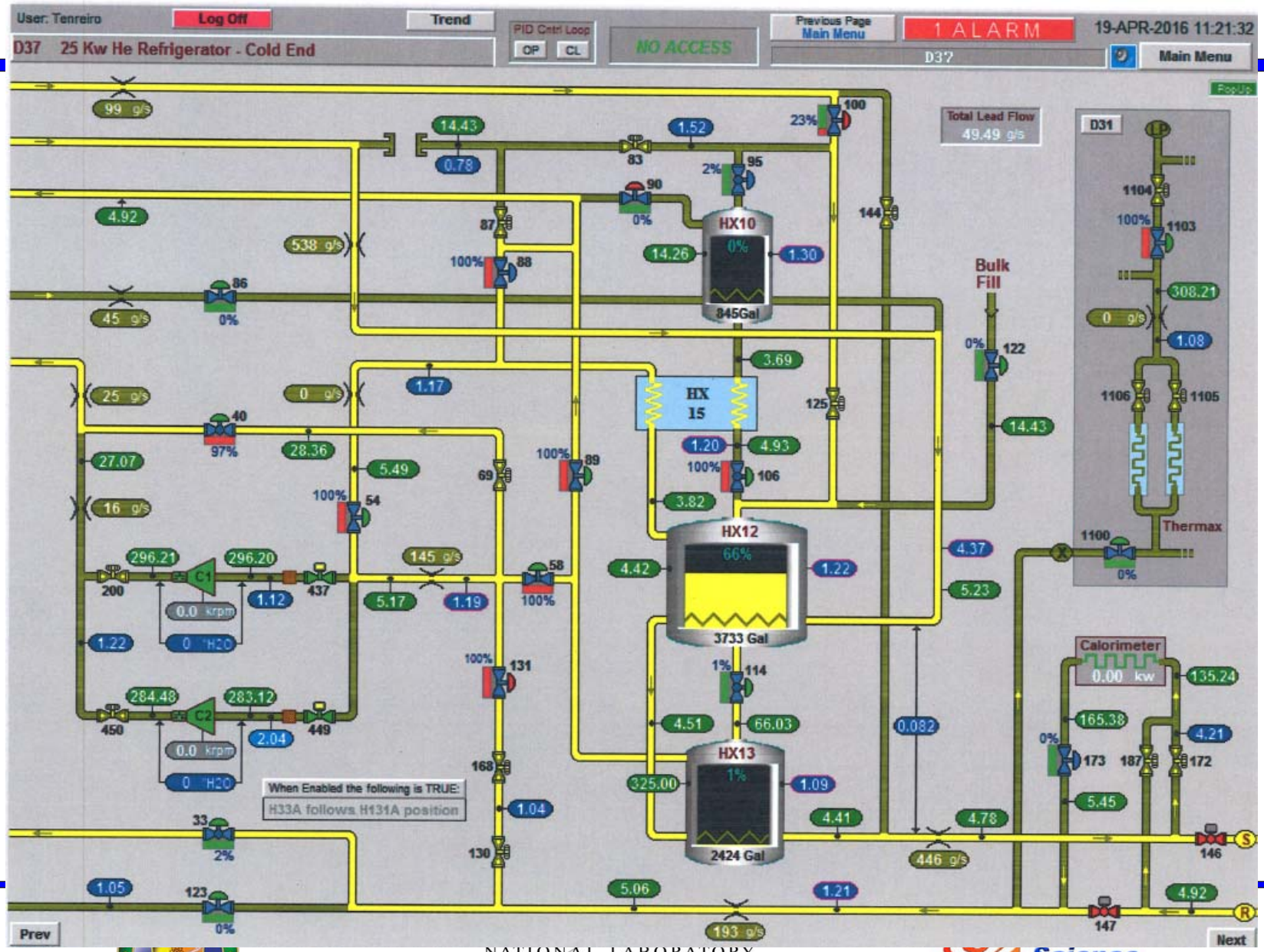
Expander 5 – 6 (45K to 10K)



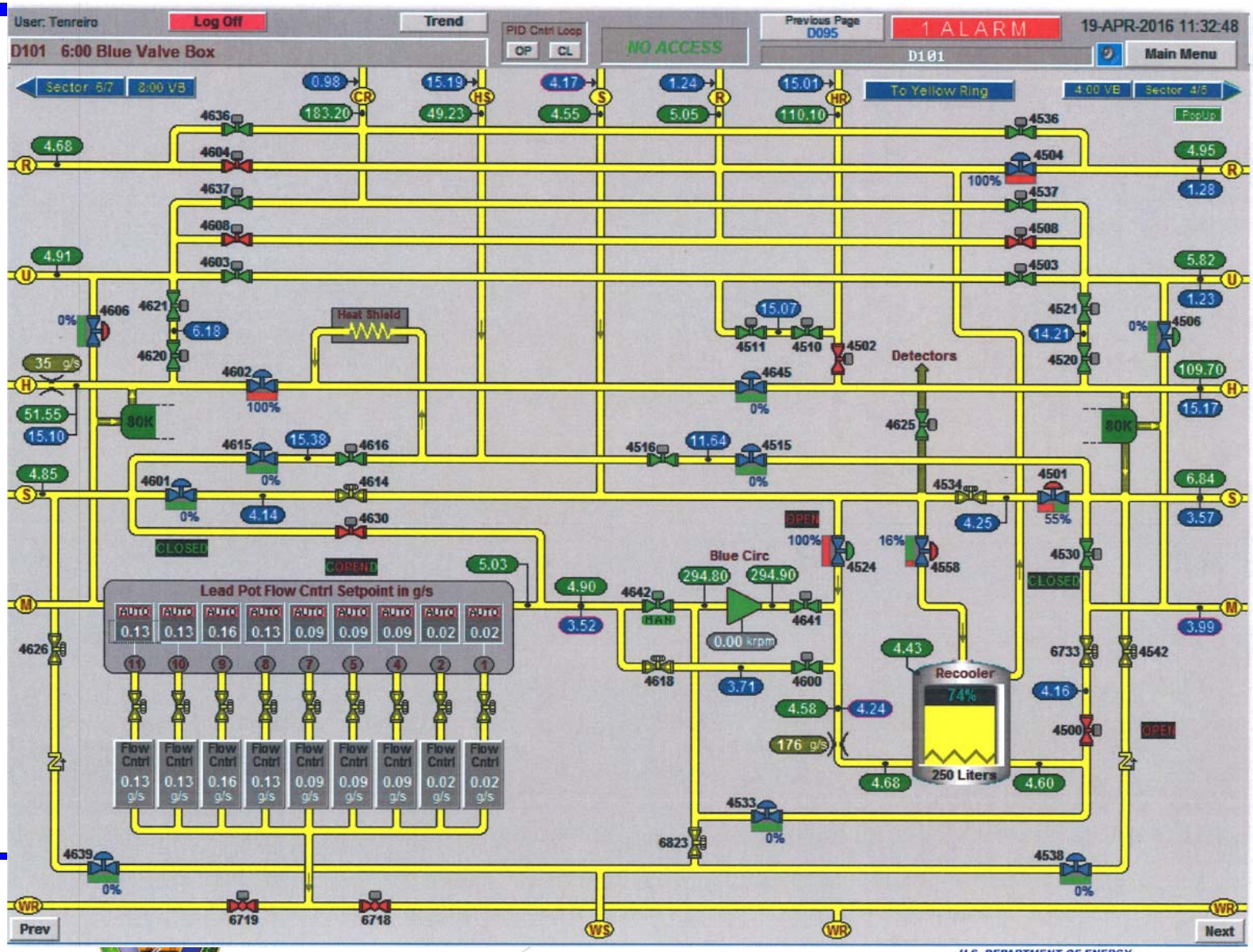
Expander 7


User: Tenreiro
Log Off
Trend
PID Cntrl Loop
OP
CL
NO ACCESS
Previous Page
Main Menu
1 ALARM
19-APR-2016 11:20:38
D36 25 Kw He Refrigerator - Load End Expander
D36
Main Menu
HX 20
HX 21
HX 22
HX 23
HX 24
10.63
9.72
15.07
10.32
9.69
1.15
5.62
13 H2O
5.13
4.30
82
4.32
4.81
74
100%
4.22
4.93
1.21
38
55.46
15.07
5.49
206
8%
15.18
592 g/s
6.31
205
204
96%
0 psi
6.67
15.09
Cold End Turbine
7
1256.4 rps
5.58
4.37
34
238
To Expander-7 Control Page - D59
Prev
Next

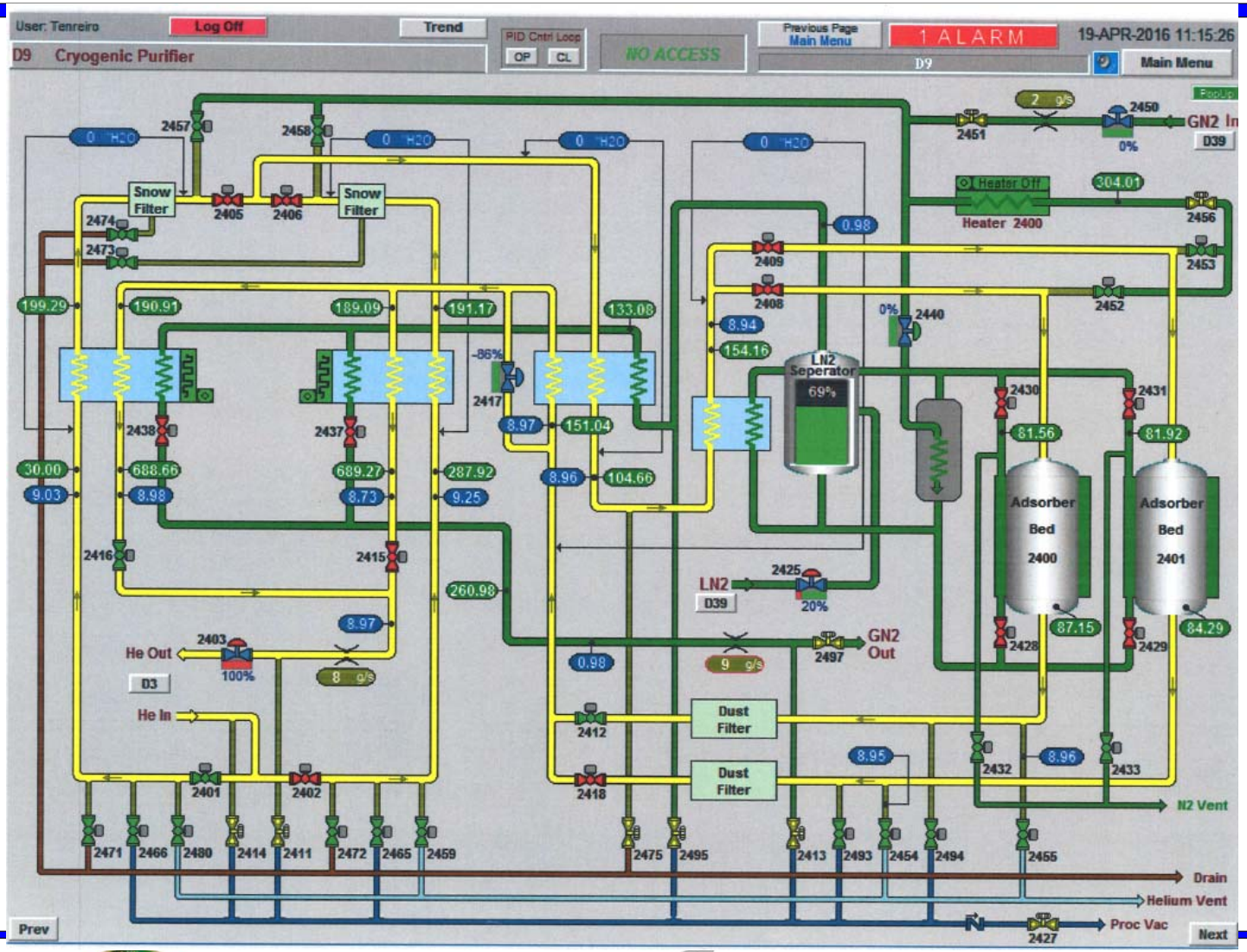
Plant's Main Subcooler



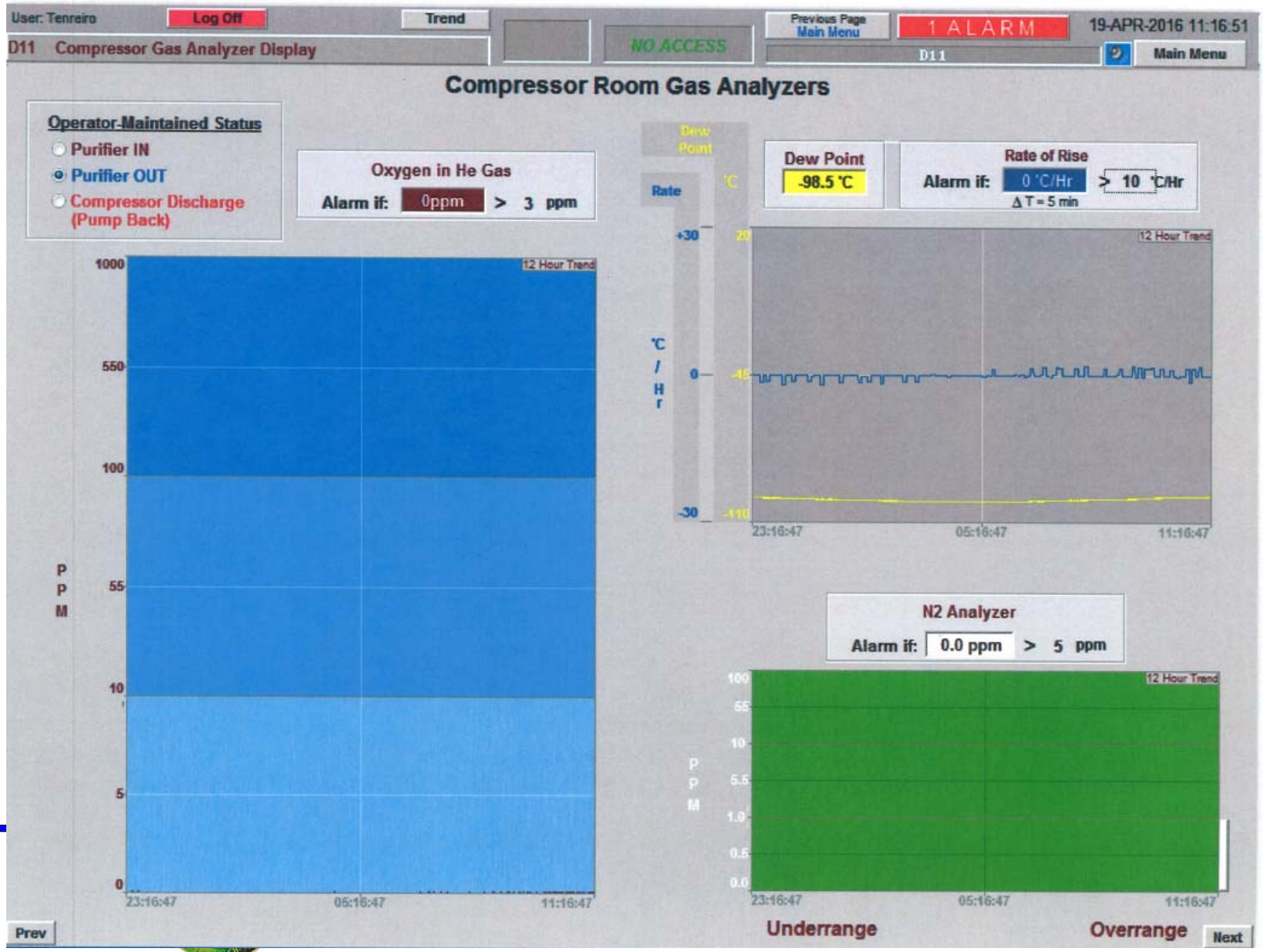
Valvebox with SC Magnet Current lead interface



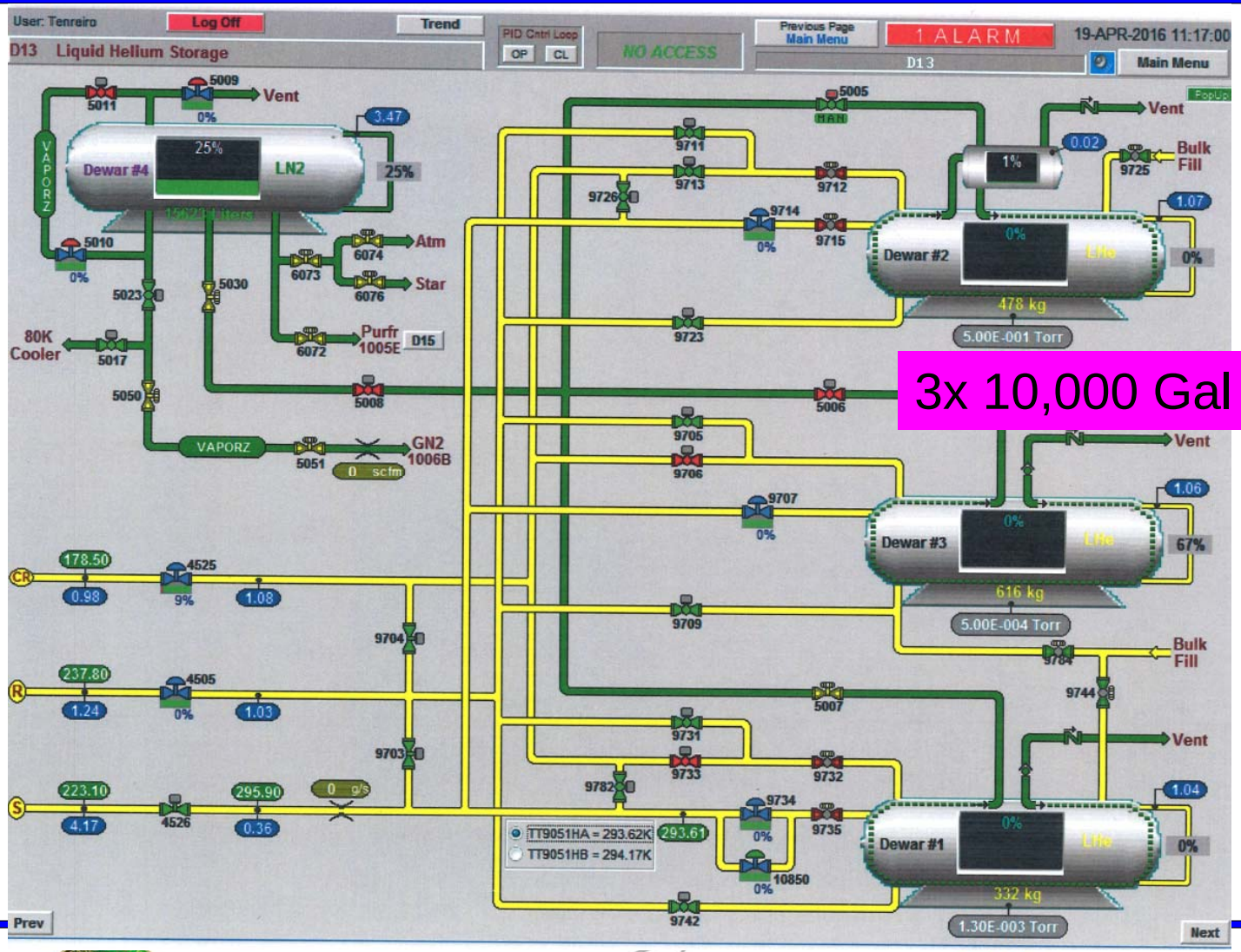
250 g/s Purifier



Gas Analyzer Station

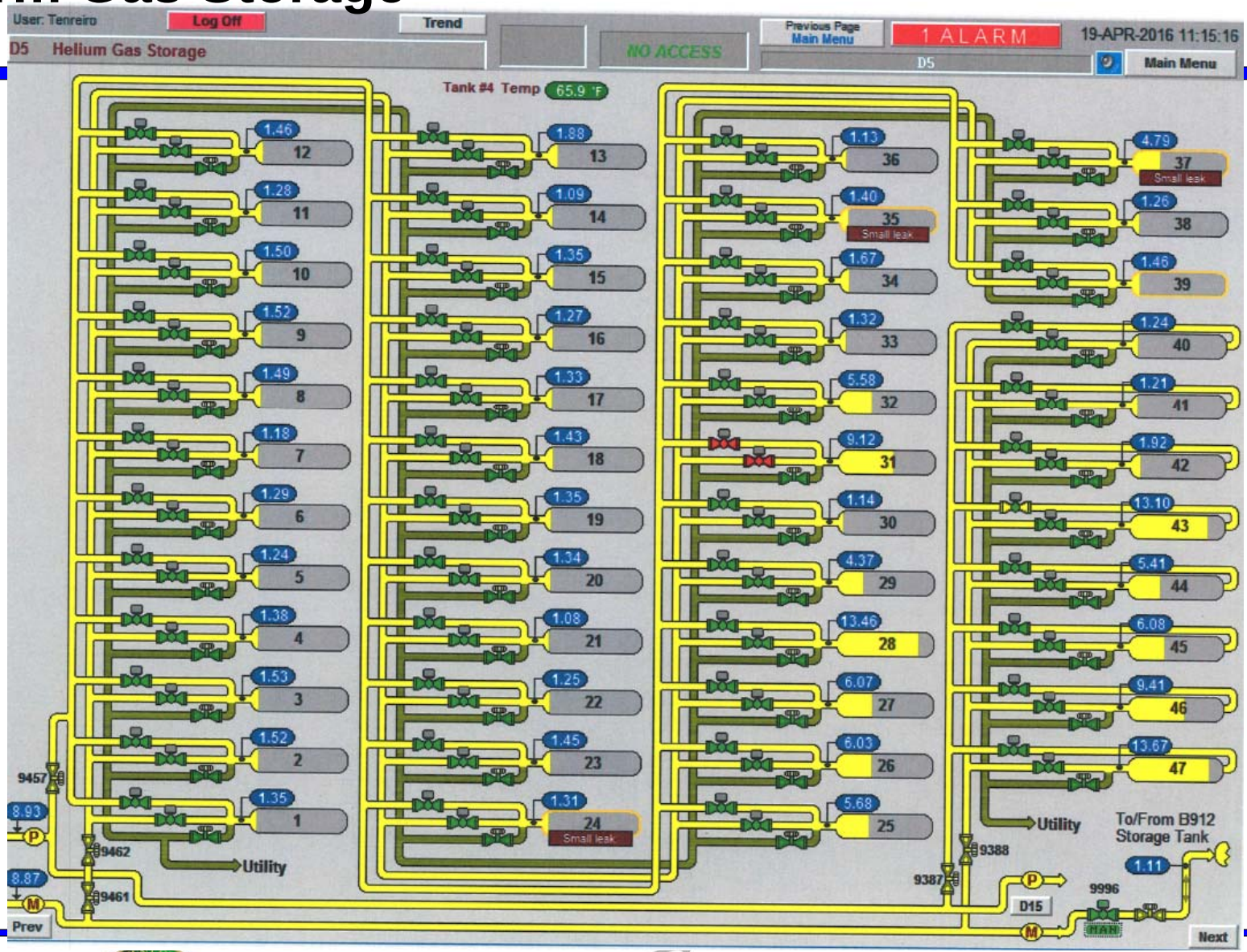


Liquid Cryogen Storage



3x 10,000 Gal LHe

Warm Gas Storage



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Blue E-Lens Solenoid