General Design Testing And Operation Of SC Magnet Systems: sPHENIX Detector

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2016 Workshop on Cryogenic Operations

chaired by Arkadiy Klebaner (Fermilab) at ***Wilson Hall***

Thursday, October 27, 2016

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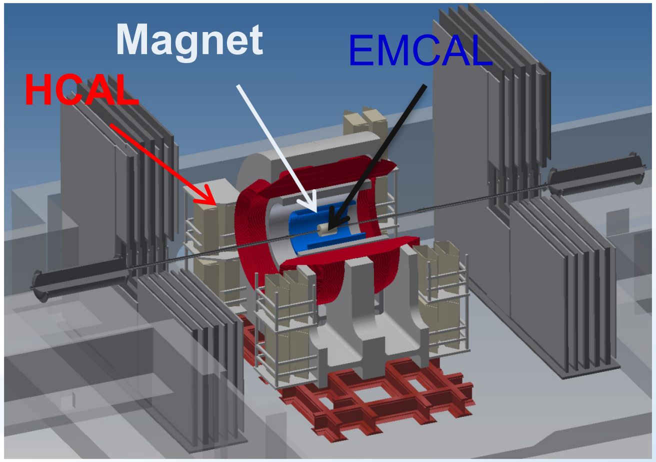
Agenda

- Review of sPHENIX project
- Goals for testing
- Overview of the design
  - Magnet configuration
  - Testing setup
- Operations of the Low Power Test
- Discussion of results and lessons learned

sPHENIX

- Major upgrade to the PHENIX Experiment at RHIC
- Primary purpose is to measure jets in heavy ion collisions
  - Measure jet energy using calorimetry
  - Good solid angle coverage (|h|< 1, Df=2p)
- Provide a basis for a future detector at eRHIC
  - Study nucleon structure and QCD in nuclei over a broad range of x and Q2 using deep inelastic polarized ep and eA collisions



Testing Goals

- Check Solenoid functionality
  - Stored for several years after BaBar experiment was decommissioned
  - Shipped to BNL from SLAC
- Examine thermo-siphon cooling method
  - Verify if temperature instabilities exist
- Preparation for High Power Test
  - Magnet flux return required

Testing plan

Low Power Test Goals:

- Checkout cryogenic components, instrumentation and operations.
- Checkout magnet current loop components, instrumentation and operations.

High Power Test Goals:

- Install SC cable extension
- Test splice joints that have been disassembled and remade several times
- Power to full current 4600A

BaBar Operation

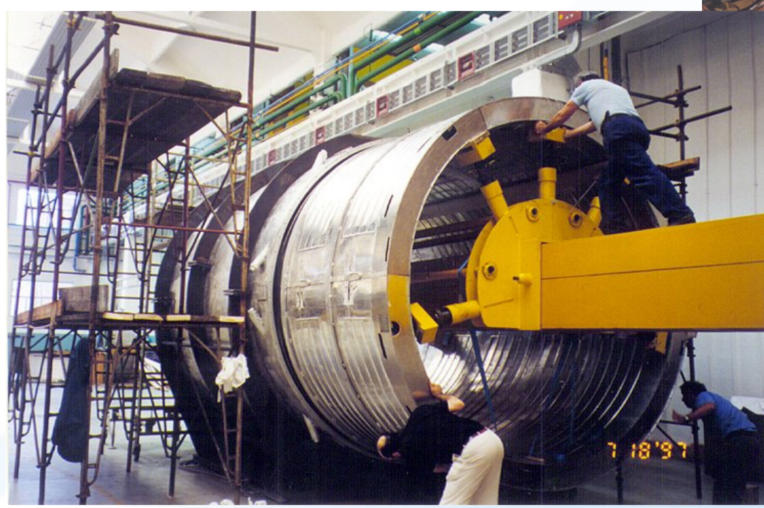
Thermo-siphon Design

- SLAC operation shows loop is not stable.
- Instability probably resulted from too much subcooling.

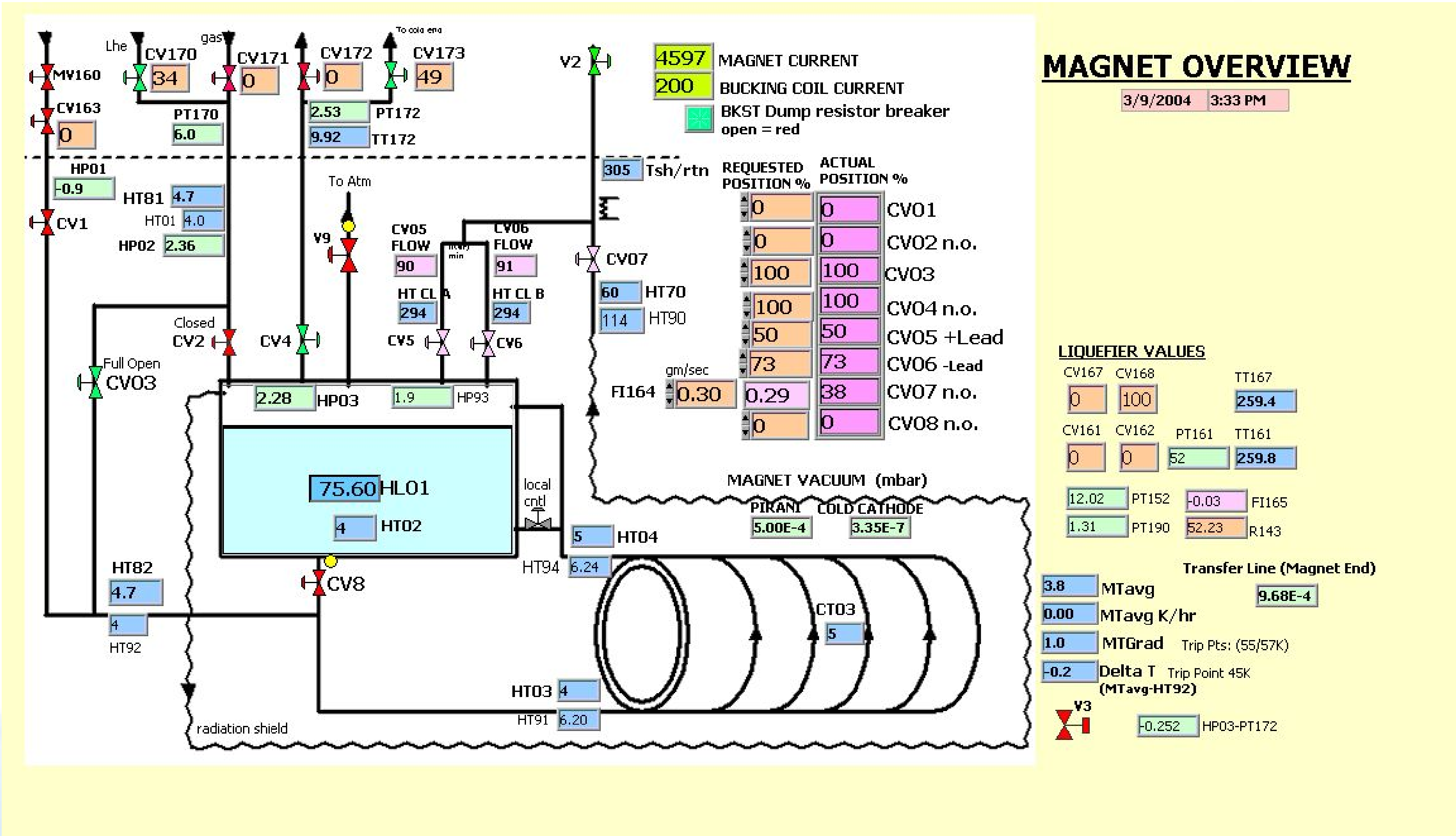
- As a result, nucleate boiling does not initiate until tube surface temperature has risen appropriately, then once siphon starts, the helium begins to cool and fluctuation cycle restarts
  - Phase separator too small compared to the magnet cooling tube volume. The vapor generated causes large spurts in liquid draw from the separator when vapor is generated

Magnet Design

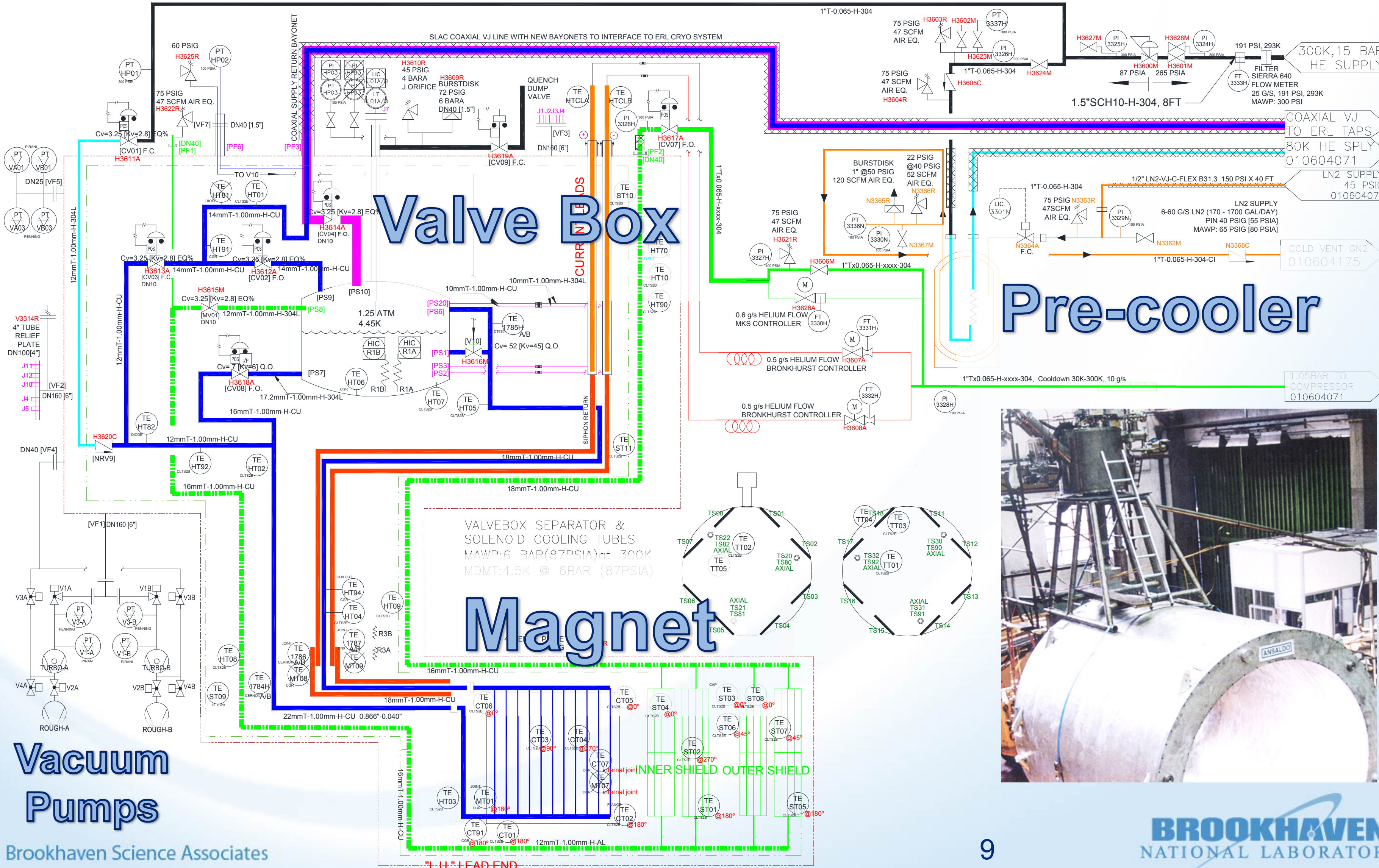
- **COIL COOLING**
  - Conductively cooled by helium through aluminum tubes welded on aluminum outer support cylinder.
  - Designed as thermo-siphon loop
    - Liquid level was not stable, reported from SLAC
    - Operated with forced flow from plant
  - Parallel tubes on aluminum support cylinder
  - Top and Bottom Headers
- **Valve Box**
  - 25L He Reservoir
  - Common Vacuum



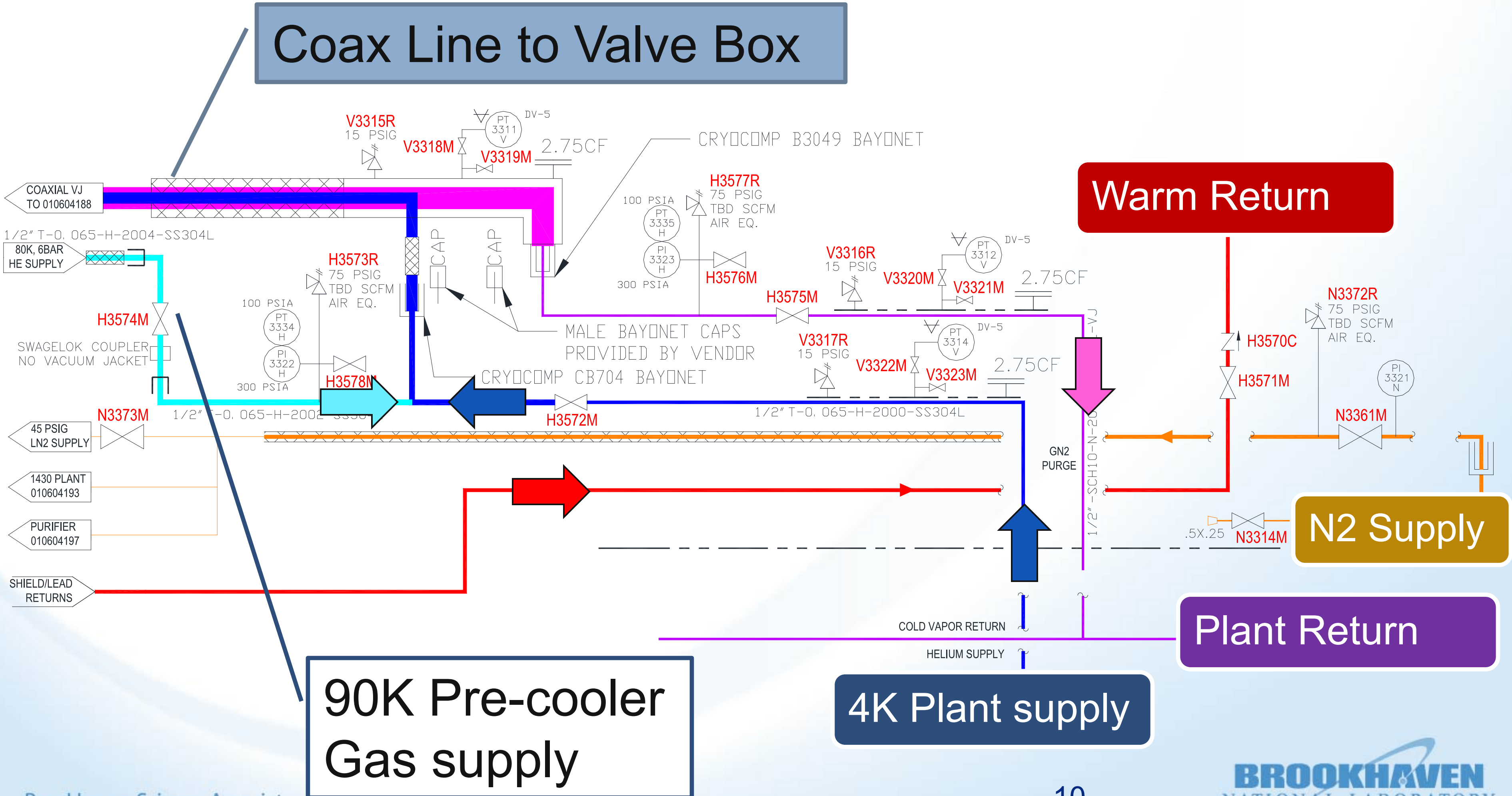
SLAC Configuration Valvebox with Thermo-siphon Reservoir



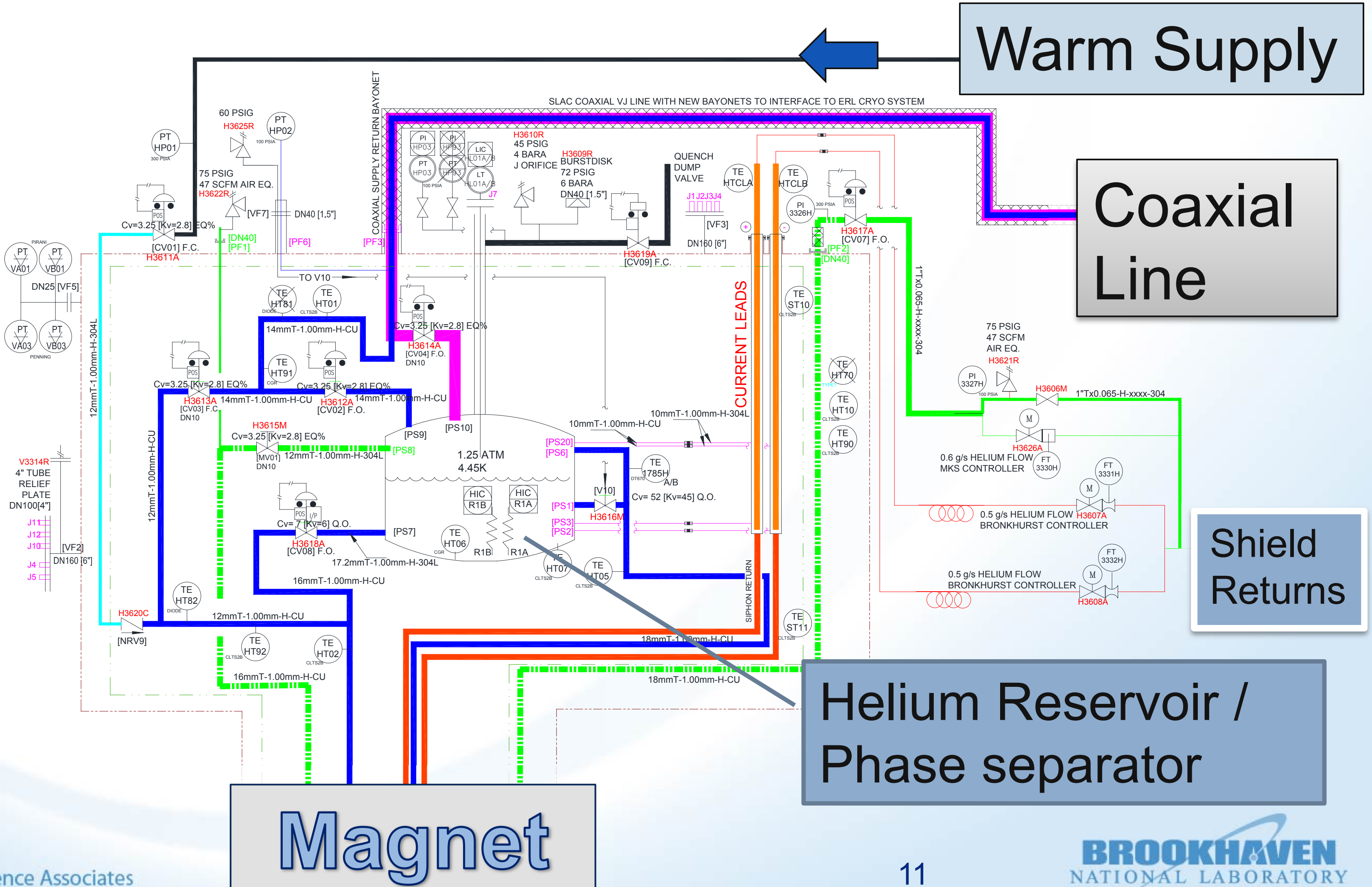
Process and Instrumentation Diagram



Process and Instrumentation Diagram Helium 1660 Plant Connections

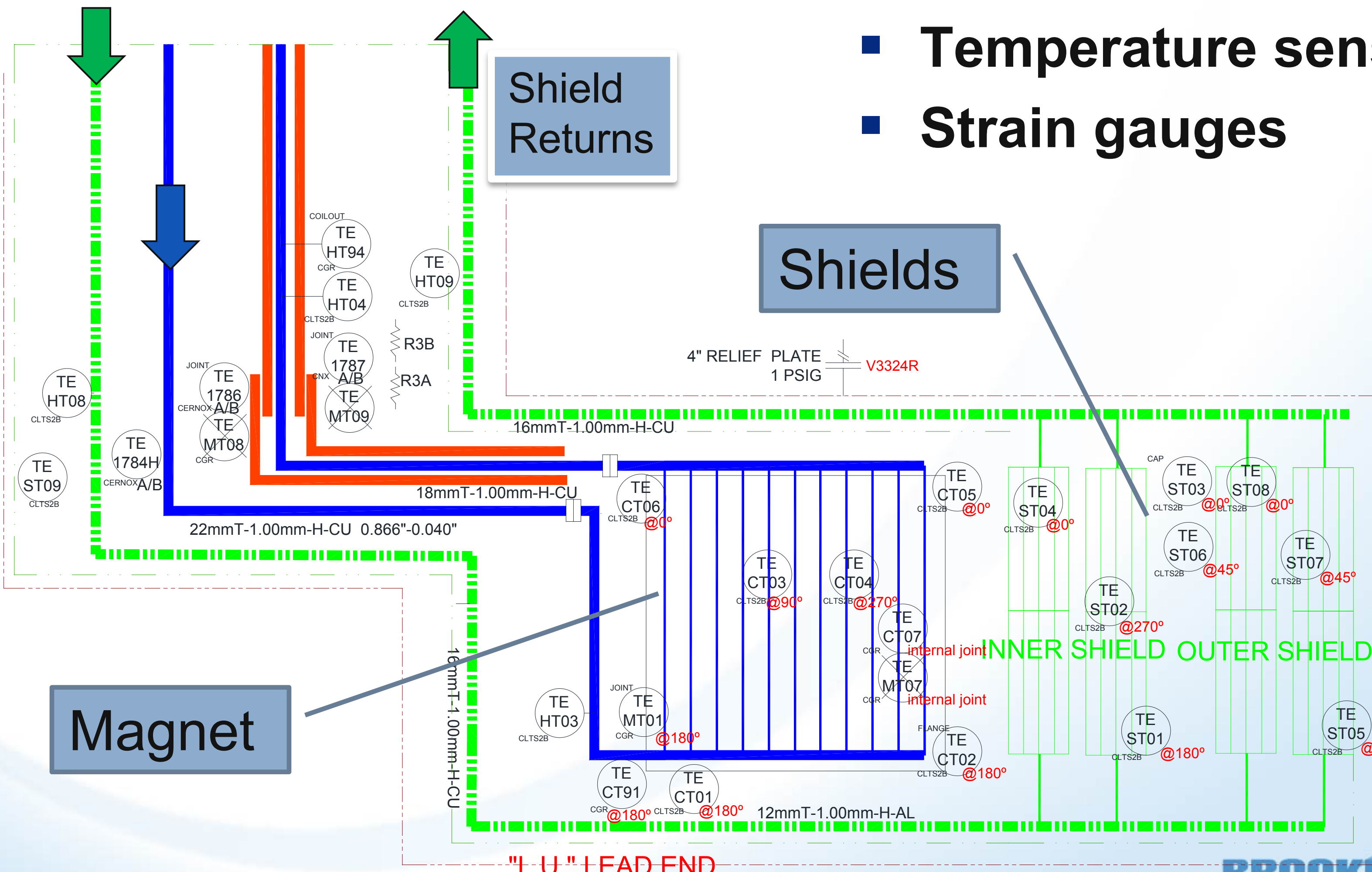


sPHENIX Valve Box



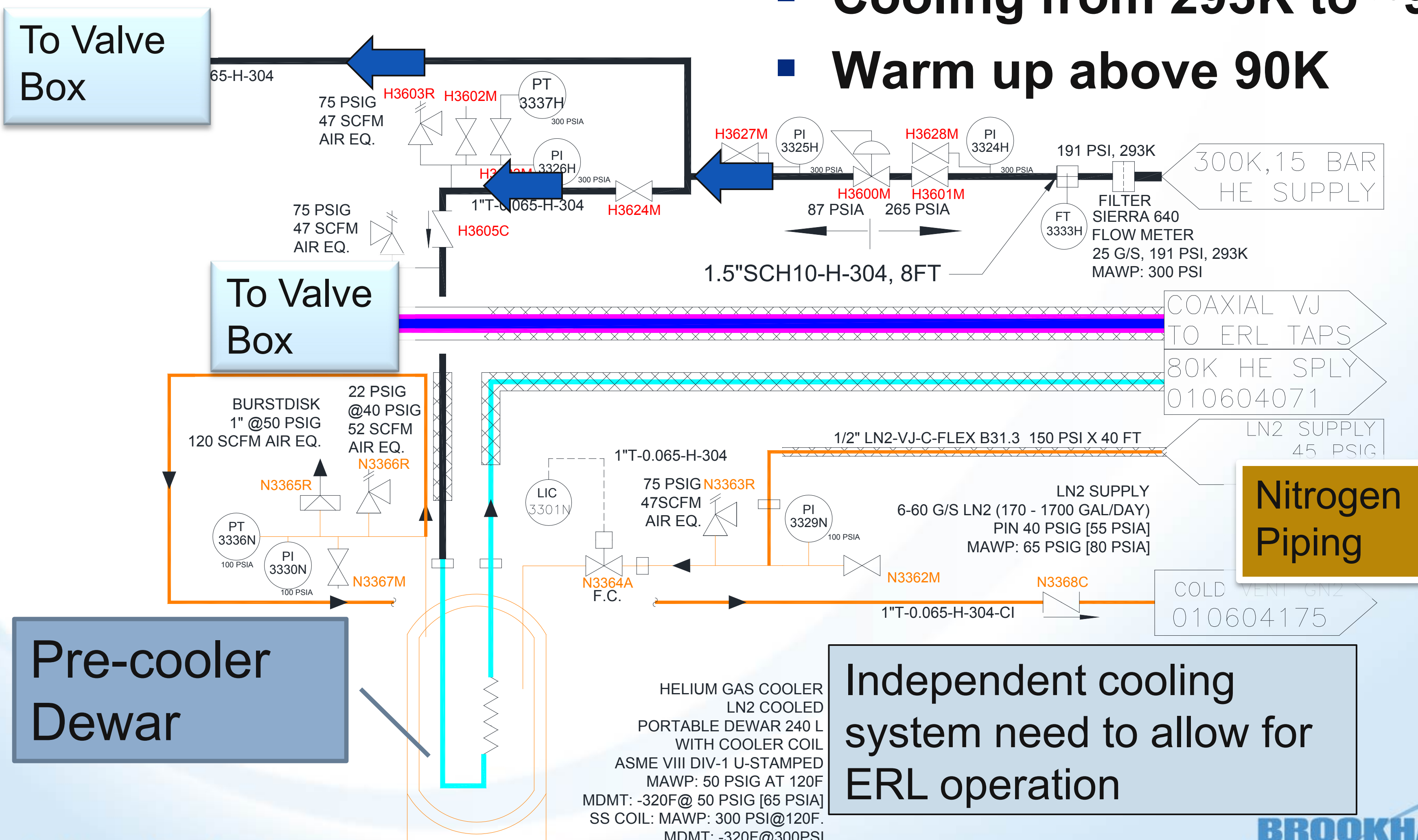
sPHENIX Magnet

- Temperature sensors
- Strain gauges



sPHENIX Pre-Cooler Dewar

- Cooling from 293K to ~90K
- Warm up above 90K

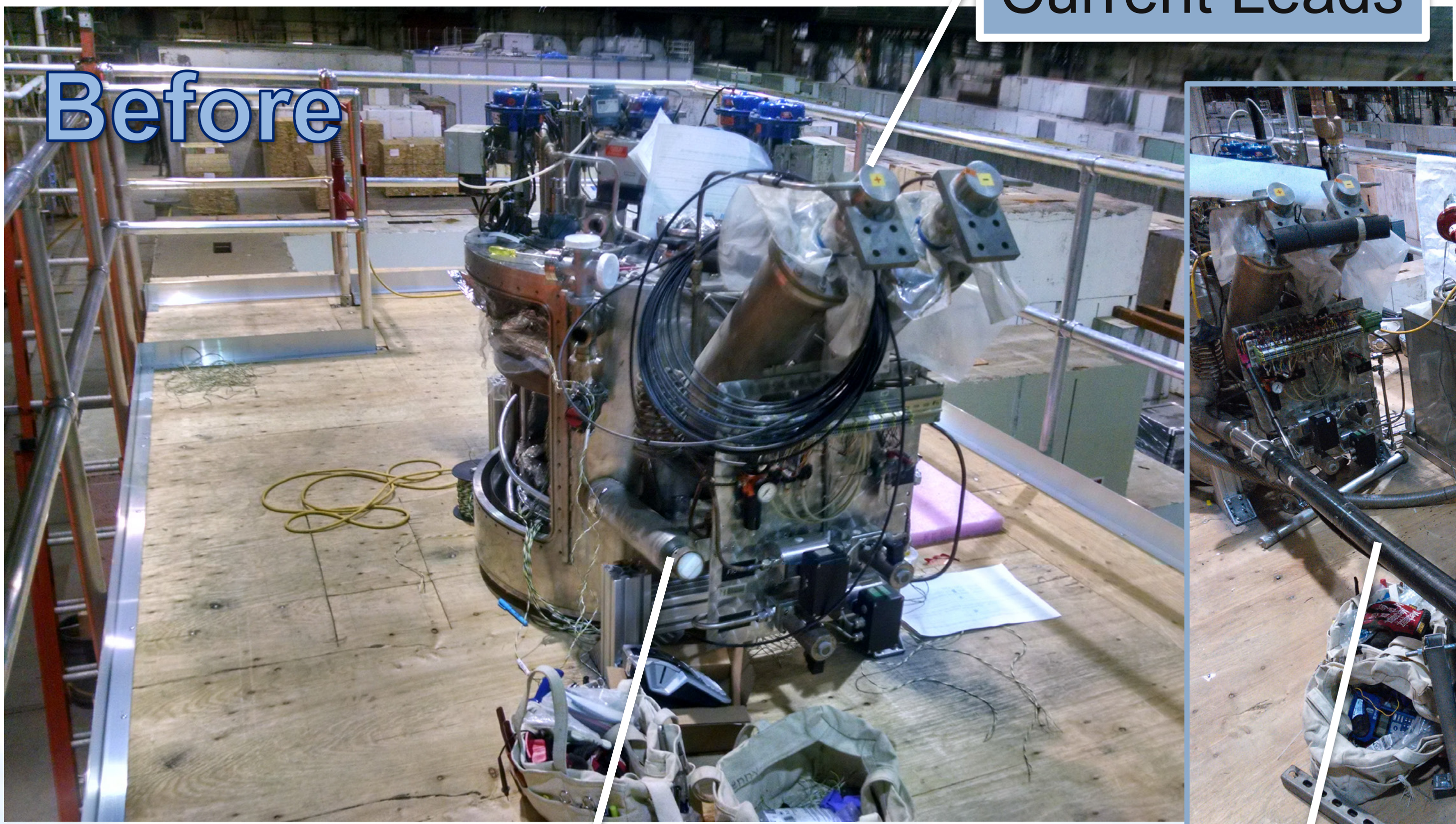


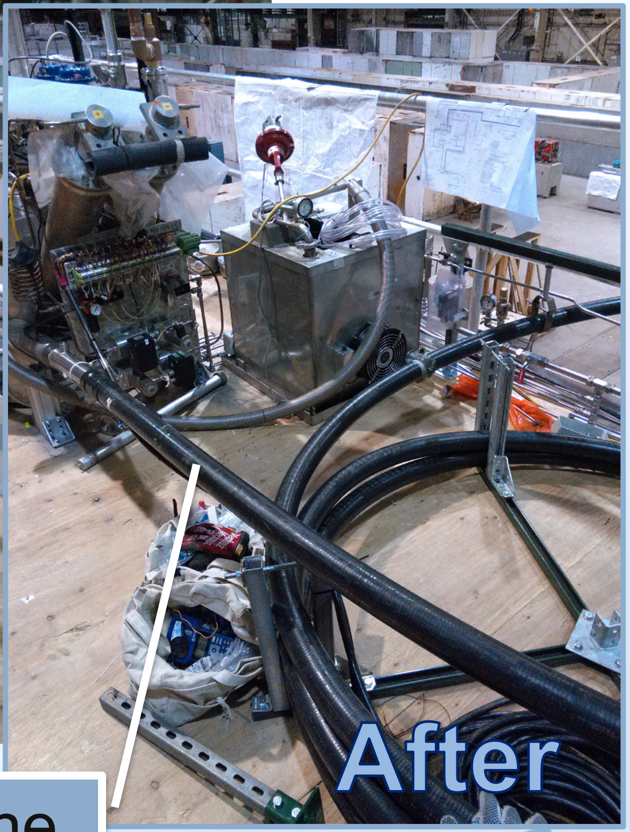
Independent cooling system need to allow for ERL operation

Low Power Test Setup

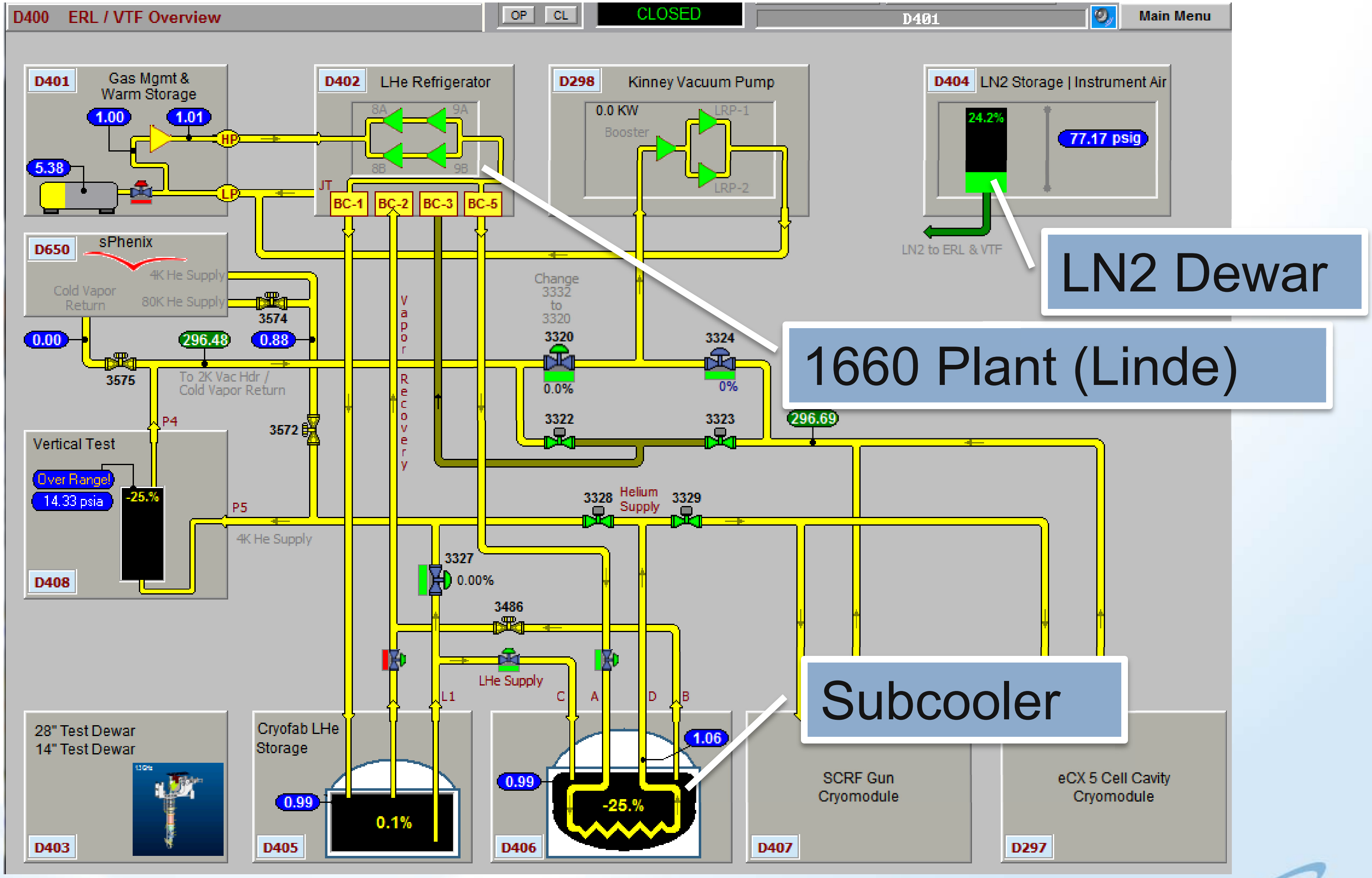
Low Power Test Setup

Valve Box on Test Platform

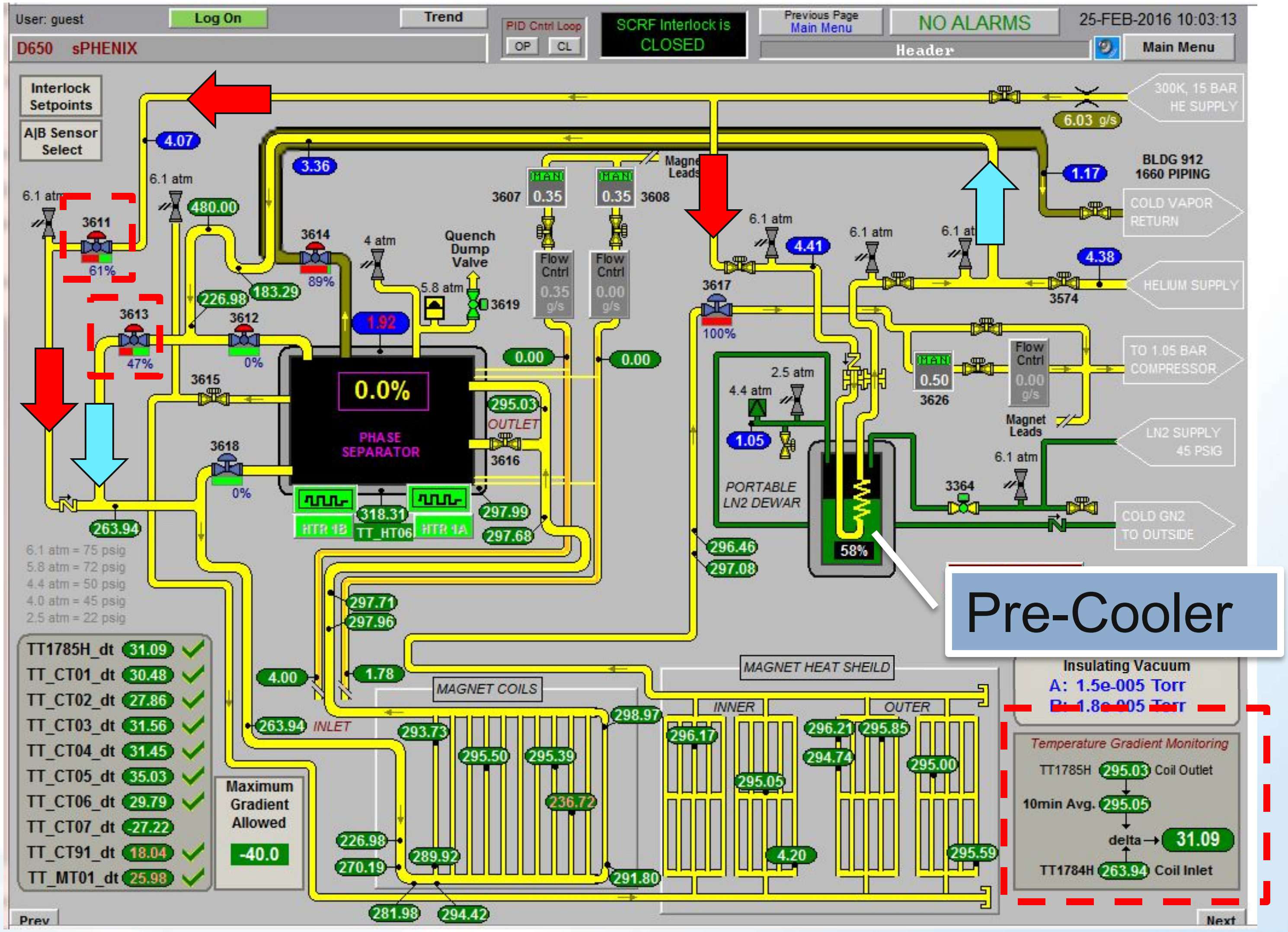




Operations – Overall Plant Control



sPHENIX Controls – Pre-Cooler



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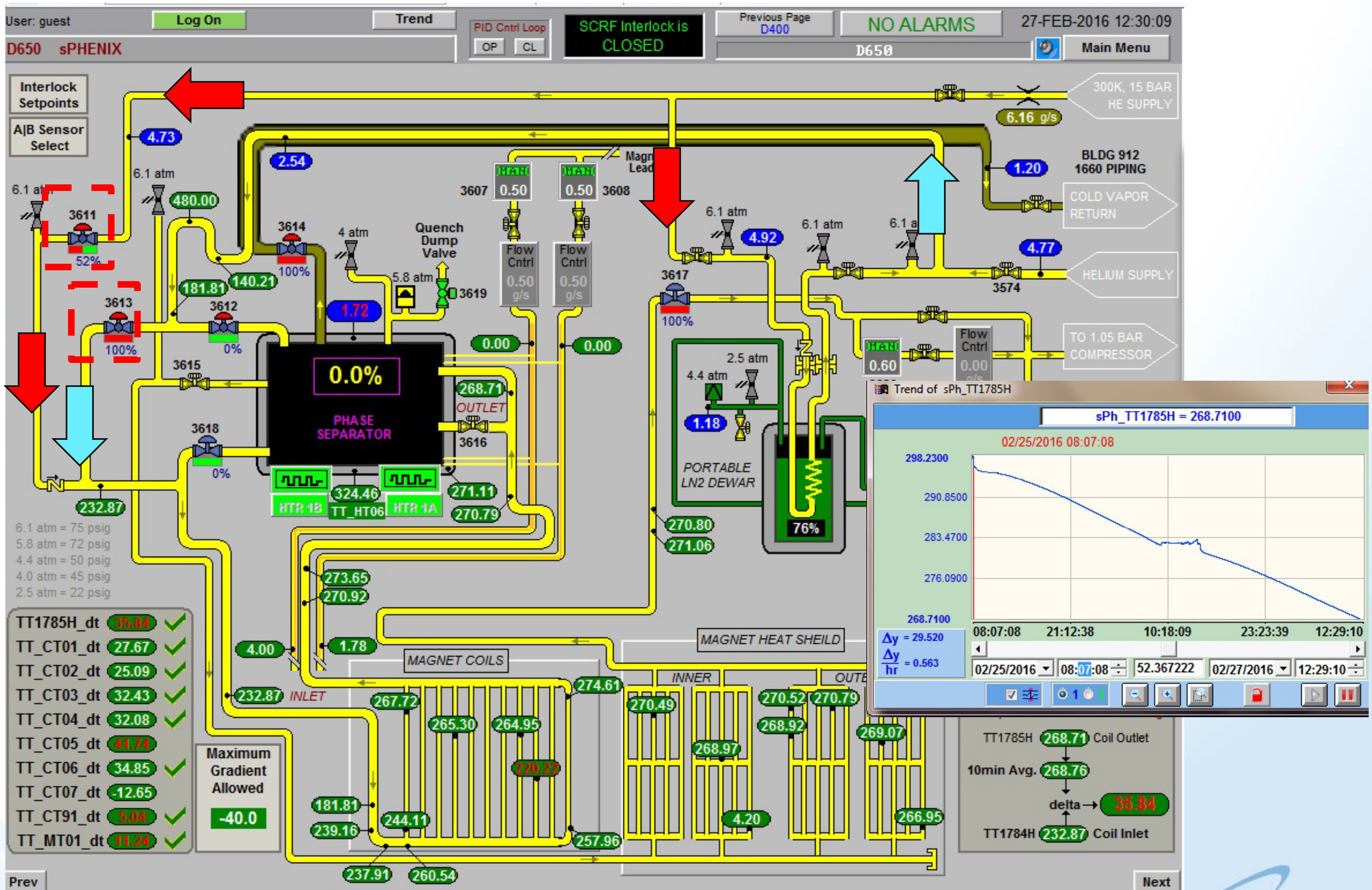

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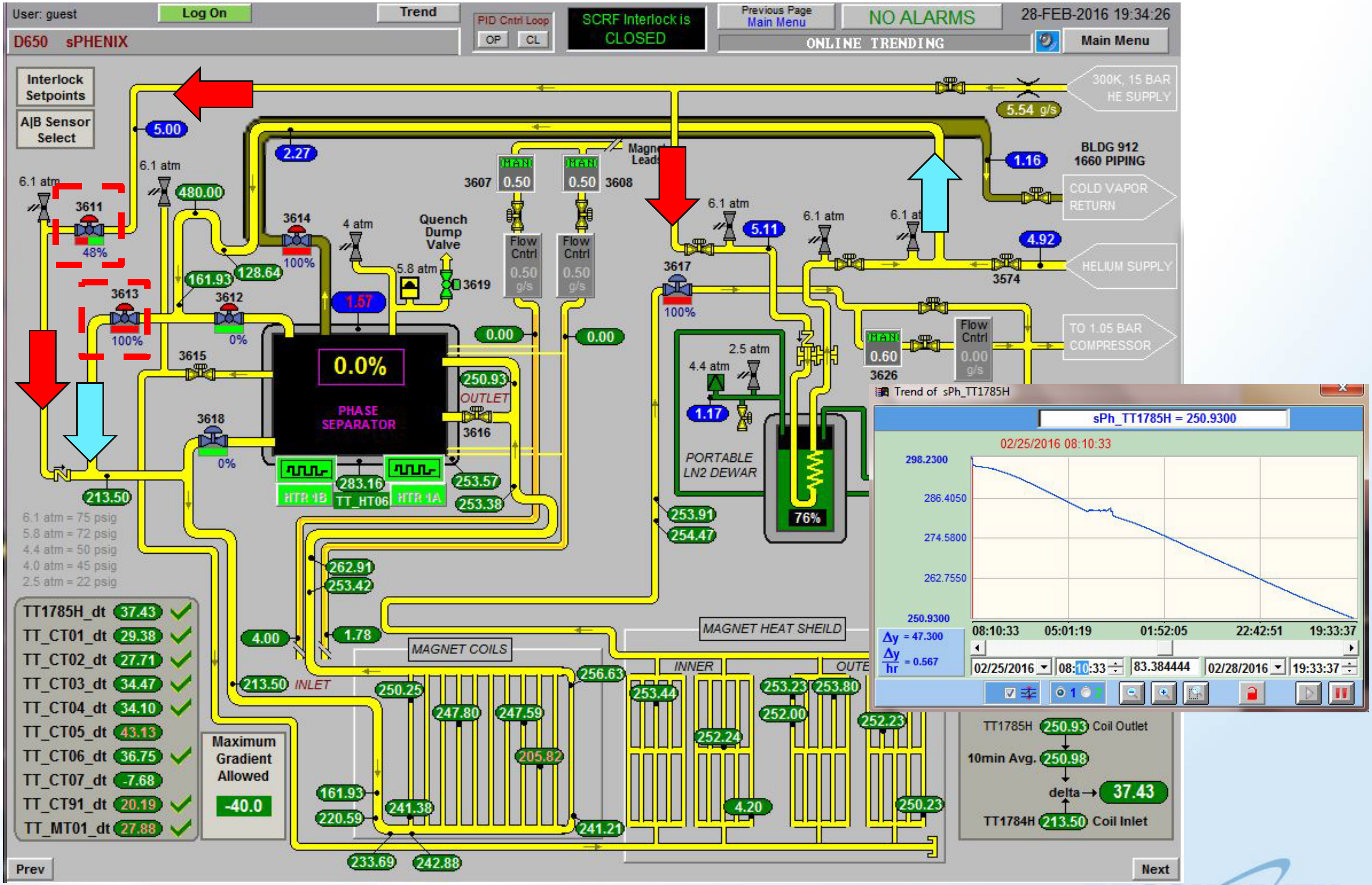

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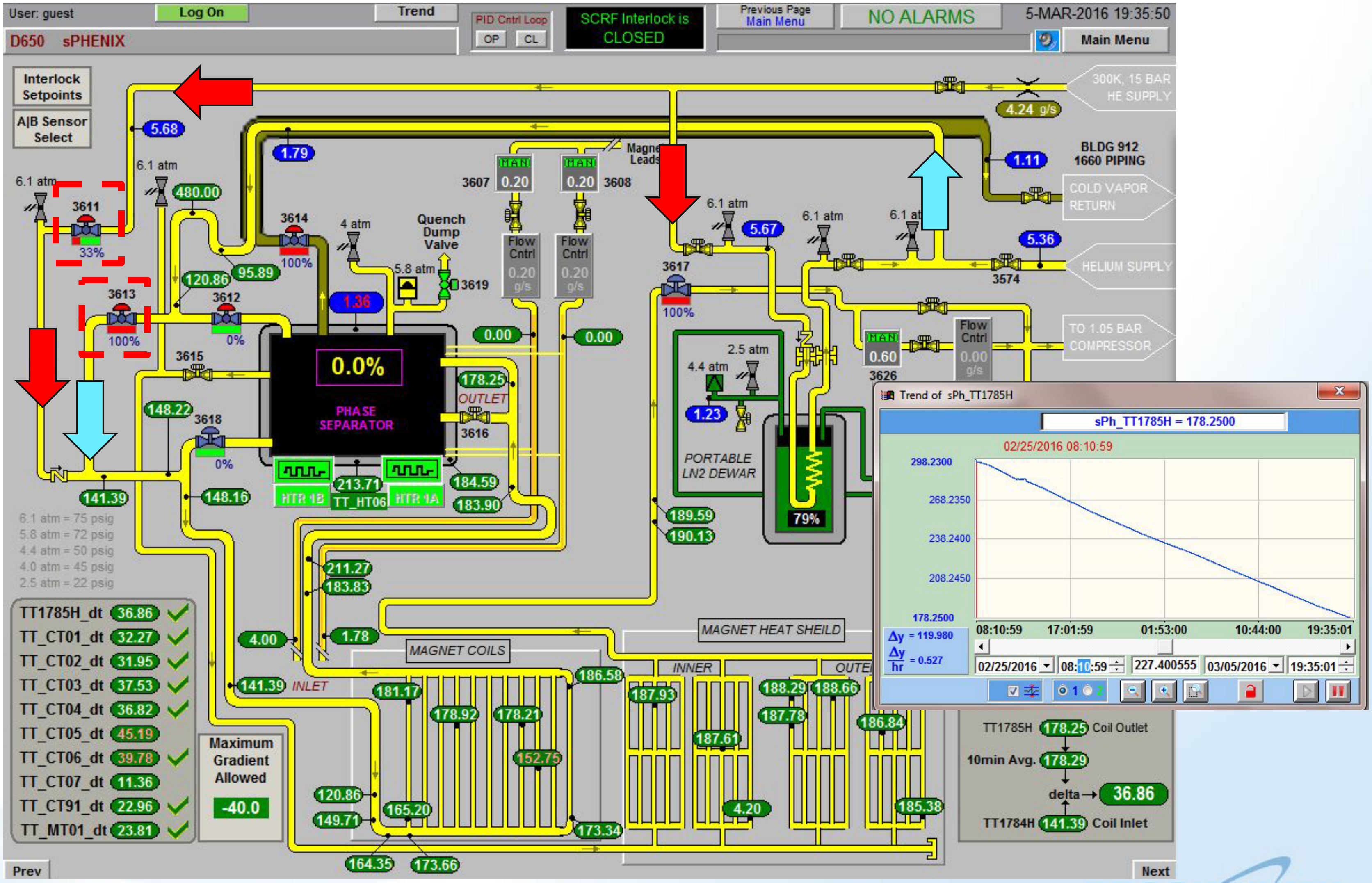
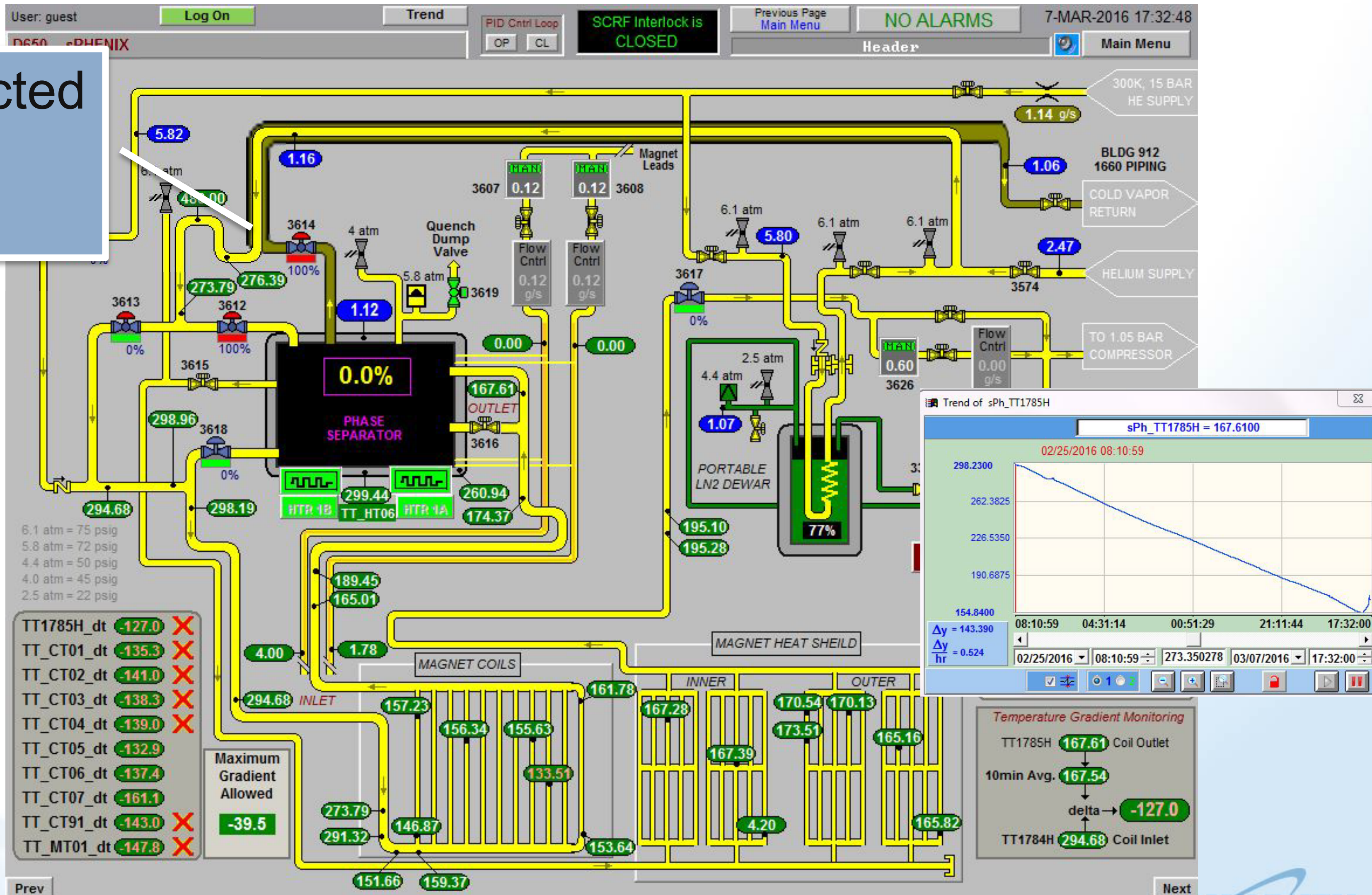


sPHENIX Controls – Pre-Cooler

Suspected Water Plug



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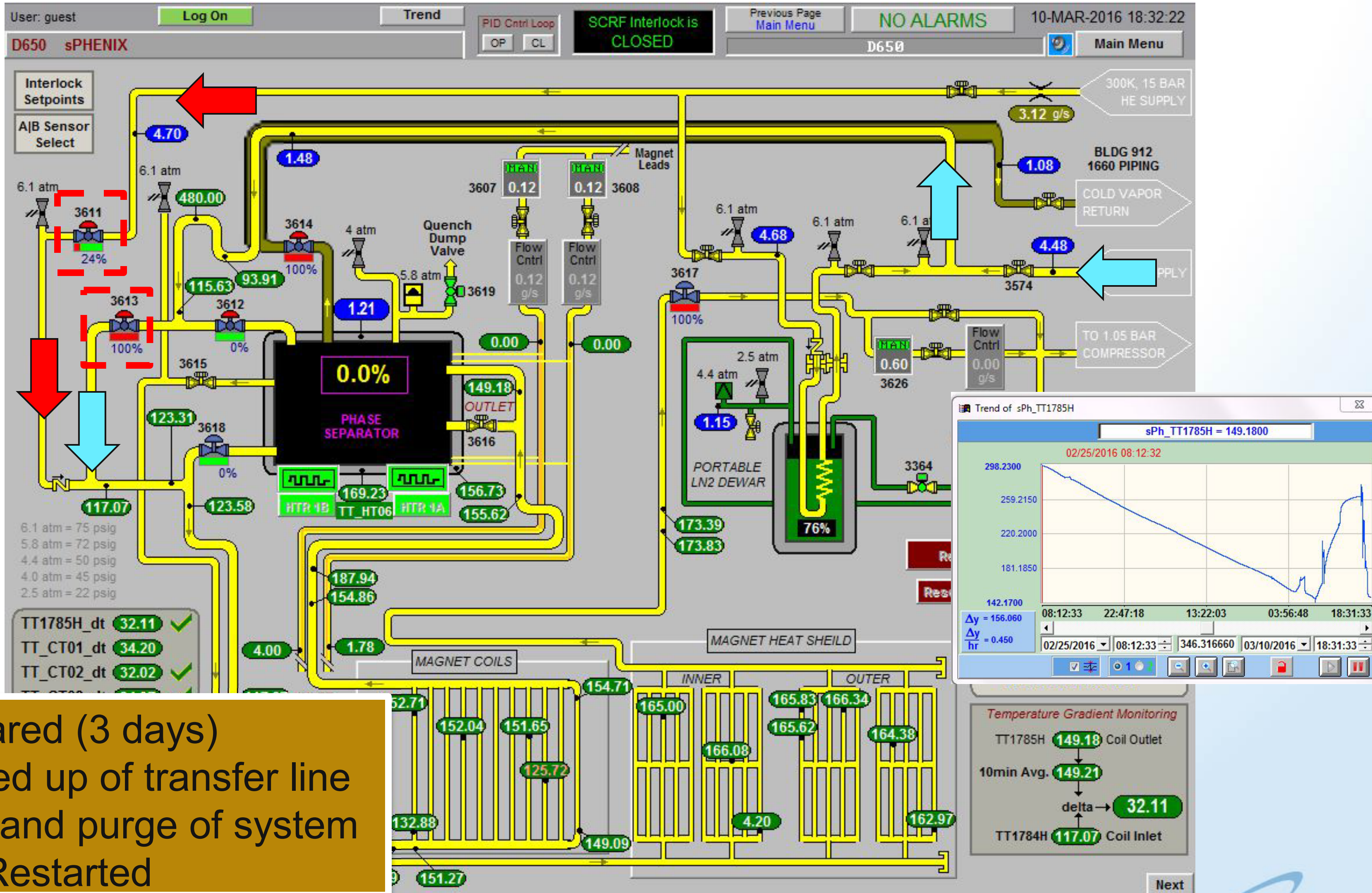
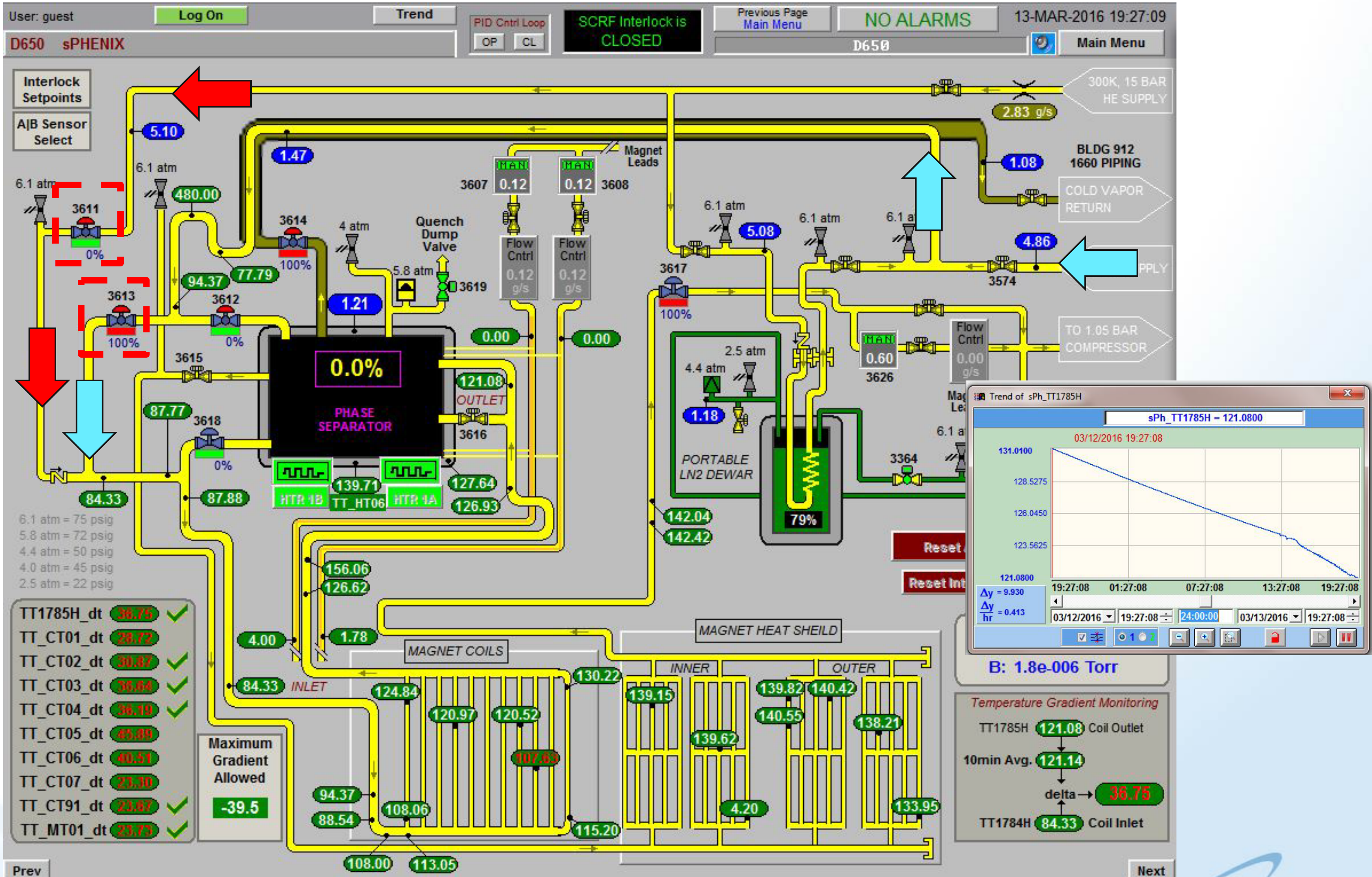


Plug Cleared (3 days)

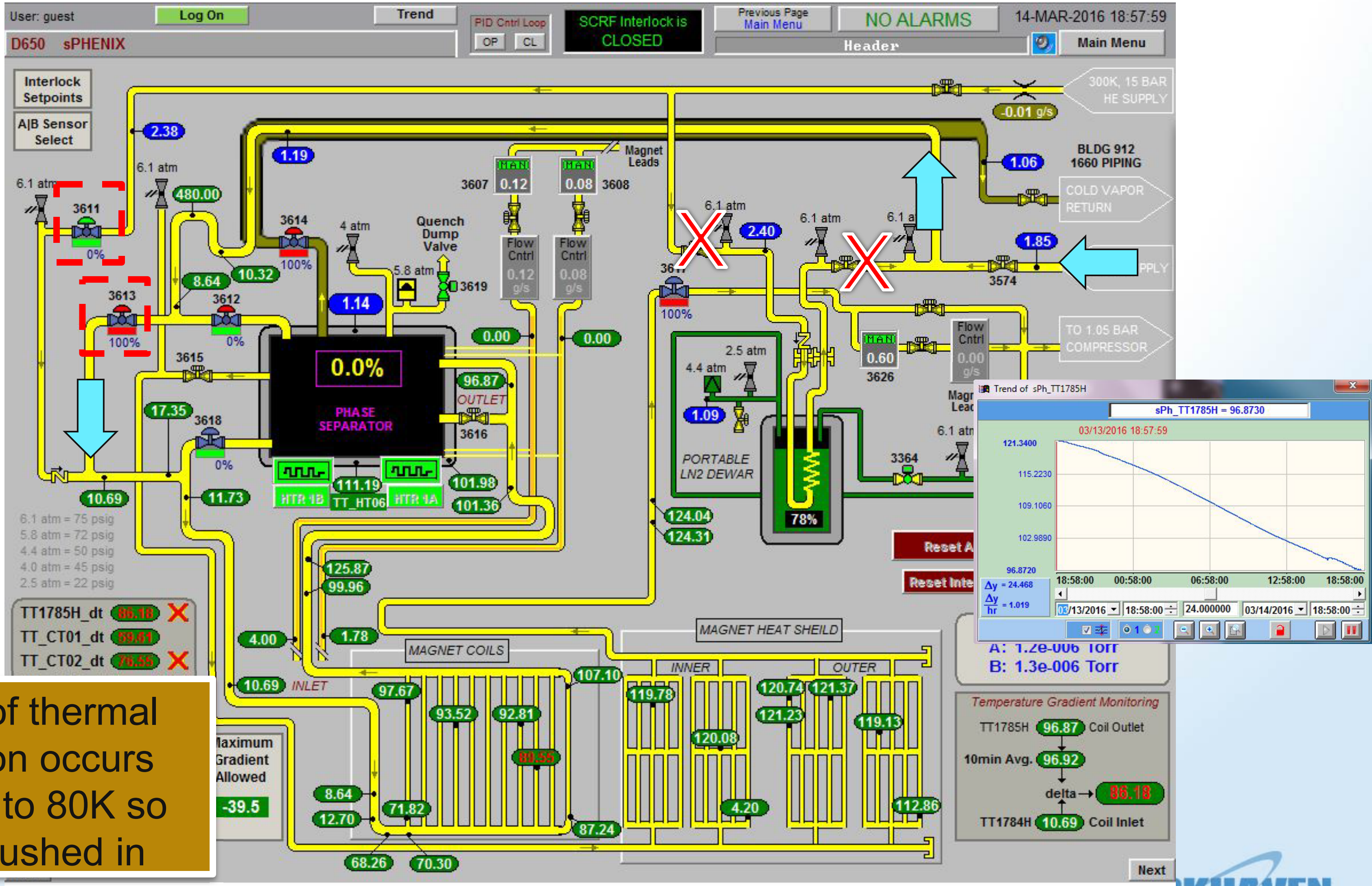
- Warmed up of transfer line
- Pump and purge of system

Cooling Restarted

sPHENIX Controls – Pre-Cooler

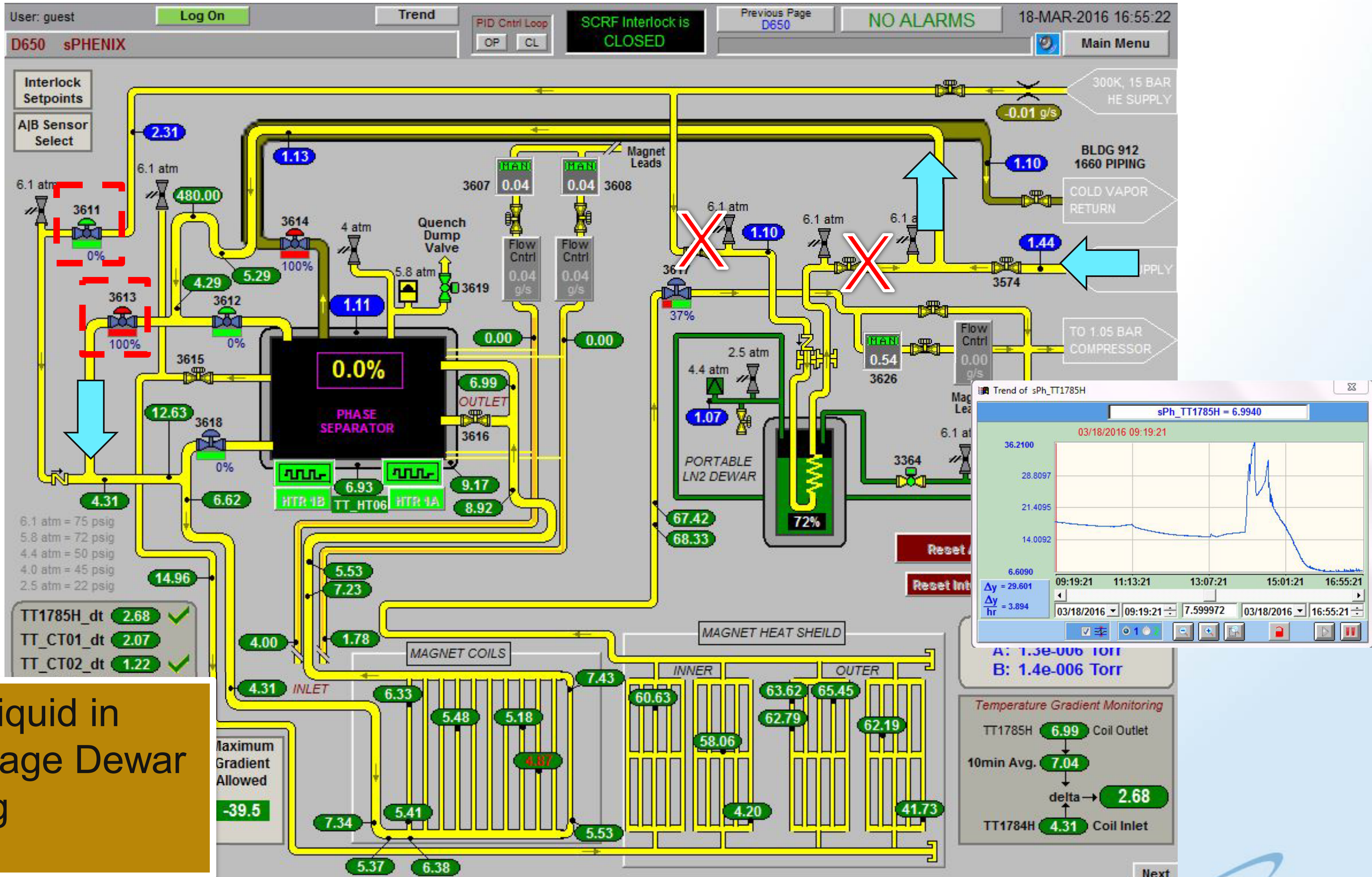


sPHENIX Controls – Plant



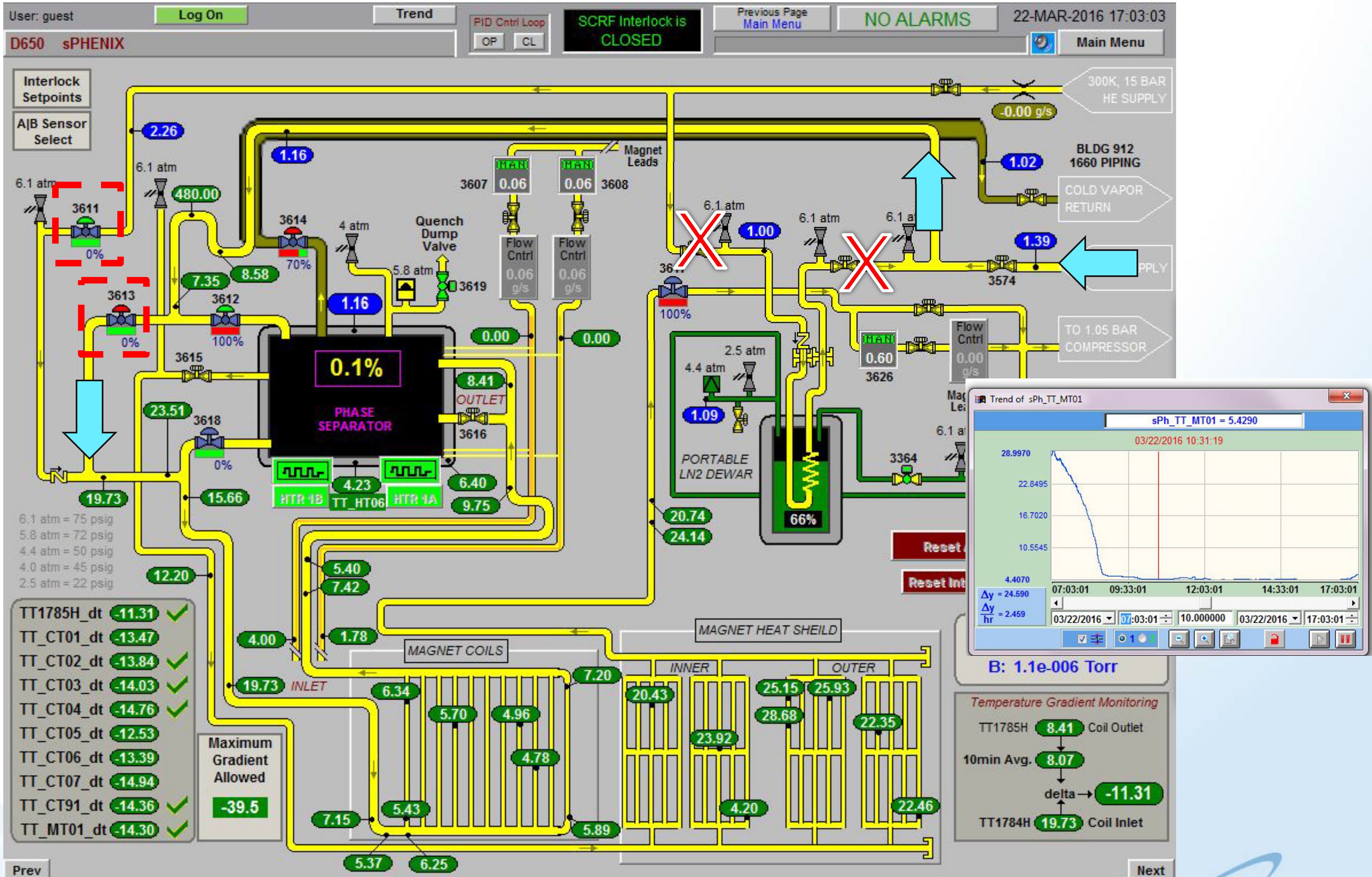
Majority of thermal contraction occurs from 300 to 80K so 4K flow pushed in

sPHENIX Controls – Plant

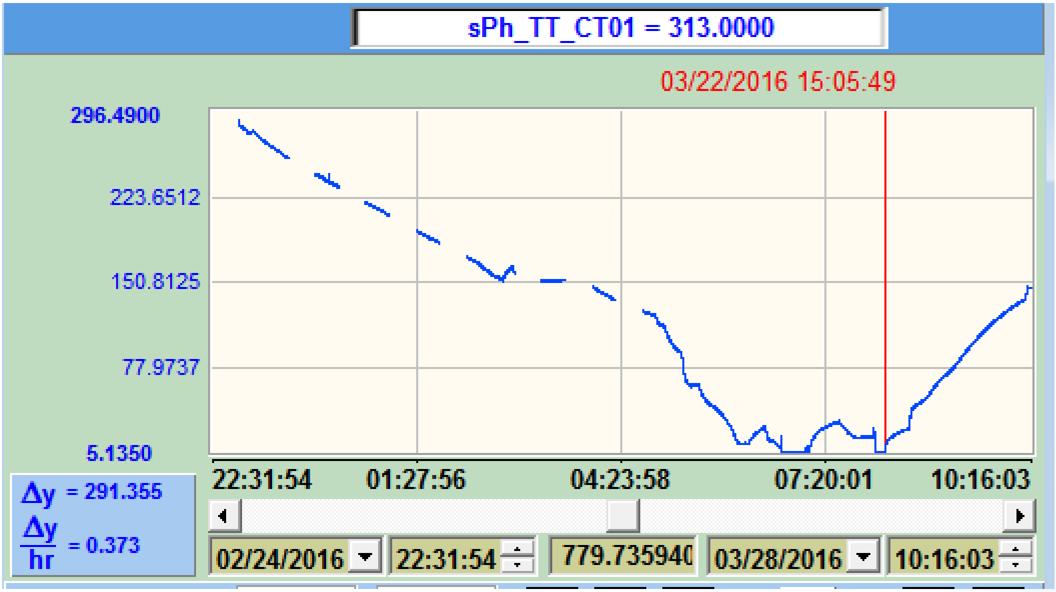


Building liquid in plant storage Dewar for testing

sPHENIX Controls – Plant (Testing)



Low Power Test

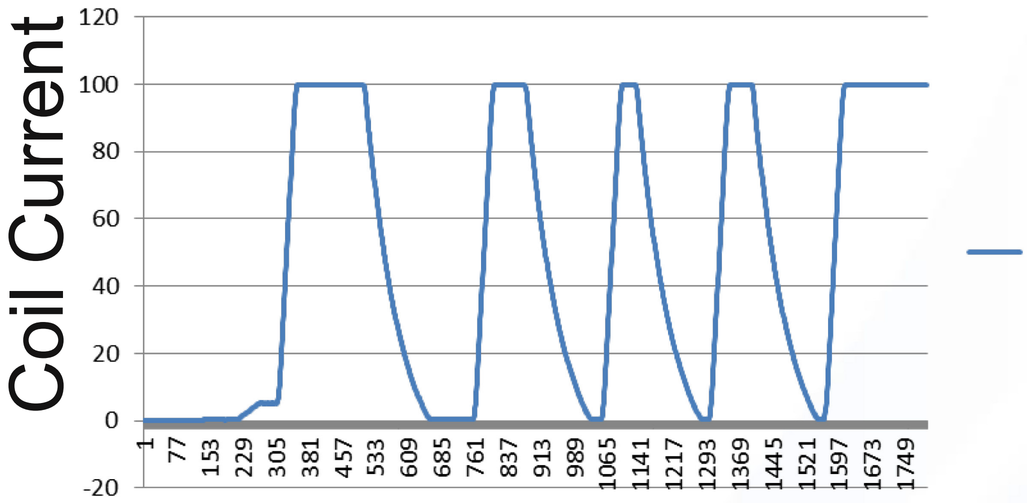


- Force Flow
  - System balance was achieved
- Siphon loop tested
  - Flow did not develop
  - Reservoir emptied too quickly to properly control
  - Larger buffer volume need

Results

- Solenoid tests complete
  - Magnetic system tested
  - Review of strain gauge data
- Cryogenic System
  - No leaks or problems discovered after full thermal cycle
  - System setup was adequate
    - Improvement discussed later
  - Siphon loop will need further study if desired

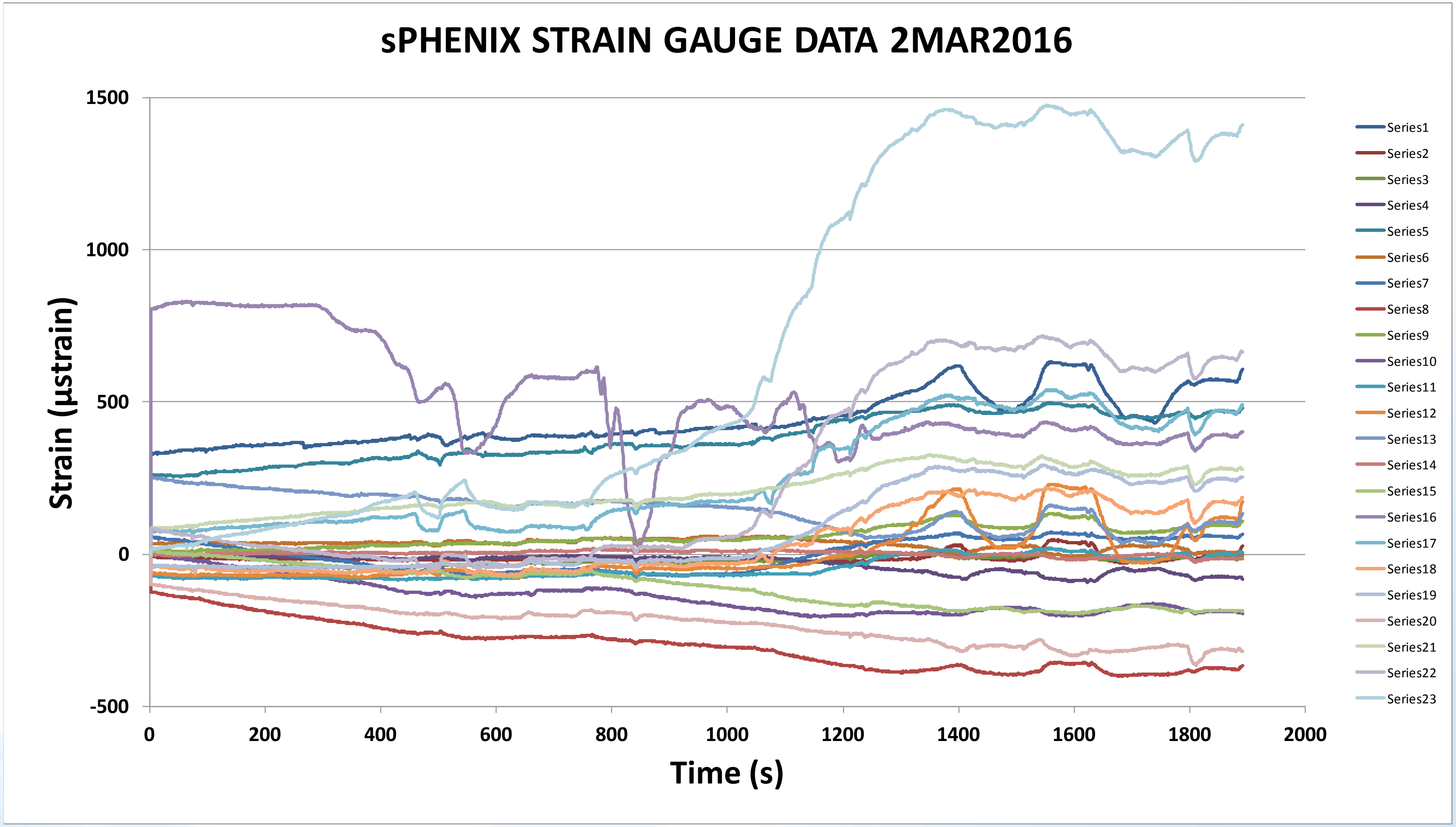
Results – Solenoid 100A Cycles



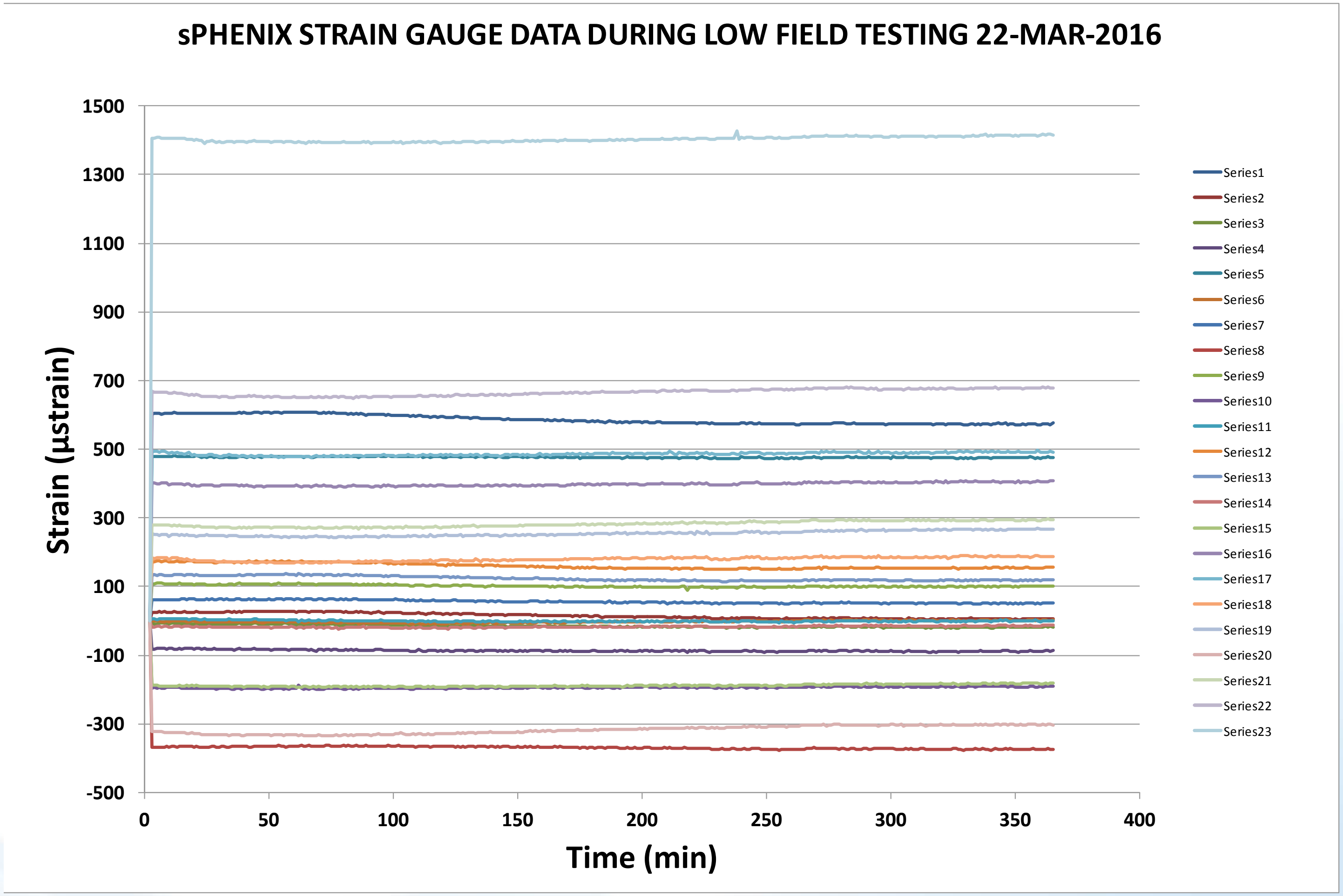
Time (S)

Ramp rate 2.5 A/S

Results – Solenoid @208K



Results – Solenoid



Operational Issues

- Poor vacuum on the insulating vacuum in the new interface for the co-ax and frosted up at the elbow. Stop and diagnose leak
  - Pump down with turbo
- Insulating vacuum pump down issues
  - Pump seals and installation
  - Control connections and setpoints
- Blockage. Water dew point was good, -65C to -70C, but since we were mixing warm gas and 100K cold gas at the solenoid valve box, it was still enough over time to accumulate enough to plug the coax VJ line.

Improvements and Upgrades

- Plant Purifier Needed
  - Prevent plugs from contamination
- Improve Cooldown Rate
  - More flow requires higher pressure
  - Raise relief set points limited to rating on coaxial line
  - Alternate piping route from 1660 plant for lower pressure drop
  - Control flow to shield
    - Manual metering valve consider replacing with automatic
- Current Lead Heaters
  - Improve air flow for high power test
  - Silicone heater to improve thermal contact verse heat tape

Reference Material

- Addition material for further discussion

SOLENOID PARAMETERS

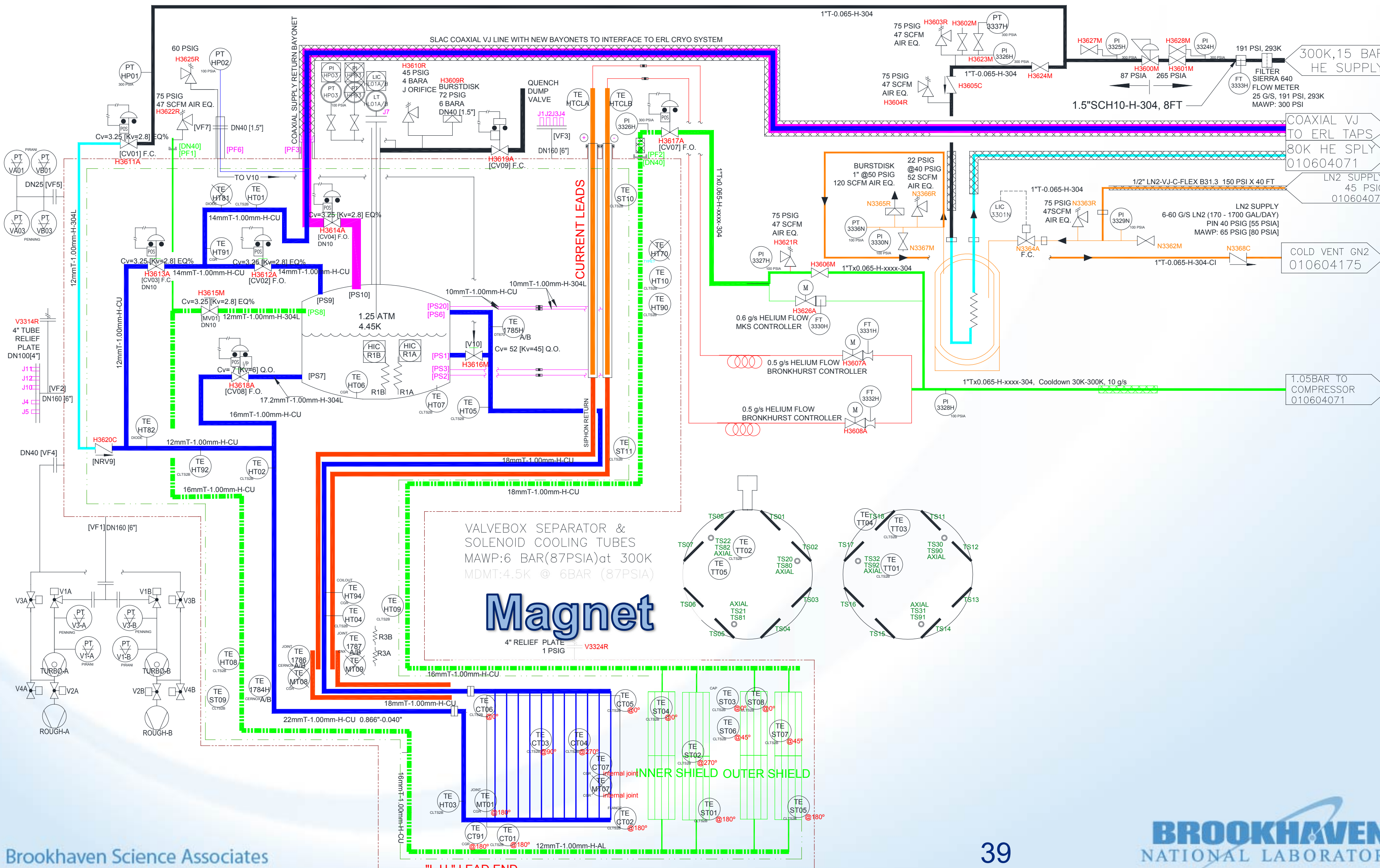
Coil Mass	
Outer diameter (m)	3.1042
Inner diameter (m)	3.0196
Length (m)	3.587
Volume (m^3)	1.460
Al Density (kg/m^3)	2700
Mass (kg)	3940.7
Support Cylinder Mass	
Outer diameter (m)	3.2052
Inner diameter (m)	3.1042
Length (m)	0.3
Volume (m^3)	0.1501
Al Density (kg/m^3)	2700
Mass (kg)	405.4
Support Cylinder Mass	
Outer diameter (m)	3.1742
Inner diameter (m)	3.1042
Length (m)	3.5888
Volume (m^3)	1.239
Al Density (kg/m^3)	2700
Mass (kg)	3344.6

Total Mass (kg)	7690.8
Integral of specific heat (J/kg)	172,790
Thermal Energy (MJ)	**1328.9**
COOLDOWN: 300K TO 90K	
LN2 USE	
1200	MJ
200	J/g
6644461	grams
8411	Liters
2222	Gallons
COOLDOWN: 90K TO 4.5K	
Liq Helium	
120	MJ
225	J/g
533333	grams
4444.4	Liters

Cryogenic Summary of Solenoid

- **Coil Energy**
  - Stored energy: 27 MJ [@4596A,2.57H]
  - Tc =8.27K @ 2.5T
  - Coil temperature after quench 37K
- **Heat Shield**
  - Duty: < 100W [Design 350W]
  - 45K
  - <0.5 g/s
- **Lead Flow**
  - **Main Coil**
    - **5000 A**
    - **0.25 g/s each lead**
- **Cool down**
  - SLAC flow: 70 G/S
  - **ΔT_{max} = < 40K**
  - Max Cooling duty: 14 kW
  - Typical duration: 7 days
- **Steady State**
  - 4.5K load: ~ 25W [Design 70W]
  - Siphon Separator vessel and solenoid
- Operation modes
  - **Thermo-siphon loop**
  - **Forced flow cooling from plant**

Process and Instrumentation Diagram



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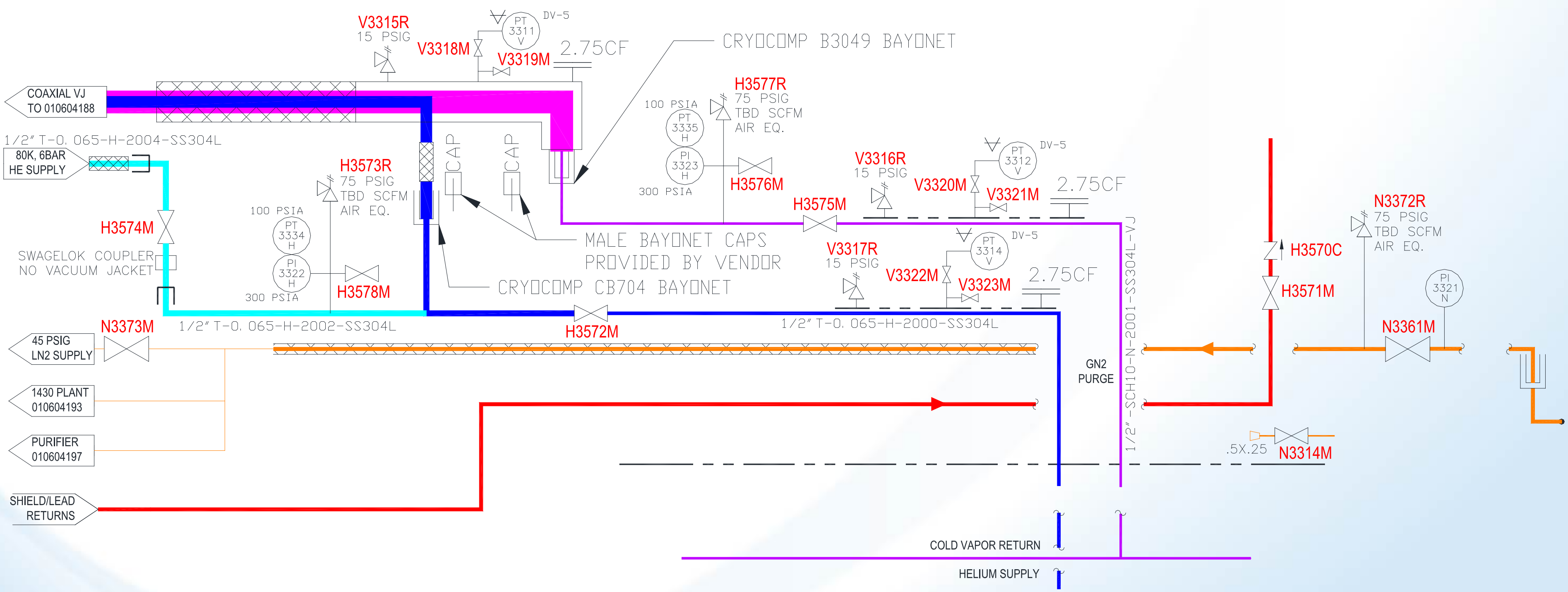

Cooling Methods

Forced circulation

- Subcooled
  - M header, 4 bar flow gets subcooled in a subcooler heat exchanger that is submerged in LHe bath and sent to solenoid. Return to S header.
- 2-phase flow
  - Push 2 phase flow through solenoid cooling tubes.
  - Essentially equivalent of strong Thermo-siphon loop

Thermo-siphon Design

- SLAC operation shows loop is not stable.
- Instability probably resulted from too much subcooling.

- As a result, nucleate boiling does not initiate until tube surface temperature has risen appropriately, then once siphon starts, the helium begins to cool and fluctuation cycle restarts
  - Phase separator too small compared to the magnet cooling tube volume/ vapor generated and causes large spurts in liquid draw from the separator when vapor is generated


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