Cryogenic Summary - Testing D3L101 in MAGCOOL

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11/18/04

- Description
- Operating Summary
- Tests Performed
- Detail Operation
- Test Conditions
- Summary

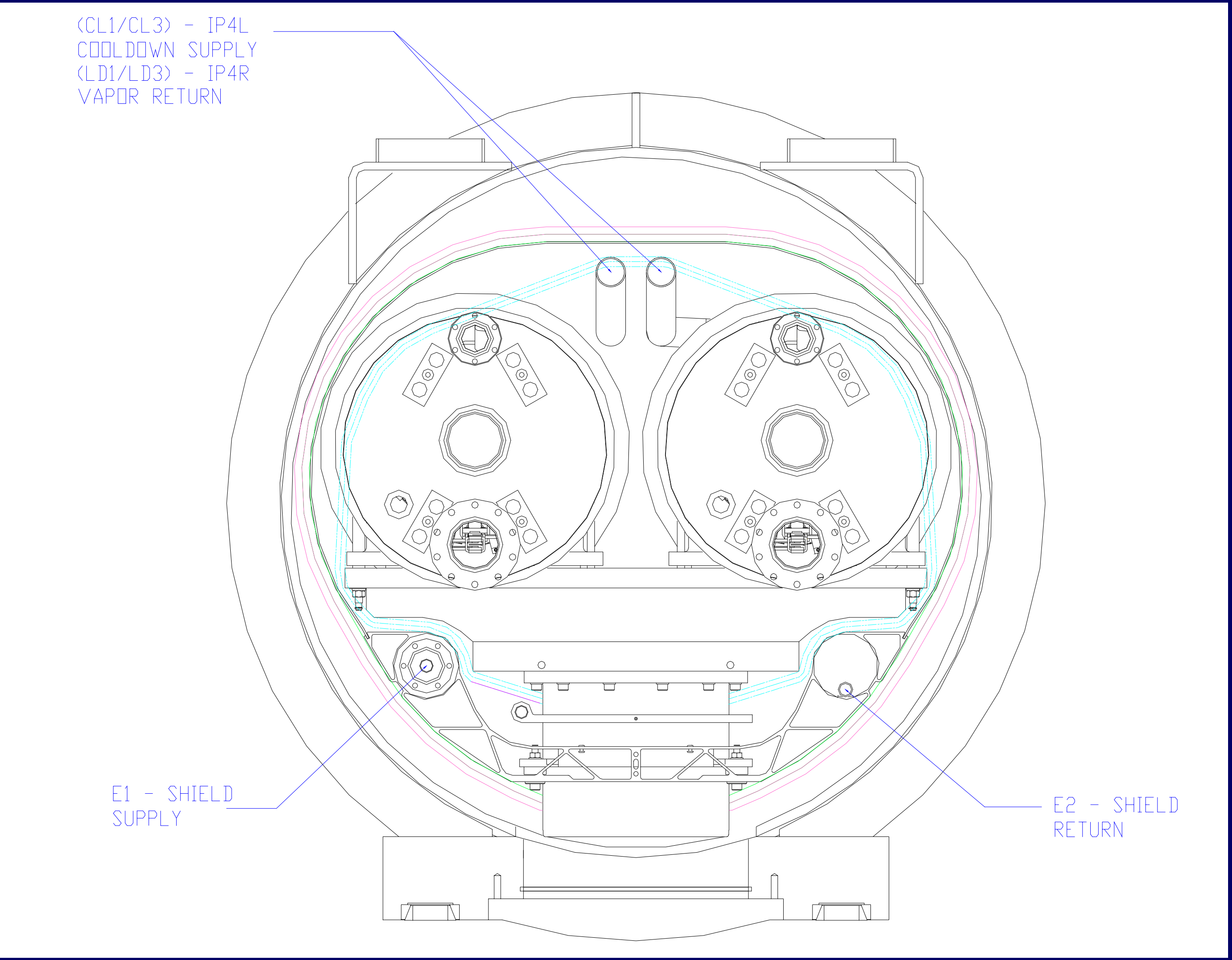
Specific of D3L101 Test

- Two cold mass with 4 – 7500 A leads
- Diameter for each cold mass is ~ 10.5”.
- Coolodwn line and JT feed from the non-lead end. Helium return from lead end.
- Filters are installed in the feed lines to D3.
- A 11.5” (9.5” active length) curved level probe is installed in each cold mass.

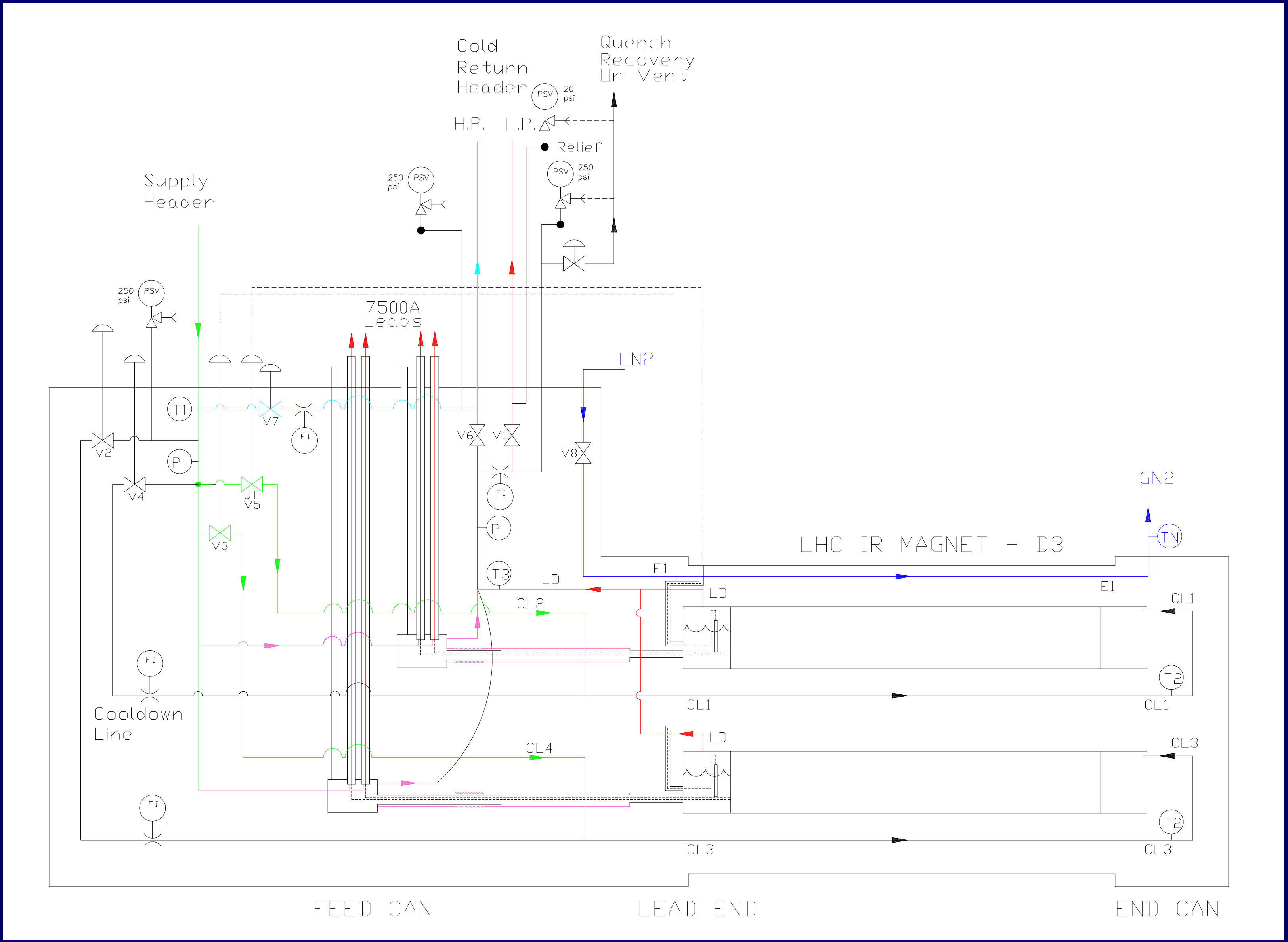
General Description – D3L101

- Magnet is installed in horizontal position
- Warm bore tubes inserted. Tests were performed with warm bore tubes evacuated for quench, and opened for field measurements.
- Information on the Warm Bore Tube and measuring device can be obtained from
    - A. Marone - andym@bnl.gov
    - G. Ganetis – ganetis1@bnl.gov
    - D. Sullivan– dans@bnl.gov

Cross Sectional of D3 Cryo-Assembly With Two Cold Masses as Viewed from Lead End



Flow diagram - Testing D3L101 With 2 Cold Mass

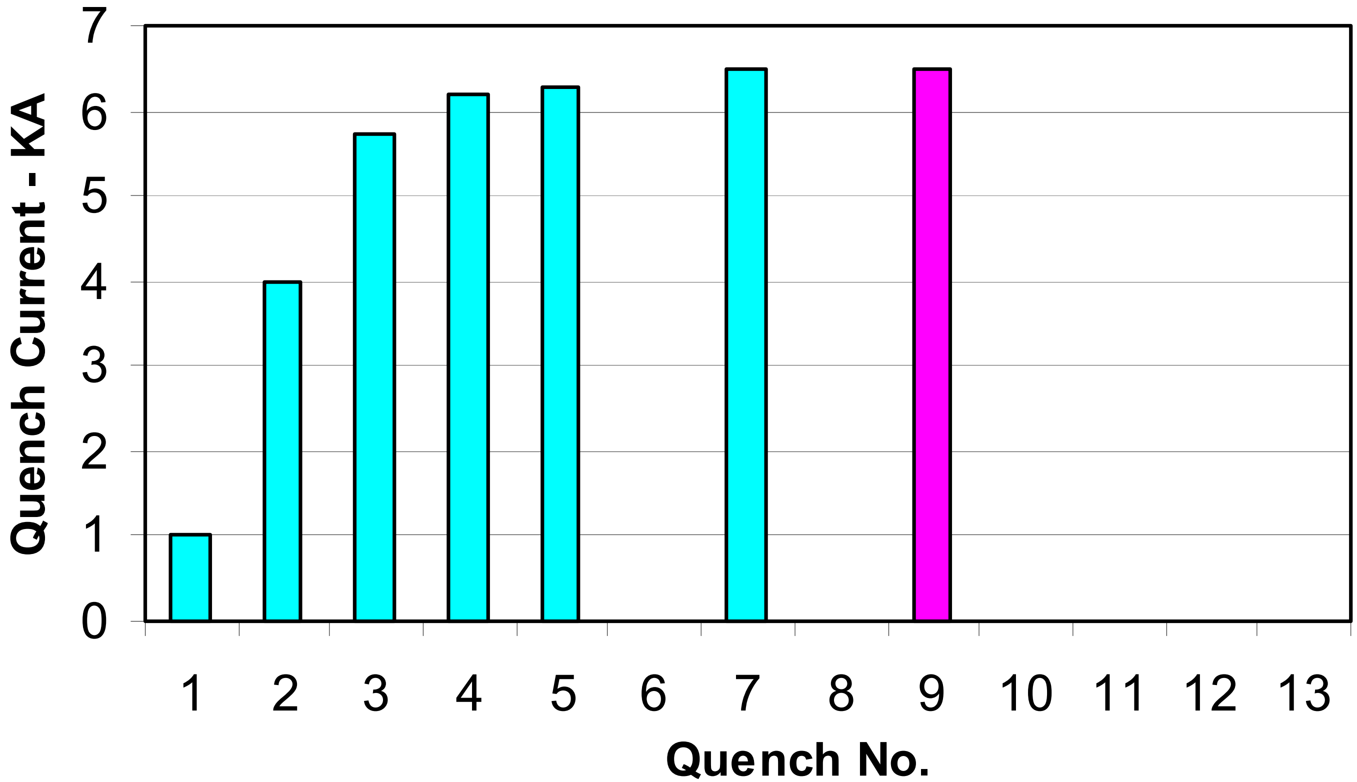


Tests Performed for D3L101

- 1st test group (forced flow cooling ~ 4.6 K),
  - Shut off - 1000 A (10/29)
  - Ramp to – 4000 A (10/29)
  - Strip Heater – 4000 A (11/1)
  - 1st quench – 5728 A (11/1)
  - 2nd quench - 6191 A (11/2)
  - 3rd ramping - 6300 A, no quench (11/2)
  - 4th ramping – 6500 A, no quench (11/9)

- 2nd test group (liquid helium ~ 4.7 K),
  - 1st ramping - 6500 A, no quench (11/9)

Quench Current of D3L101 with Warm Bore Tubes Evacuated (1000 A is shut off, 4000 A is strip heater)



No. 1 - shut off, No. 2 - 4000 A,
No. 3, 4 - Natural, No. 5, 7 - no quench
No. 9 - liquid mode, no quench

Operation (10/14 – 28)

- 10/14 –20 Close vacuum enclosure. Pump on insulating vacuum. Weld the feed through connector. Initial pump down, pressure test, electrical connections
- 10/20 - 21 Warm measurement
- 10/22 Pump & purge
- 10/25 – 26 Cooldown I
- 10/27 5 K cooldown using E19 & E20. Due to trip of E19, D3 reaches 12 K and stay at 12 K.
- 10/28 Resume 5 K cooldown with E19 & E20. Reach 8 K at 3 PM. Perform cold check.

Operation (10/29)

- 10/29 Reach test condition for forced flow, 1000A shut off
  Ramp to 4000A – stay for ~ 6 min.
  Cold helium leaked out from the area where 4 current leads located.
  Reduce system pressure and perform leak check
  Found one leak from a swage lock joint
  Warm end of the two plus leads are icy and are well beyond suitable operating condition.
  Not sure if there was any leak through O-ring associated these leads.
  No leak after warm up.
  Resume cryogenic operation

Operation (10/30 – 11/2)

- 10/30 - 31 Keep at test condition through weekend.
- 11/1 Ramp to 4000 A at 10 A/s with 1 minute stay at every thousand ampere. Investigate voltage across four current leads under same lead flow.
  Ramp to 4000A for strip heater quench.
  1st quench - 5728 A
- 11/2 2nd quench – 6191 A
  3rd ramping – 6300 A no quench,
  stay at 6300 A for ~ 20 min.
  Switch to liquid cool mode unsuccessfully, due to valve actuator and I/P on JT valves.
  Back to forced flow cooling

Operation (11/3 – 7)

- 11/3 Perform field measurement – 1 AC cycle and 5 DC loops.
- 11/4 Perform field measurement – 2 AC cycle and 5 DC loops.
  Unexpected lead quench occurred due to incorrect control on lead flow.
  Resume test after temperature recovers.
  Complete field measurement for left bore as schedule.
- 11/5 Perform field measurement – 1 AC cycle and 4 DC loops.
- 11/6 – 7 Keep D3 at test condition through weekend

Operation (11/8 – 12)

- 11/8 Perform field measurement – 1 AC cycle and 6 DC loops. Complete field measurement.
- 11/9 Ramp D3 to 6500 A and stay 15 min. in forced flow cooling.
  Switch to liquid cool.
  Verify D3 at 6500 A under liquid cool condition.
- 11/10, 12 D3 in Drifting.
  Troubleshoot Warmup compressor CS6

Operation (11/15 – 17)

- 11/15 Temperature in D3 reaches ~ 120 K after drifting for 5 days.
  Start Warmup for ~ 1/2 hour. Found 300 K helium was introduced due to opening of valve 42 caused by its I/P failure. Change I/P. Shutdown Warmup for the night.
- 11/16 Proceed warmup after some difficulties with CS6.
- 11/17 Warmup complete

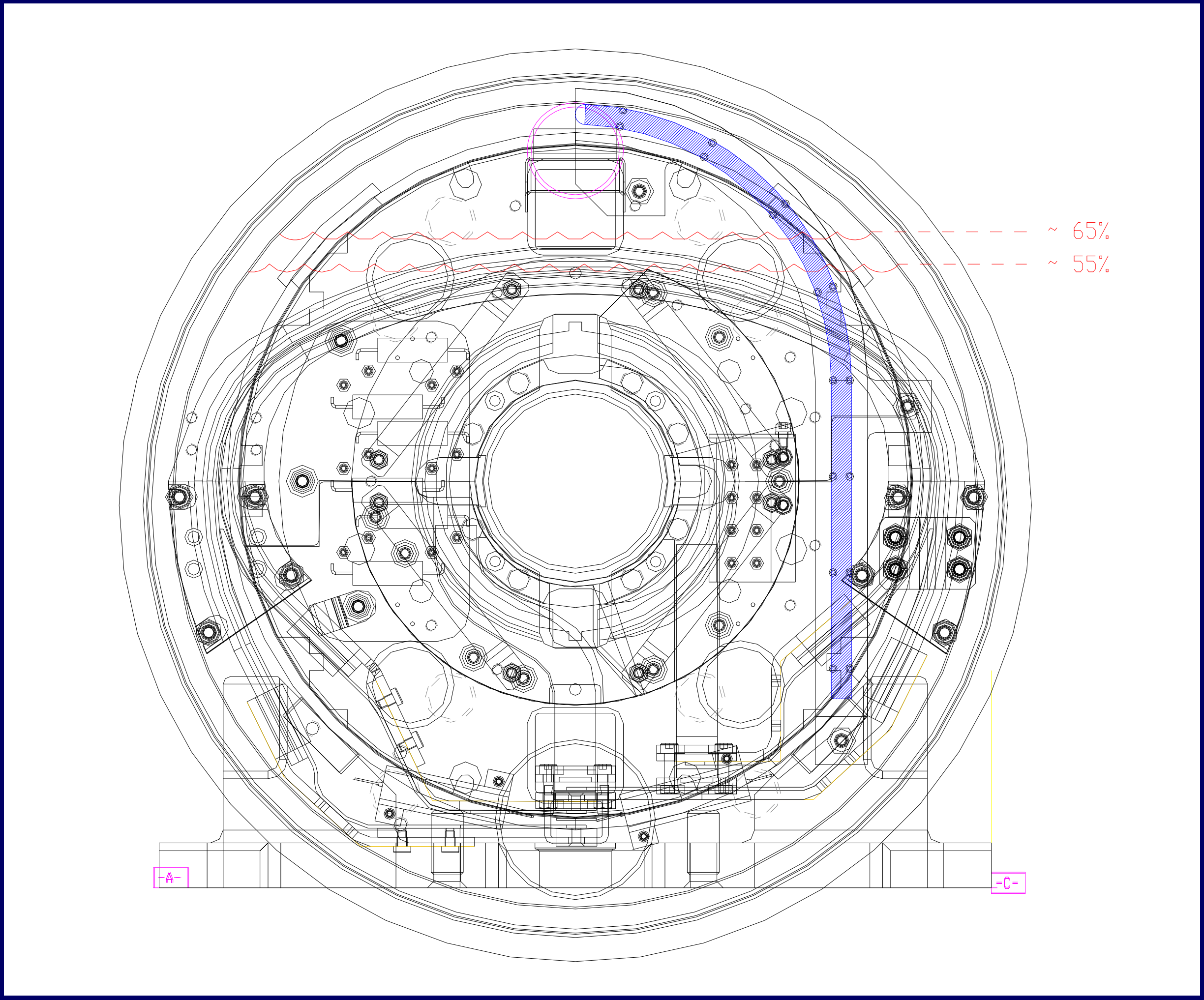
Test Conditions

- Forced flow cooling - 12 atm, 4.6 K & 55 - 60 g/s total flow for the two cold masses
- Liquid helium cooling – 1.45 atm, ~ 4.7 K

  Liquid level ~ 55% (~ 3 cm above coil,
  ~ 4 cm below vent,
  ~ the height of the superconducting flex joint)

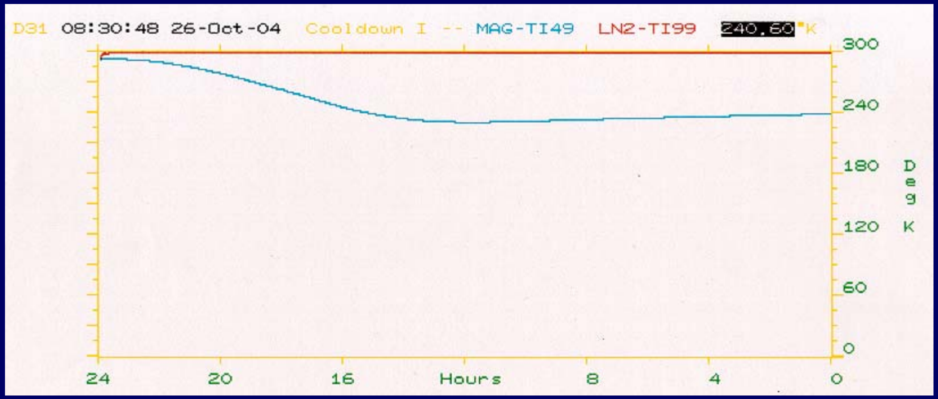
  Desired liquid level for operation should be 60 – 70%

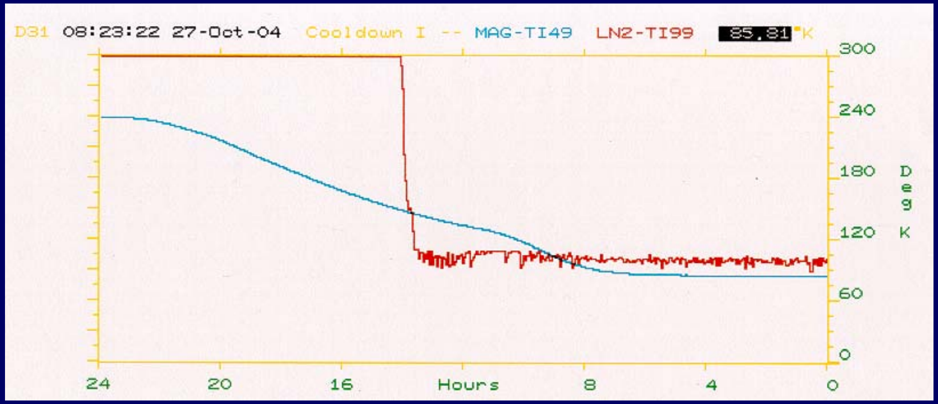
End View of D3 With Curved Level Probe (Blue), Vent Hole (Magenta), 55% and 65% Liquid Levels (Red) and Superconducting Flex Joint at ~ 55%



Cooldown from 300 – 100 K for D3L101

(10/25 – 10/26/04)

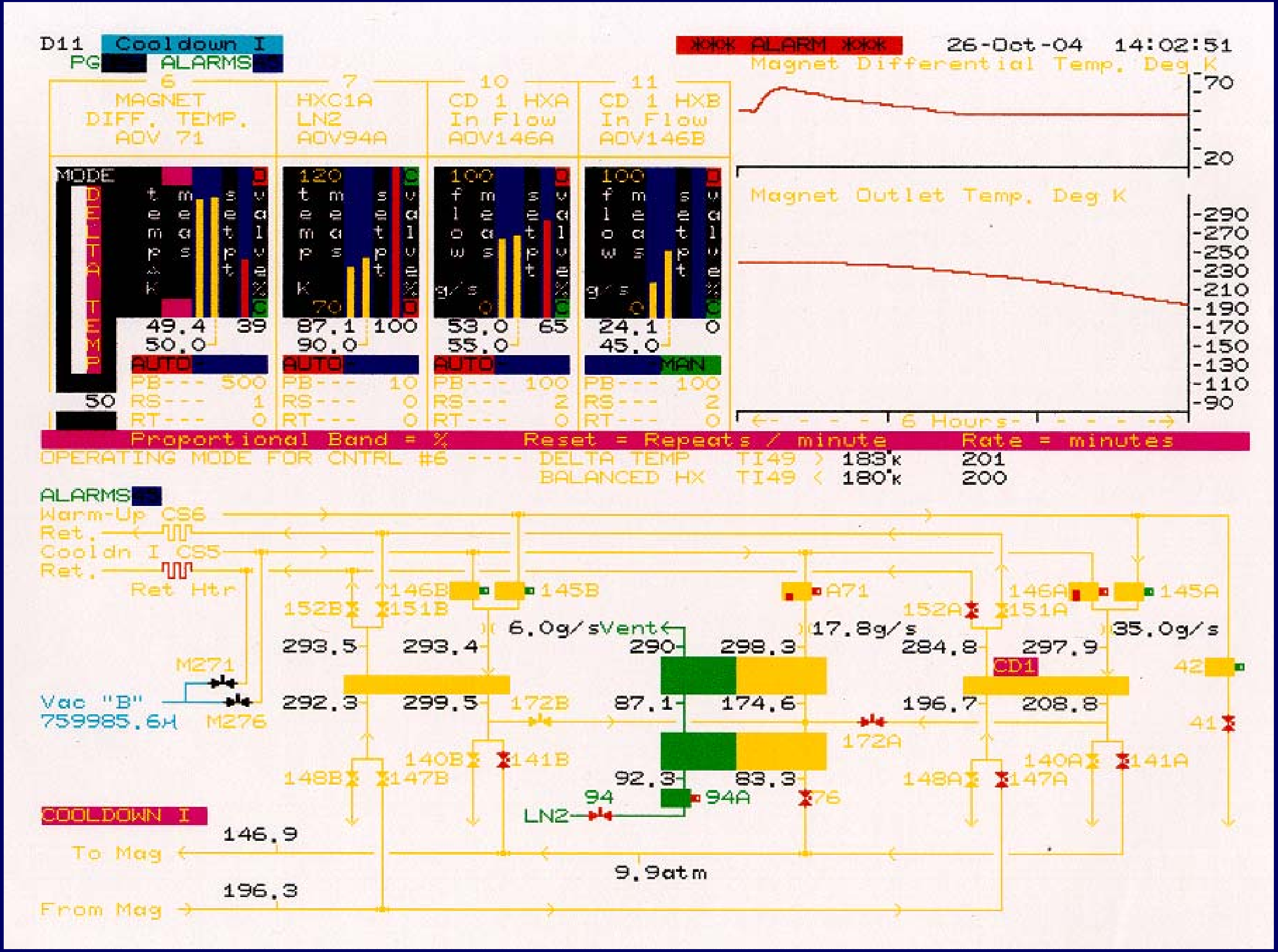




- Weight of D3 cold mass is twice that of RHIC dipole magnet. In principle, 100 K cooldown can be achieved in ~ 32 hours.
- 100 K Cooldown time ~ 48 hours due to malfunction of controller in MAGCOOL
- Use 45 and 55 g/s of helium flow.
- Cooldown rate:

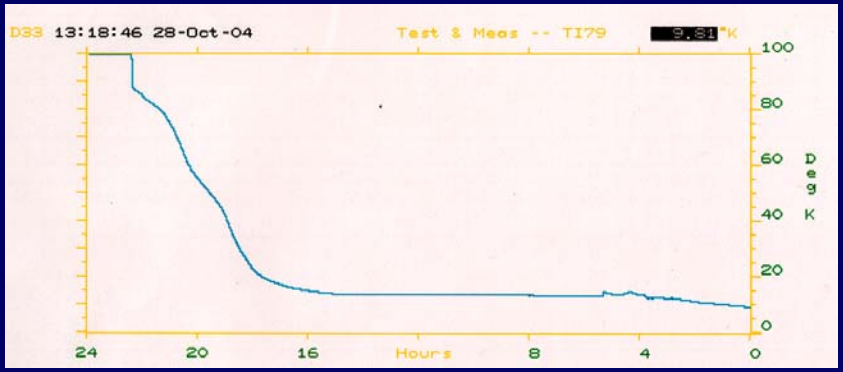
~ 7 K/hour 300 – 240 K
~ 13 K/hour 240 – 80 K

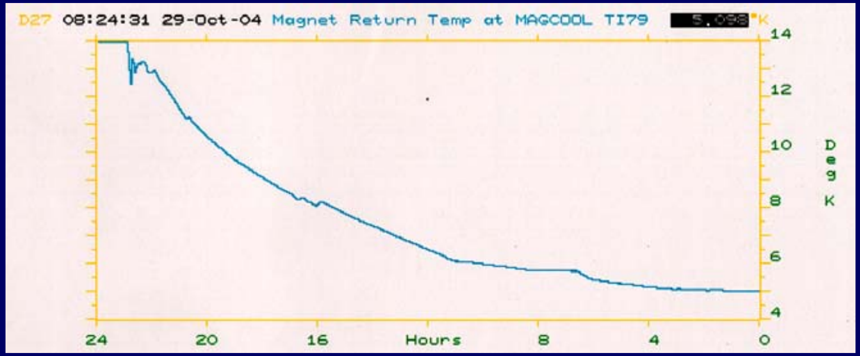
Operating Condition for 100 K Cooldown of D3L101



Cooldown from 100 – 5 K for D3L101

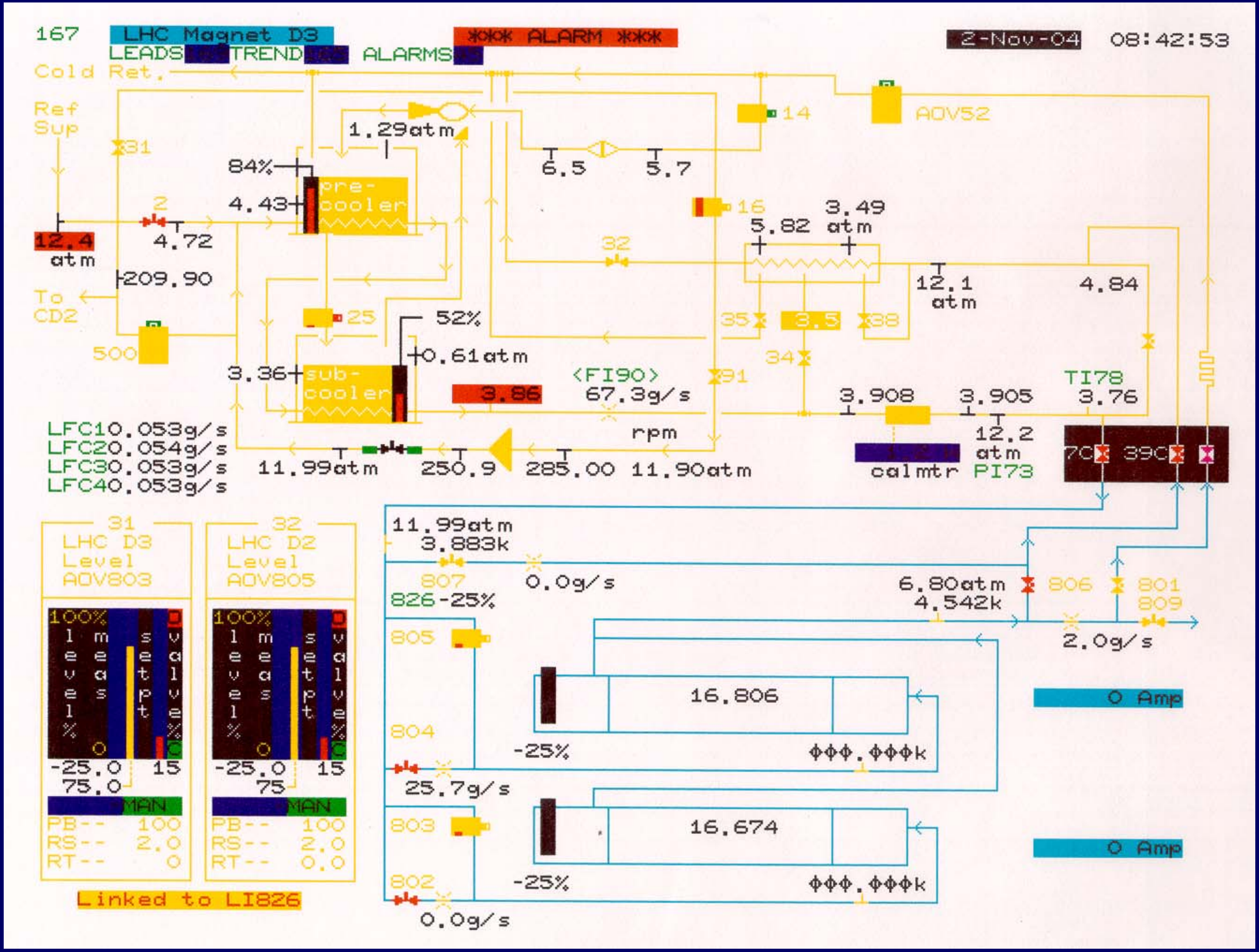
(10/27 – 10/28/04)





- Cooldown time (80 to 20 K) is 5 hours, ~ 12 K/hr using E19 & E20.
- Due to E19 trip, D3 stays at ~ 12 K overnight.
- Cooldown time (12 to 5 K) is ~ 24 hours, using E19 & E20 (at ~ 150 rpm).
- Total cooldown time from 80 K to test condition could be ~ 30 Hours if E19 did not trip.

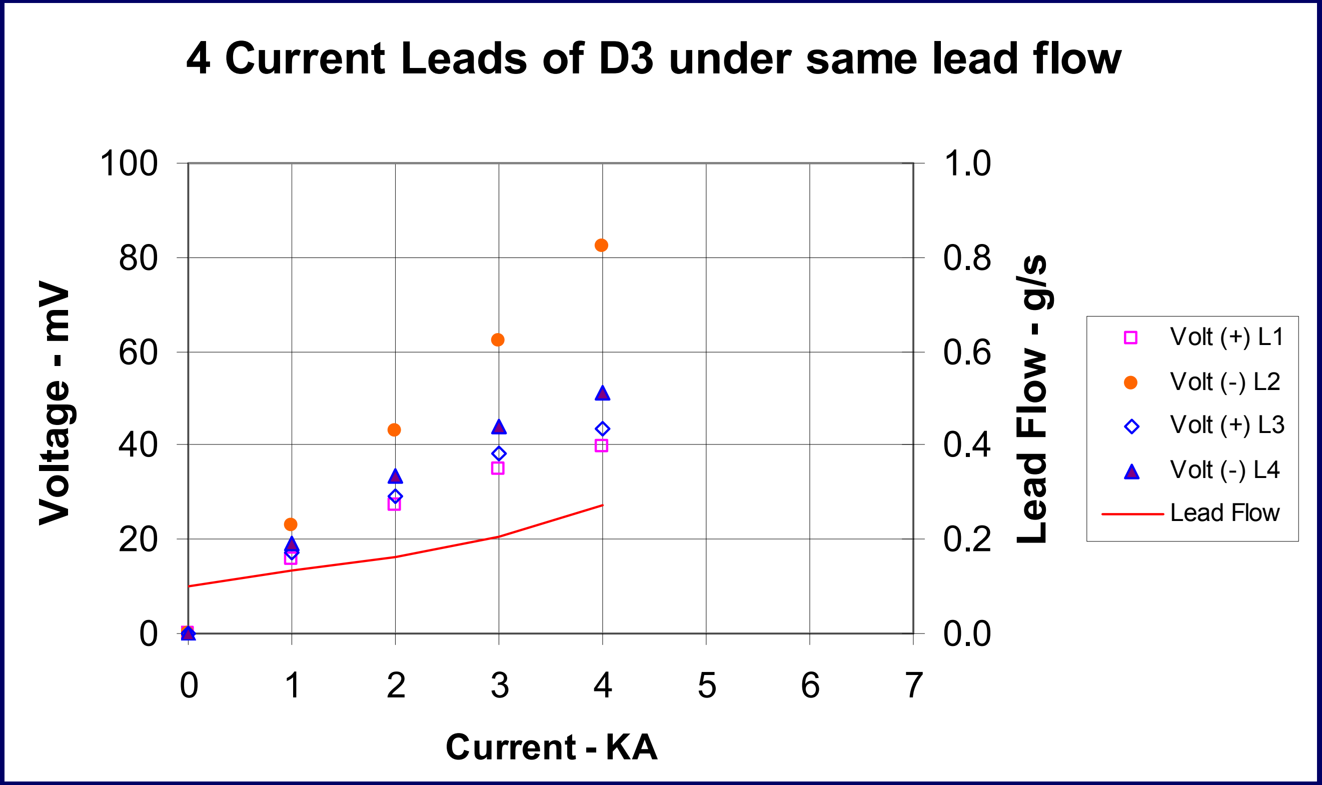
Forced Flow Cooling of D3L101 Prior to 6191 A Ramping



Lead Flow and Voltage Across the 4 x 7500 A Leads for D3L101 Under Same Lead Flows

Ramp rate is 10 A/s. Stay ~ 1 min. at 1000, 2000, 3000 and 4000 A
Tare flow is 0.049 g/s below 10 A, and equals 0.10 g/s above 10 A

As shown, lead 1, 3 and 4 develop similar voltage. These 3 leads are considered normal and use almost same amount of cooling flow. The voltage drop of Lead 2 (the old – lead) is about two times larger probably caused by a bad joint. Lead 2 requires more cooling flow.

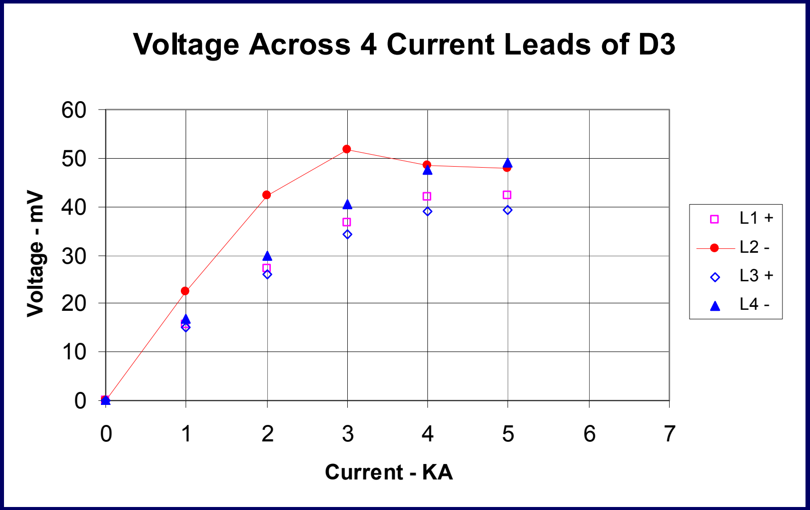


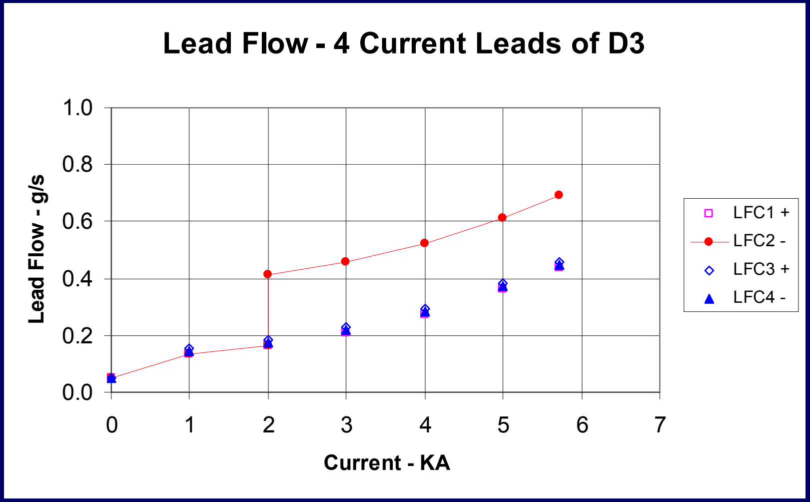
Voltage Across the 4 x 7500 A Leads for D3L101 With Adjusted Lead Flow as a function of Current

Ramp rate is 10 A/s. Stop for ~ 1 min. at 1000, 2000, 3000, 4000 and 5000 A, D3 quenched at 5728 A.

Upper figure: Voltage drop as a function of current.

Lower figure: Lead flow as a function of current.
Below 10 A, tare flow is 0.049 g/s for all 4 leads. Above 10 A, tare flow is 0.010 g/s for lead 1, 0.012 g/s for lead 3 and 0.011 g/s for lead 4.
For lead 2, tare flow was increased to 0.35 g/s at 2000 A to prevent excessive voltage drop.

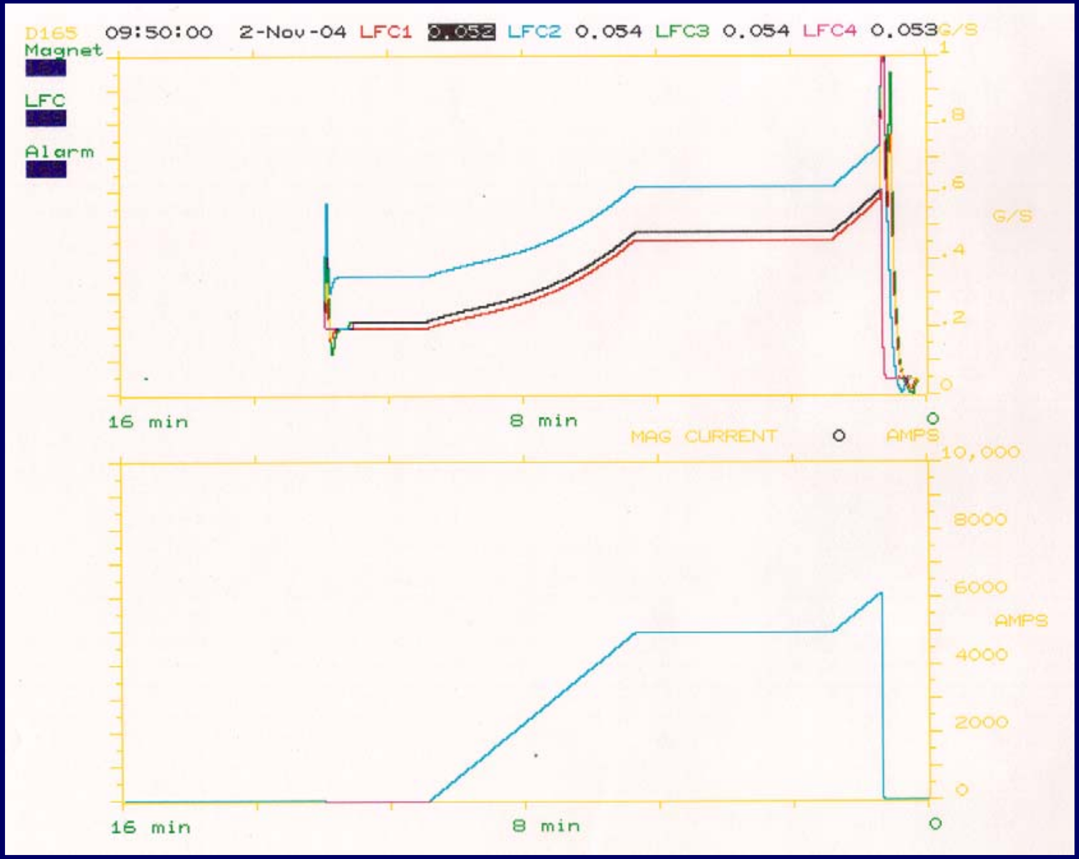




Lead Flow and Current During Ramping of D3L101

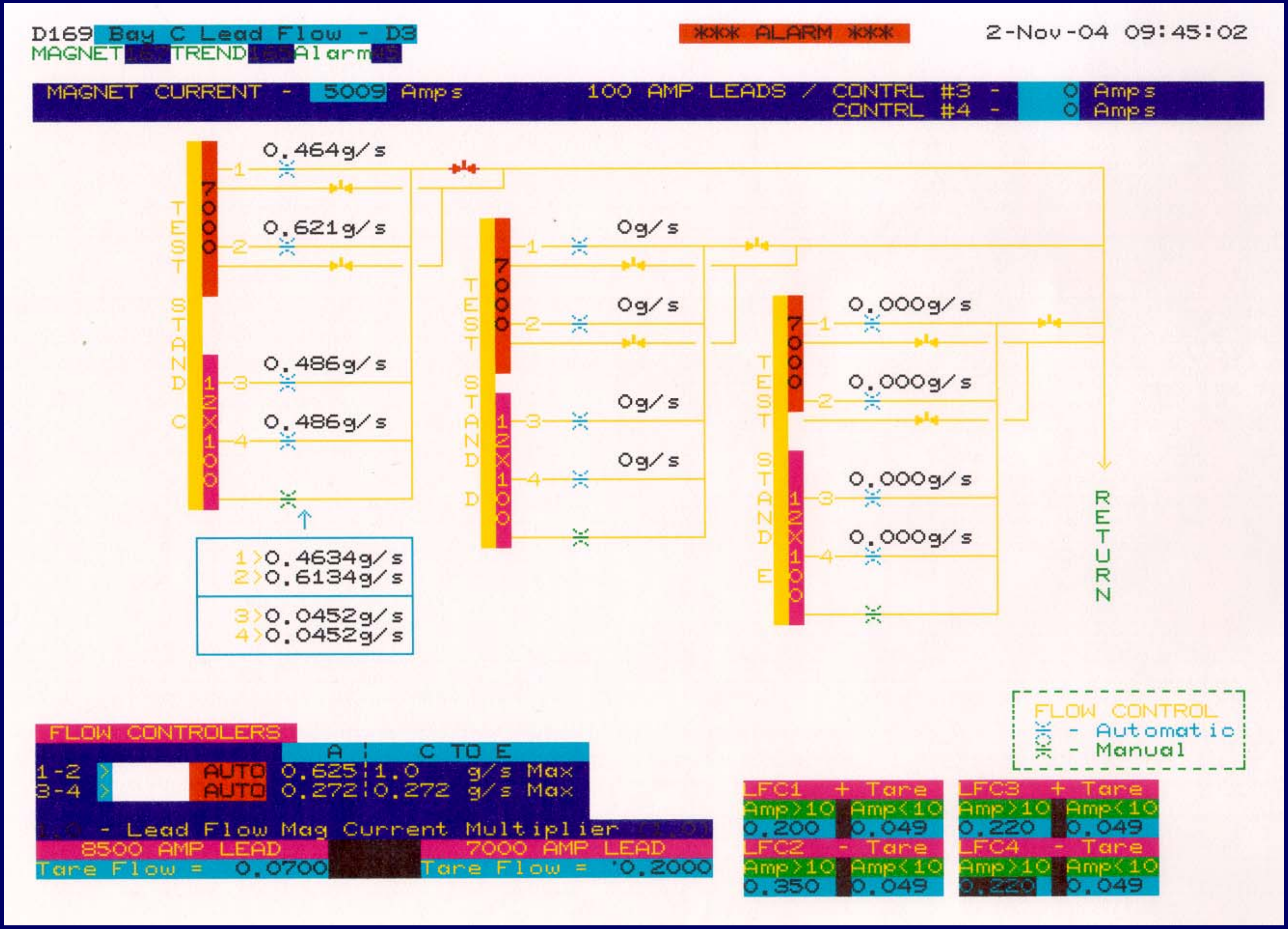
Ramp rate is 20 A/s. Below 10 A, Tare flow is 0.049 g/s. Above 10 A, Tare flow is 0.20 g/s for (+) lead 1, 0.35 g/s for (-) lead 2, 0.22 g/s for (+) lead 3 & 0.22 g/s for (-) lead 4. Need to wait for voltage recovery of the (-) lead at 5000 A for about 3 min.

Upper Figure: Lead Flow – Blue for (-) Lead 2 and Red (+), Yellow (-) & Green (+) for Lead 1, 3 & 4. Lower Figure: Current as a Function of Time



Lead Flow Control During Ramping of D3L101

Ramp rate is 20 A/s. Below 10 A, Tare flow is 0.049 g/s. Above 10 A, Tare flow is 0.20 g/s for (+) lead 1, 0.35 g/s for (-) lead 2, 0.22 g/s for (+) lead 3 & 0.22 g/s for (-) lead 4. Need to wait for voltage recovery of the (-) lead at 5000 A for about 3 min.



Current Leads

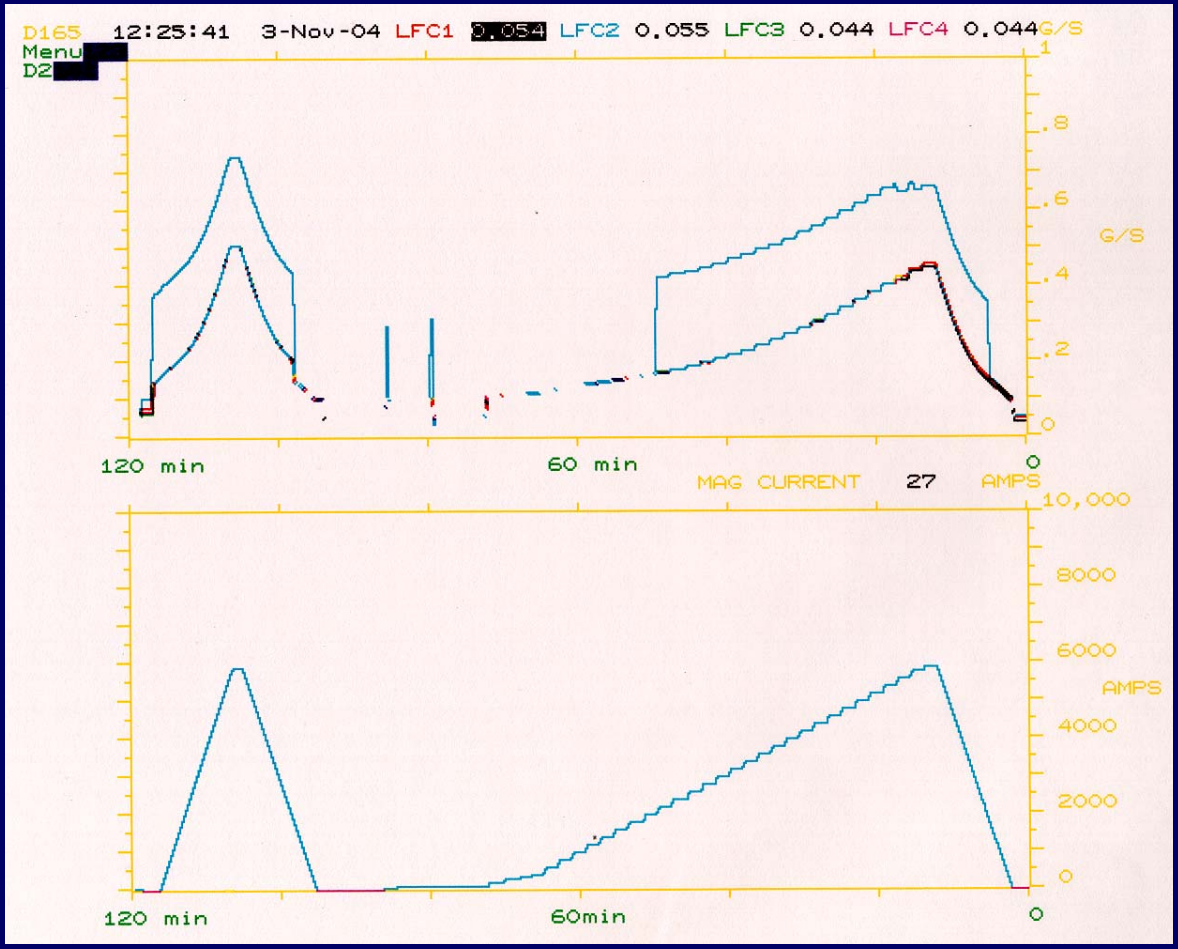
- Separate flow controllers for the four 7500 A leads
- Voltage drop as a function of current was measured with same lead flow to 4000 A
- The old (-) lead #2 has the highest voltage drop as previously experienced
- Voltage drop for the new (-) lead #3 and new (+) lead #4 are slightly higher than the old (+) lead #1
- Flow control for the old (+) and (-) leads are similar to previous D2 & D4.
- The two new leads use approximately the same cooling flow as the old (+) lead

Lead Flow and Current During AC Cycle (left figure).

Upper Figure: Lead Flow – Blue for (-) Lead #2 has the highest flow, the other 3 leads basically have same flow.

Lower Figure: Current as a Function of Time

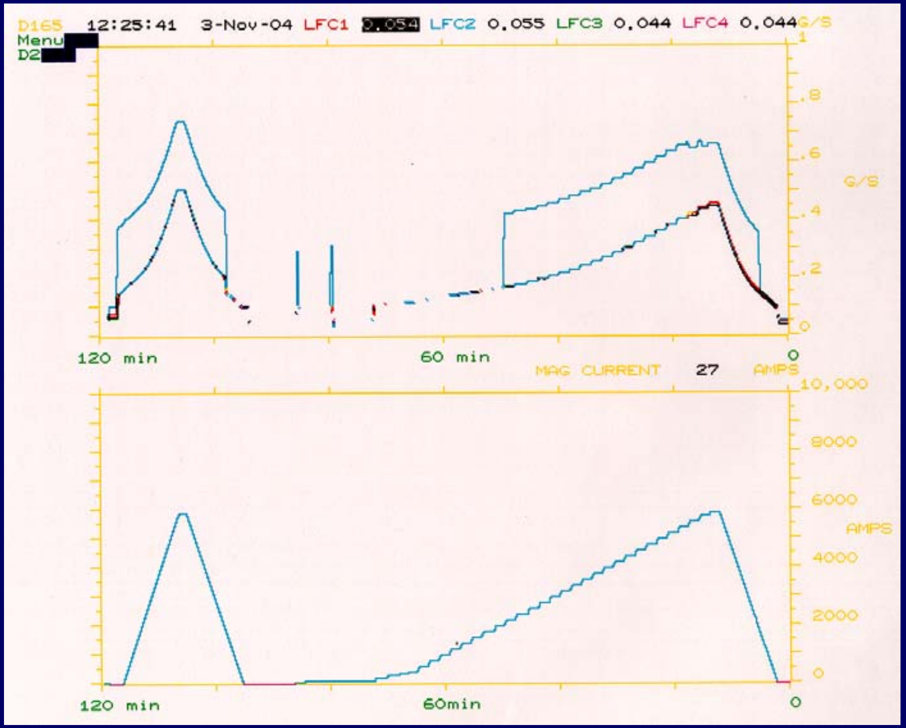
Ramp rate is 10 A/s to 5900 A.



Lead Flow and Current During DC Loop of D3L101

Upper Figure: Lead Flow – Blue for (-) Lead #2, other 3 leads have essentially same flow. Lower Figure: Current as a Function of Time. Note: DC loop is the set of curves in the right side. Curves in the left side are for AC cycle.

Ramp rate is 10 A/s with ~ 60 seconds stop at various currents during ramp up. Ramp down at 10 A/s without stop. It takes about 1 hour to reach 5900 A. There are time for the leads to be cooled. The lead flow should approach design value as shown in the (+) lead. As we know, there is a defect in the (-) lead # 2 which requires more lead flow. Tare flow is set at ~ 0.10 g/s for the 3 good leads for currents to 5900 A. Tare flow for the (-) lead #2 is set at 0.10 g/s below 2000 A and 0.35 g/s afterwards. Flows need to be slightly reduced during ramp down.



Lead Flow and Current During DC Loop of D3L101

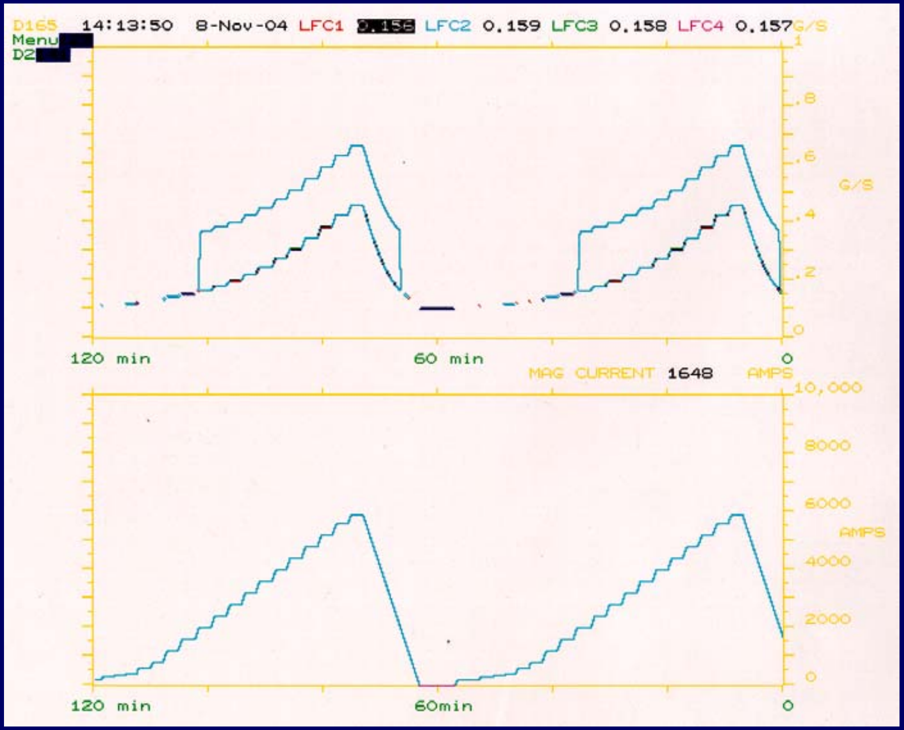
Upper Figure: Lead Flow – Blue for (-) Lead #2, other 3 leads have essentially same flow. Lower Figure: Current as a Function of Time. As shown, no. of steps were reduced compared to the 1st DC loop.

Ramp rate is 10 A/s with ~ 60 seconds stop at various currents during ramp up. Ramp down at 10 A/s without stop.

It takes about 40 min. to reach 5900 A and 10 min. down.

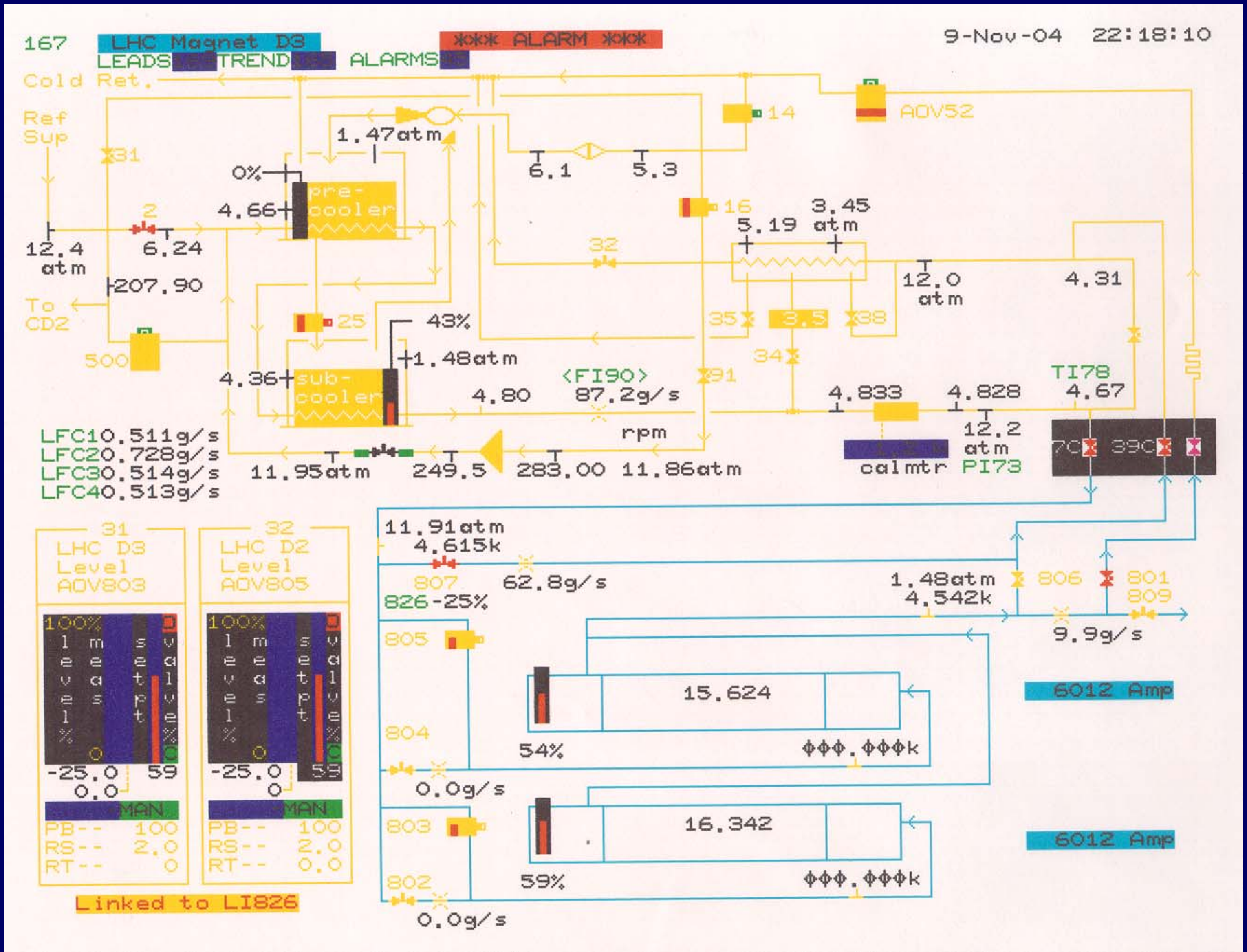
Tare flow is set at ~ 0.10 g/s for leads #1, #3 & #4 for currents to 5900 A.

Tare flow for the (-) lead # 2 is set at 0.10 g/s below 2000 A and 0.3 g/s above.

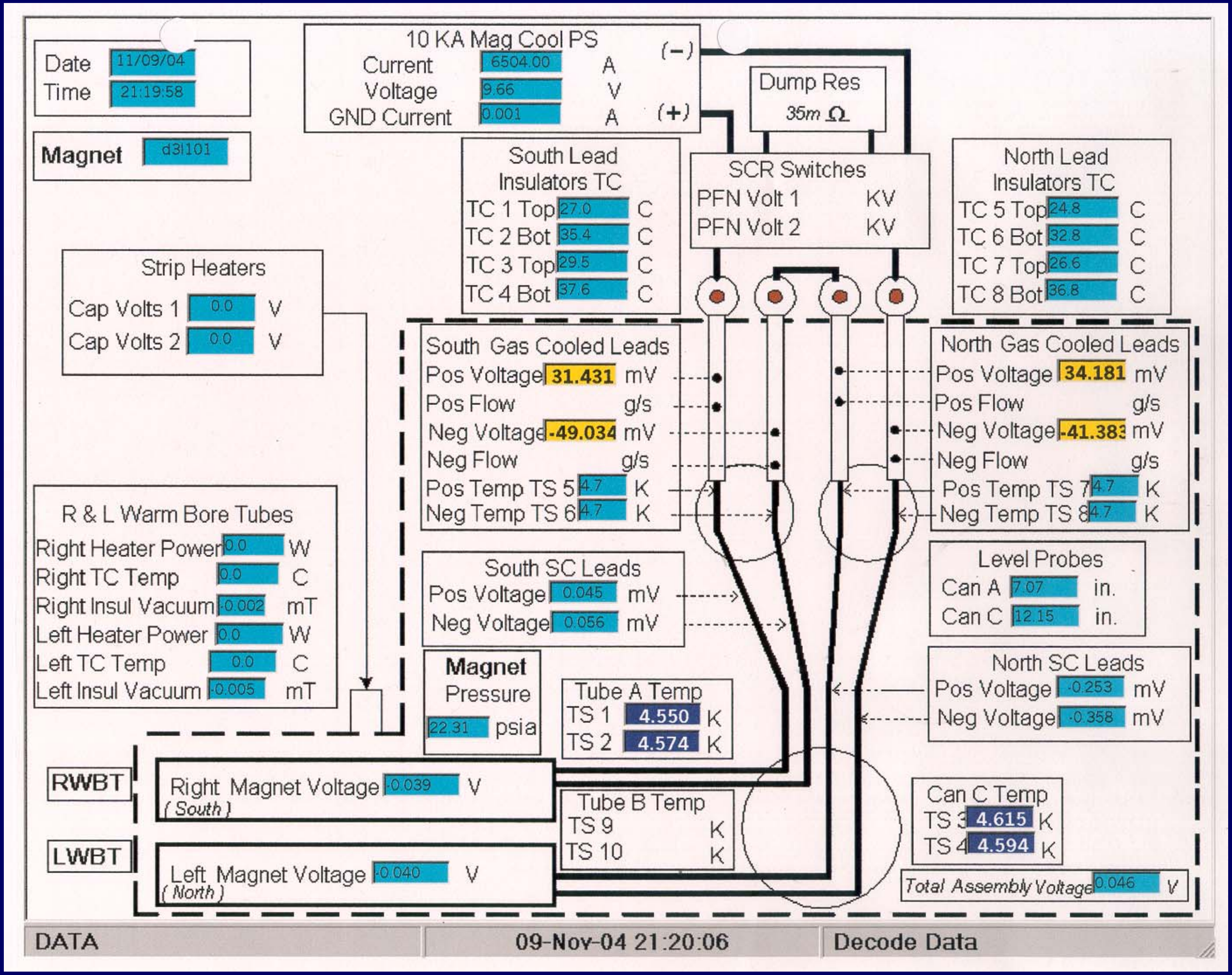


D3L101 at 6500 A in Liquid Cool Mode

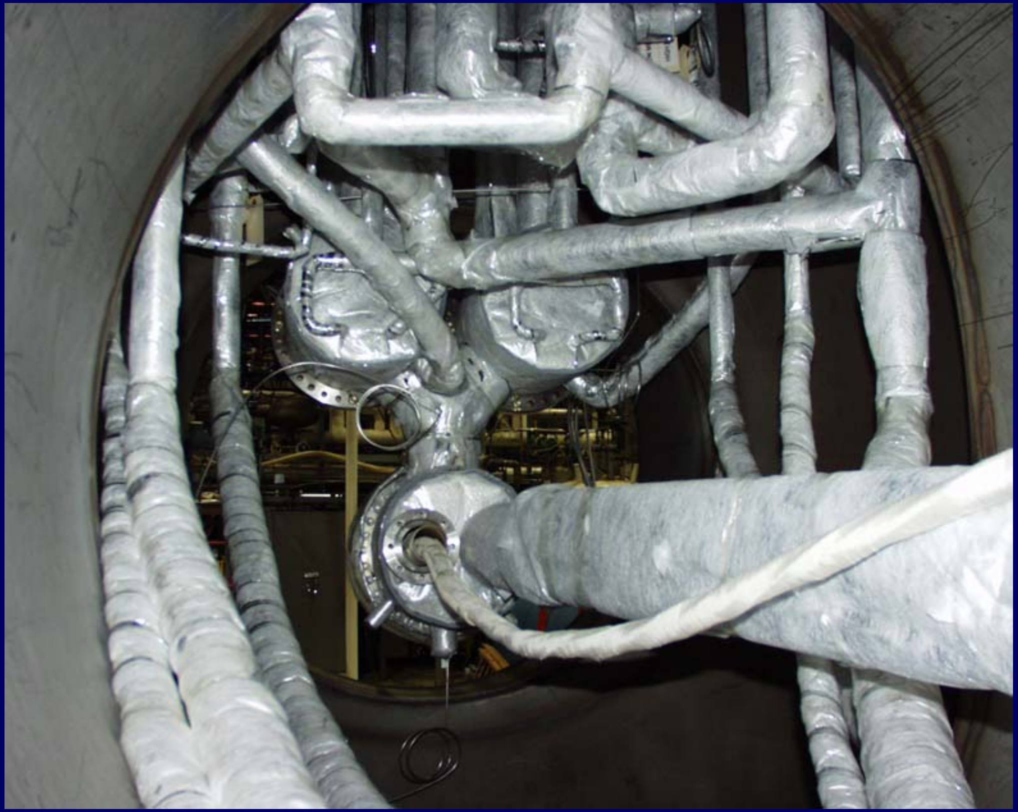
Warm Bore Tube Evacuated, JT valve ~ 59% open and liquid levels 54% and 59% – 11/9/04

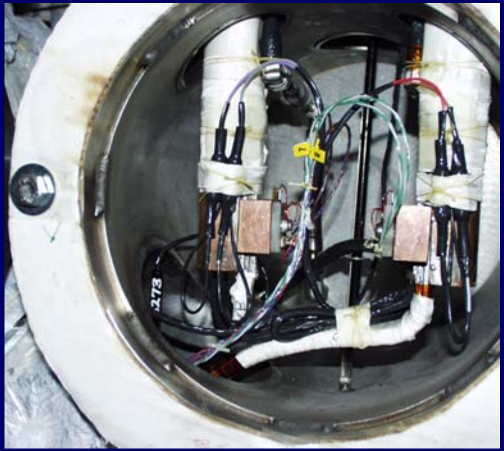


Parameters of Lead Pot for D3L101 at 6500 A in Liquid Cool Mode - 7” liquid in Can A and 12” in Can C

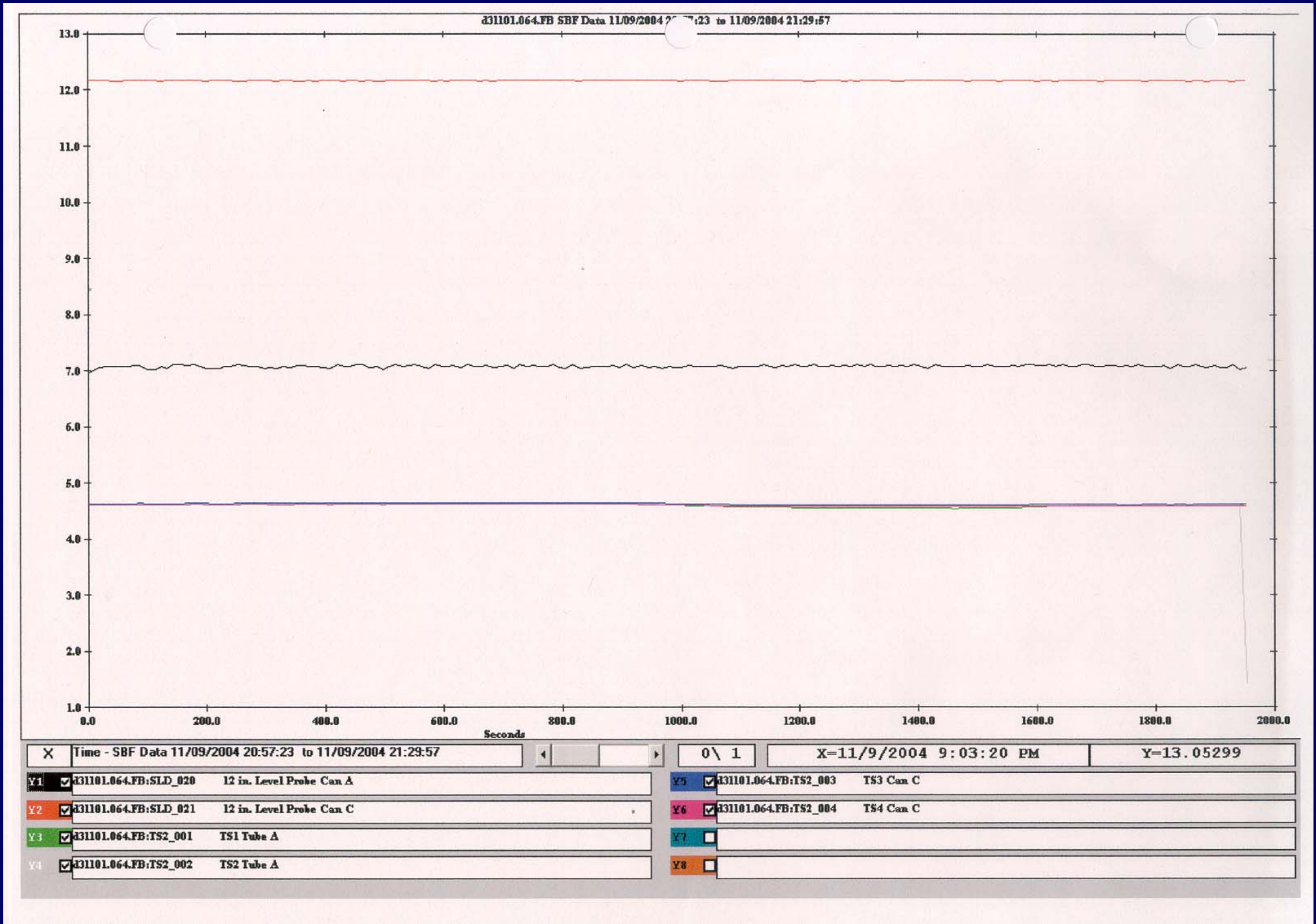


Picture of Can A, B (Upper) & C (Lower) in Feed Can Buses From D3 are connected to Can C (left). Beam Tubes are Located between Upper and Lower Cans



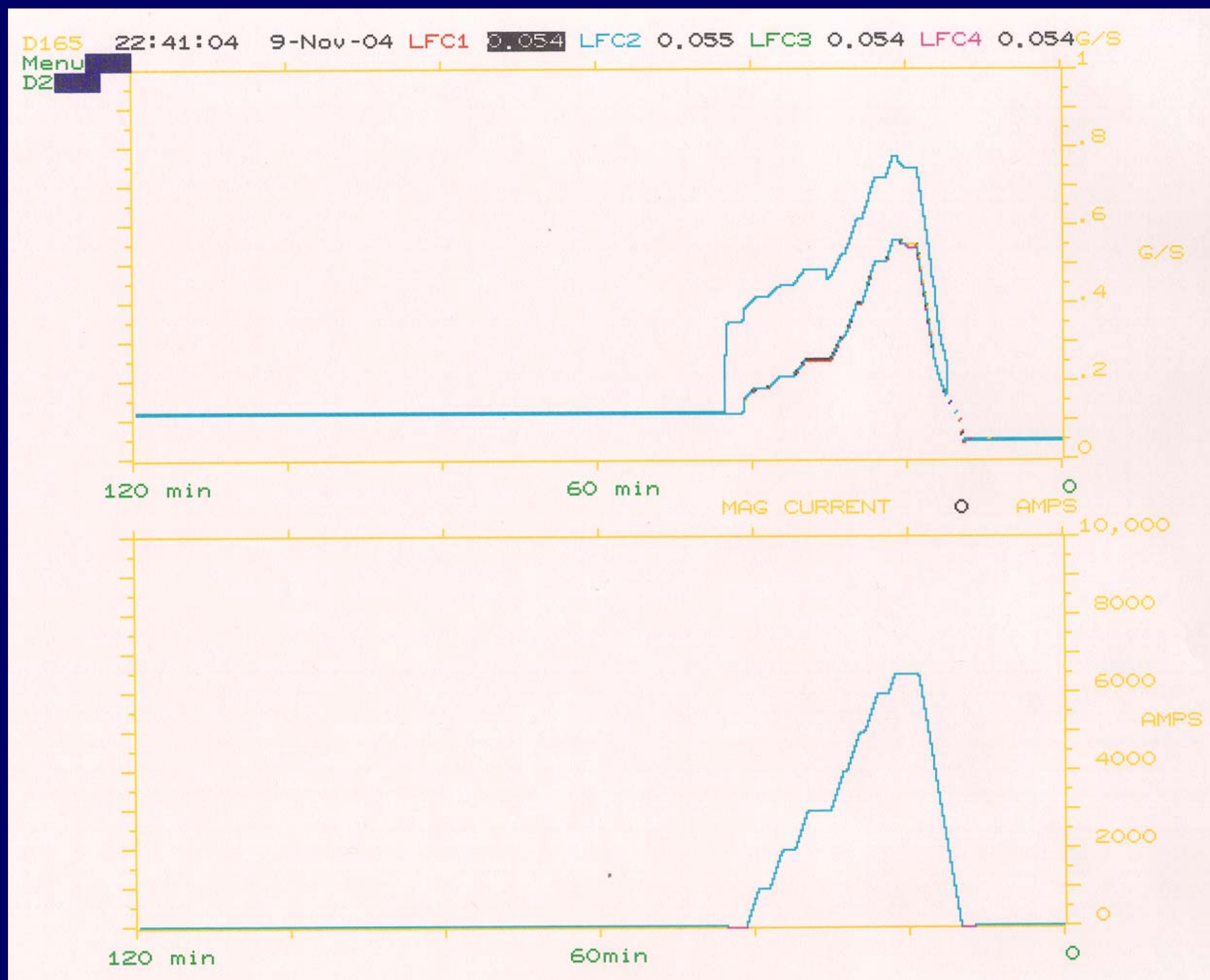


Liquid Level in Can A and Can C During Ramping of D3L101 to 6500 A in Liquid Cool, 7” in A and 12” in C



Lead Flow and Current During 6500 A in Liquid Mode.

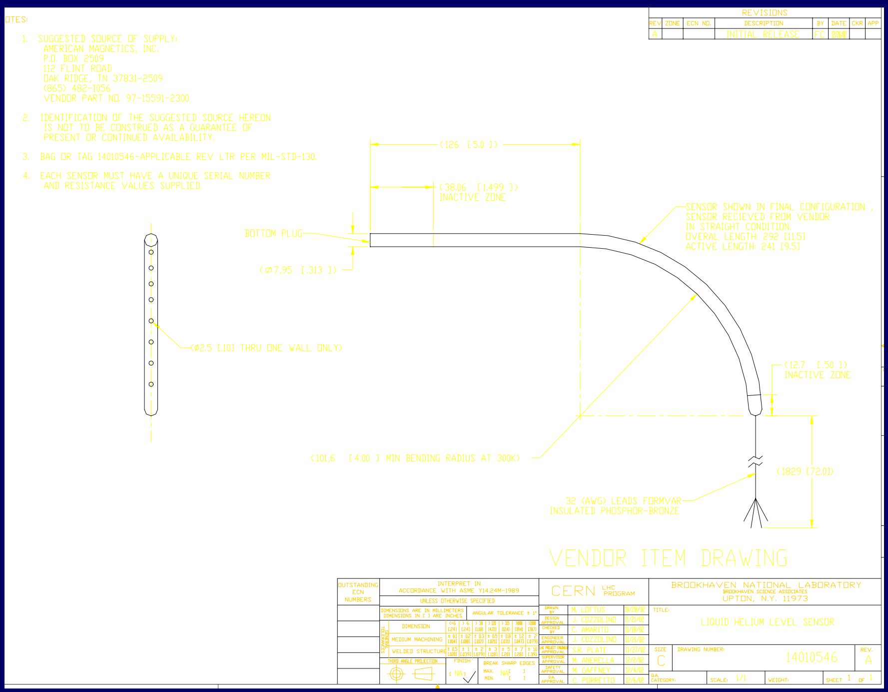
Upper Figure: Lead Flow – Lead #2 has the highest flow, the other 3 leads basically have same flow. Lower Figure: Current as a Function of Time (showing Ramp Rate and Current Stops).

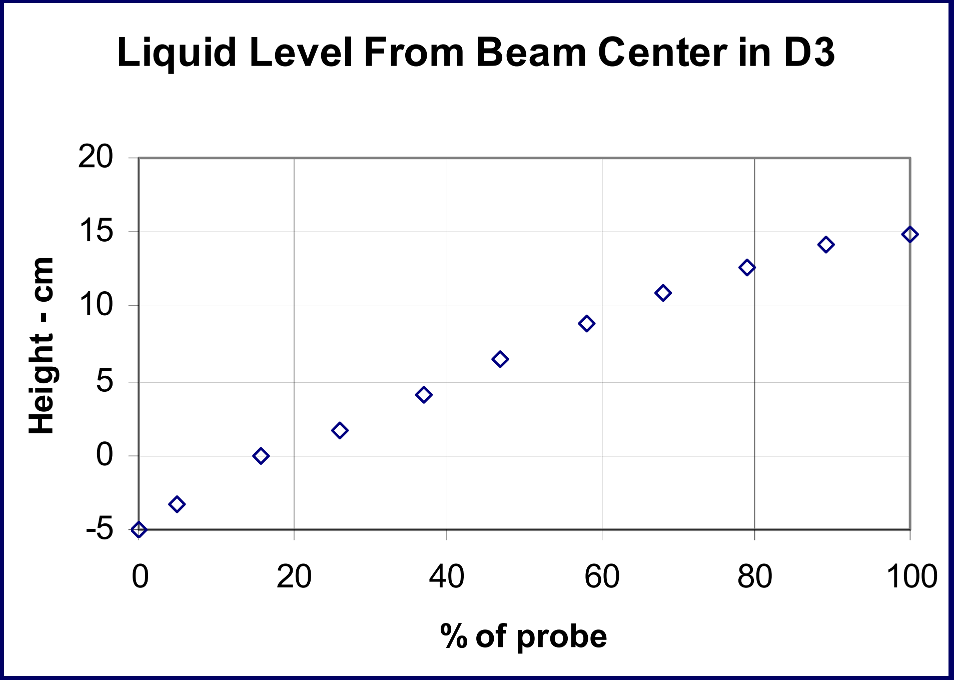


Liquid Level in D3L101

Level gauge is curved as shown in the left.

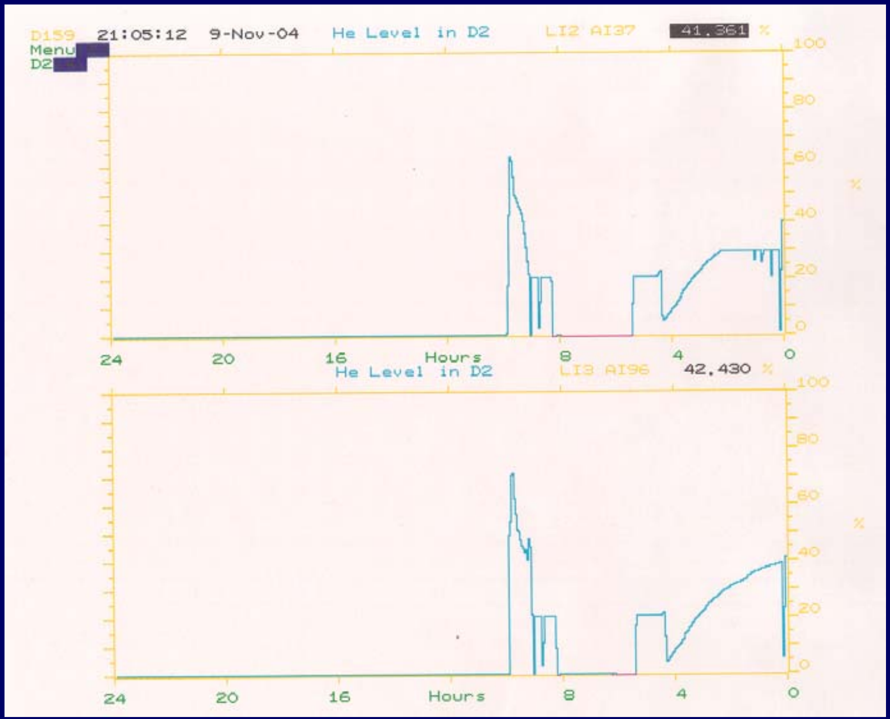
Height from beam center as a function of % level probe

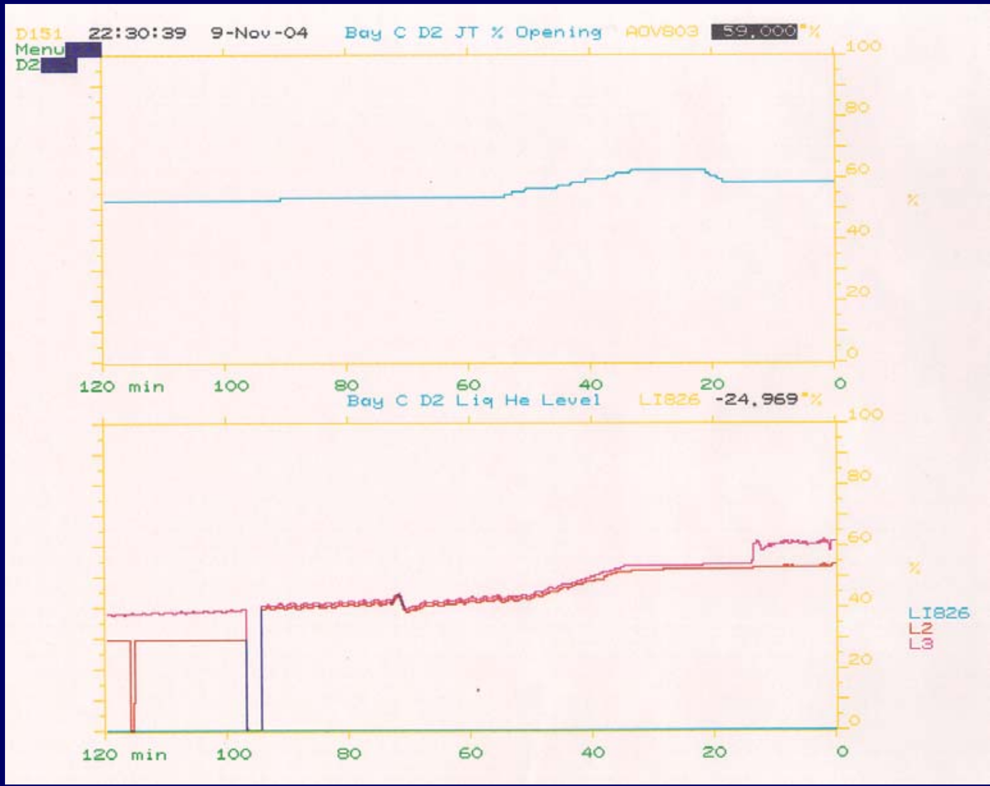




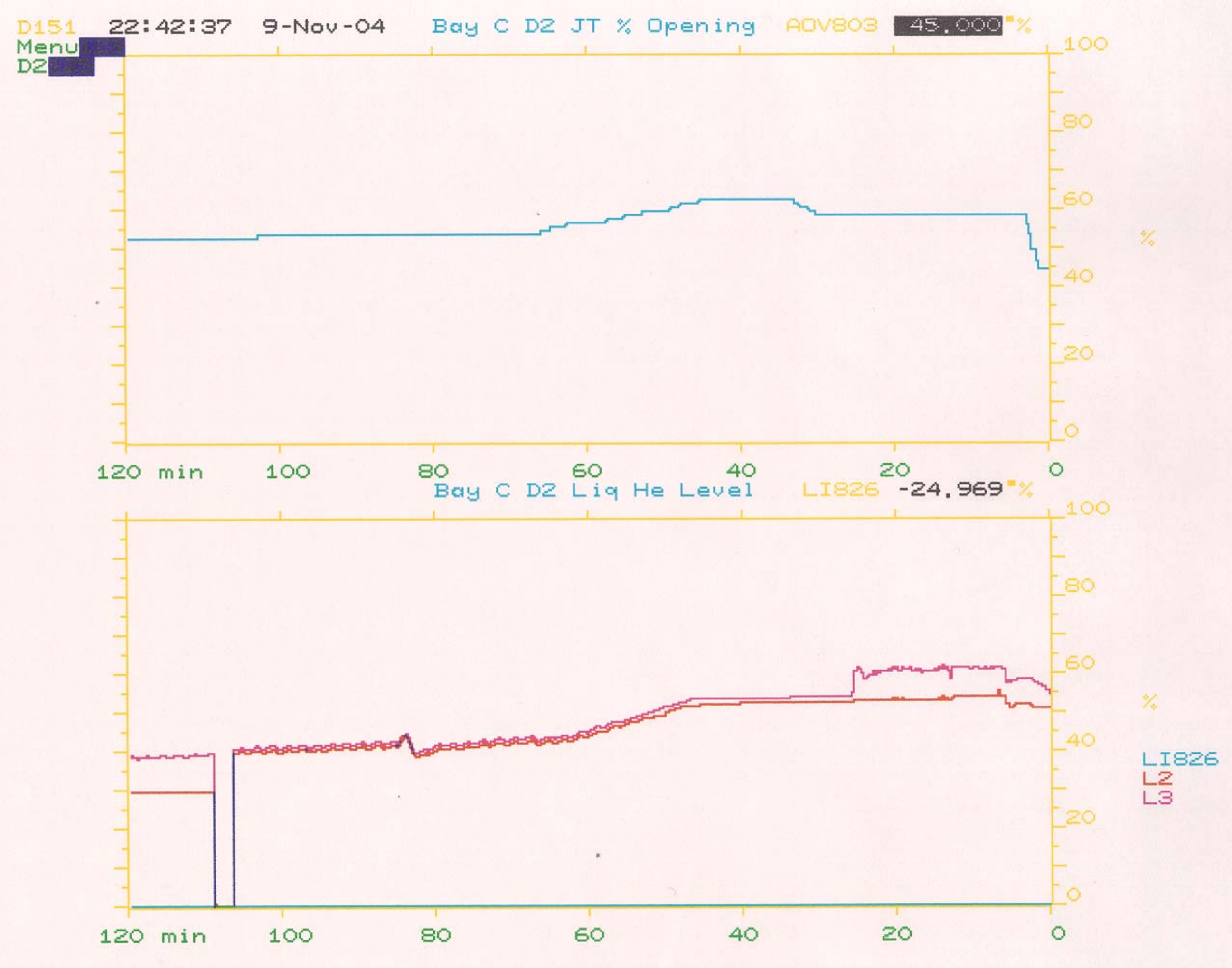
Liquid Level in D3L101 as a Function of Time

As shown in left figure, two level gauges gave consistent readings until LI822 (DML301) hangs up at 30%. The redundant gauges were switched in through connector change. As shown in the right figure, the redundant gauges give consistent level readings.

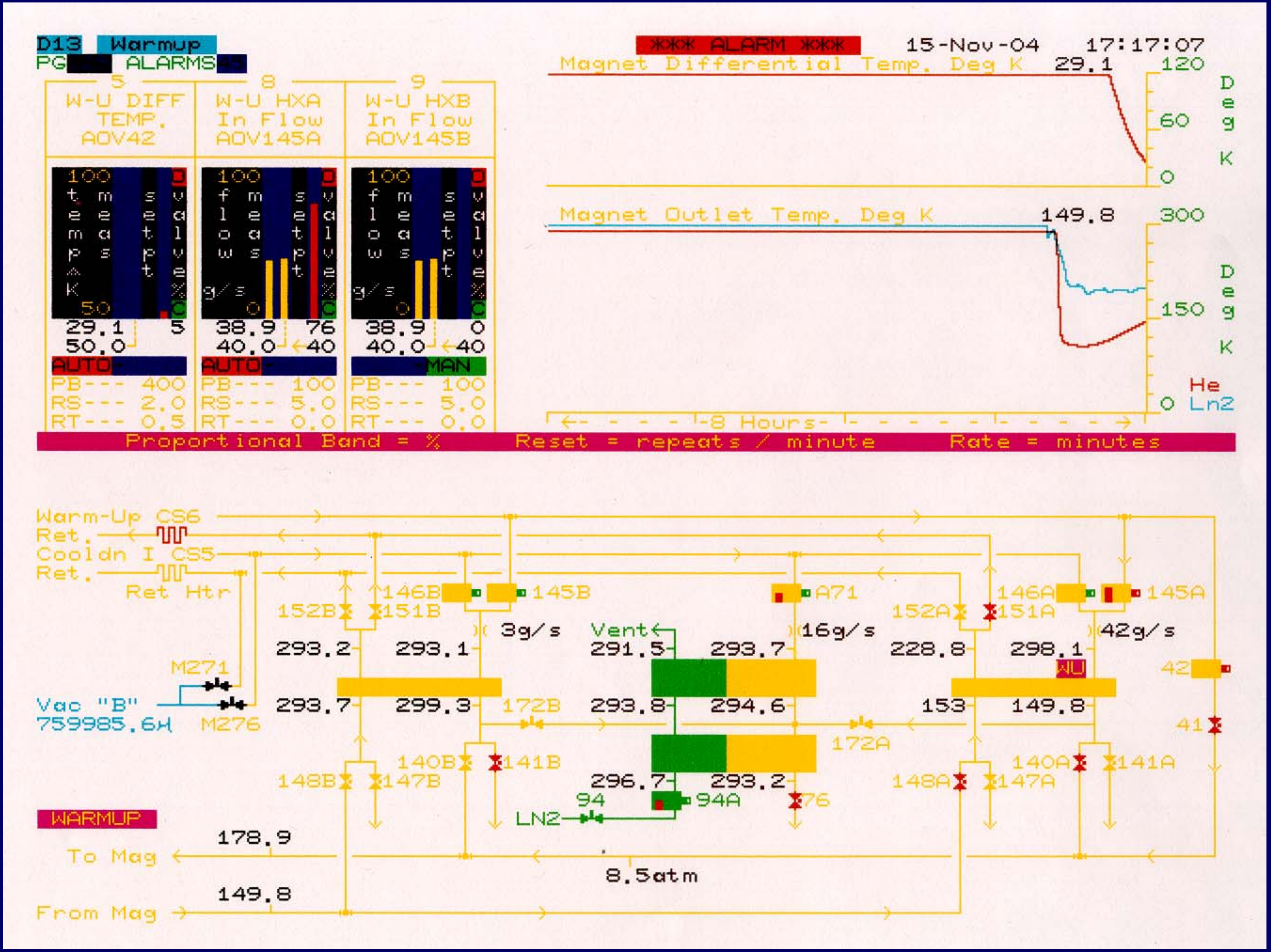




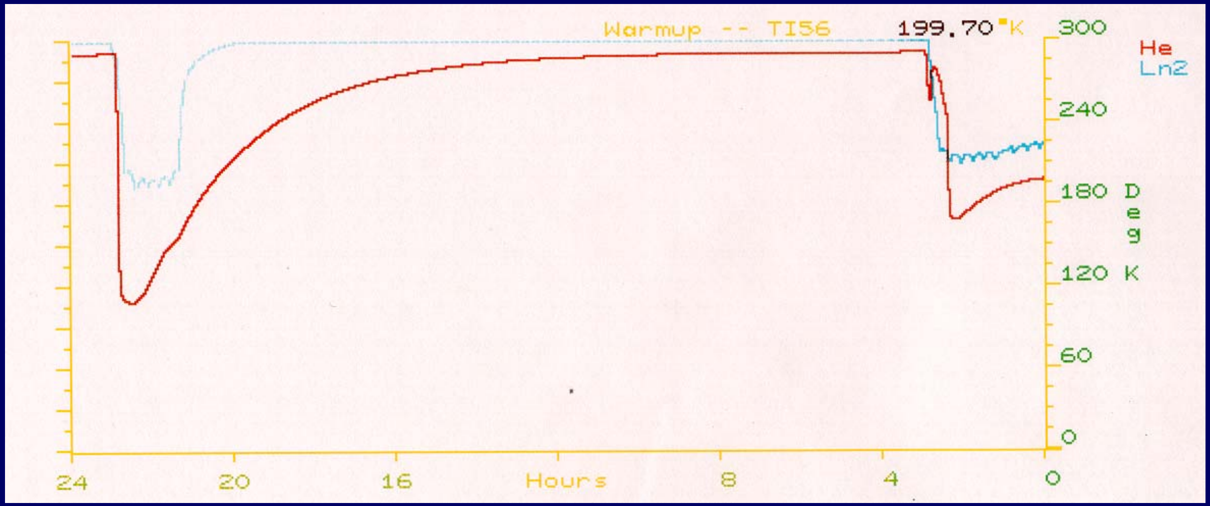
Opening of one JT Valve and Liquid Level in D3L101 as a Function of Time, 6500 A Ramp Started when Levels are 54% and 55% in the two cold masses



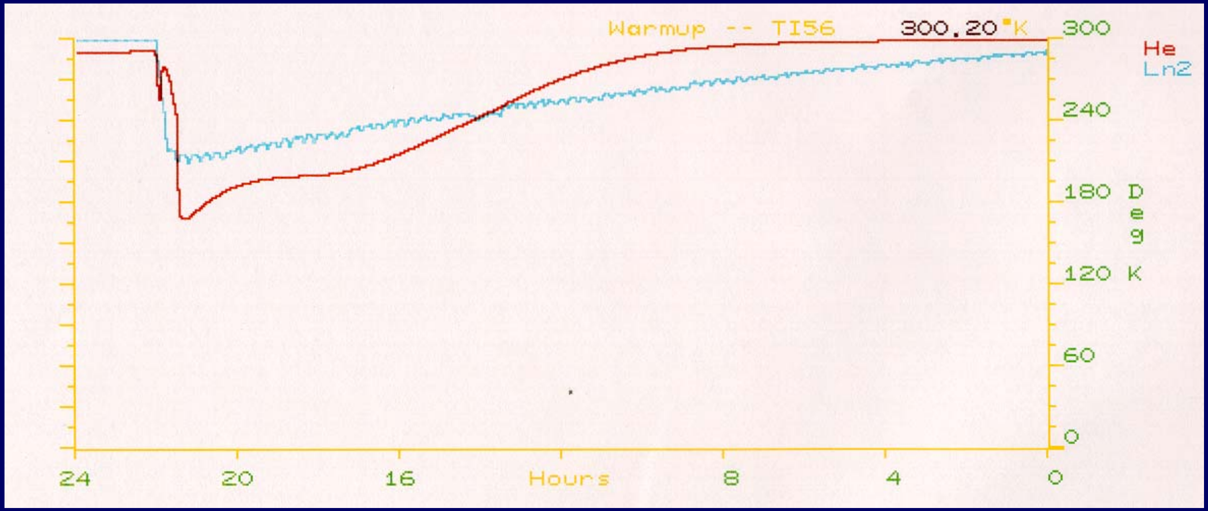
Process Control for Warmup D3L101 – 11/16/04



Warmup of D3L101 after drifting for ~ 6 days



Warmup began when D3 ~ 120 K



180 – ~300 K in 16 hours

Problems

- During switching over to liquid cool on 11/2, DOV802 leaks and prevents the cold mass from entering liquid condition.
- Apply air to the top of the actuators. DOV802 becomes tight.
- Both I/P for the JT controllers failed. One I/P was replaced and the JT valve worked. Unable to repair the other I/P.

- During the liquid cool switching process on 11/9, leakage of valves similar to 11/2 were encountered. After tightening the valve seats as practical as one can, it remains very difficult to cooldown D3. We suspected slow cooldown is related improper cooling in the lead pot. Cooldown rate appears to improve after tare flow increased to 0.12 g/s, from 0.05 g/s, for all 4 leads. It took more than 6 hours to reach 50% level and cold end of the low temperature cold box in MAGCOOL is not fully cold.

Summary

- Complete field measurement for D3L101 with two warm bore tubes. Warm bore tubes are evacuated for quench tests. In field measurement, warm bore tubes are open with 75 F nitrogen flow.
- Demonstrate cooling of D3L101 in liquid mode.
- Verify D3L101 at 6500 A in both forced flow cooling and liquid cool.