The Operation Manual of

Pagani & Lamborghini

Version 0.4.5; last changed: 2019-08-26

1 Important

Authorized operating personal only.
If at any point you are uncomfortable or you do not know what you are doing, find someone who does.

The manual provided by Bluefors is a helpful reference[1], but **DO NOT** follow the procedures for cooldown and warm-up given in that manual - you risk the destruction of valuable equipment! Operate the fridge only as described in this document.

Contents

[1] smb://srv034.tudelft.net/staff-groups-tnw/ns/qt/Transmon/Fridges/5.%20Lamborghini/Manuals/FromBluefors/Manuals

2 General Notes

- The scroll pumps SCROLL1 and SCROLL2 take about 10 seconds to run up. After turning them on, wait until you hear a relay click and give them a few seconds to get up to speed before continuing. SCROLL1 has mixture on both sides and will slowly leak gas back from the P_4 manifold to the $\overline{V10V11}$ manifold as well as internal spaces inside the pump. This is normal. It takes about 20 minuites to fully recover a quoted P_4 value.
- Do not leave the fridge in LOCAL mode. Otherwise you are left without control when logging in remotely in case of emergency.
- Since we rarely have a want to control T_{MC}, we usually use the "sample heater" output of the LakeShore for controlling the still temperature. The correct wiring is thus: HEATER-STILL attached to "MC" of the patch panel and HEATER-MC not attached. Shown in figure 2.
- This is a living document and is updated to reflect the best known operating procedures. If you spot a mistake or think of an improvement contact MJS or BT.

Naming conventions and alternative names:

- T_1 the upper pulse tube flange, nominally 50K.
- $T_2 = T_{PT}$ the flange with the pulse tubes around $3 - 5$K when running.
- $T_5 = T_{still}$, the still temperature.
- $T_6 = T_{mc}$, the mixing chamber temperature.
- $P_1 = P_{VC}$, the vacuum can pressure.
- $P_2 = P_{still}$, the still pressure.
- $P_3 = P_C$, the condensing pressure.
- $P_4 = P_{scroll}$, the pressure at the head of SCROLL1.
- $P_5 = P_{tank}$, the helium tank pressure.
- $P_6 = P_{aux}$, the auxiliary manifold pressure.

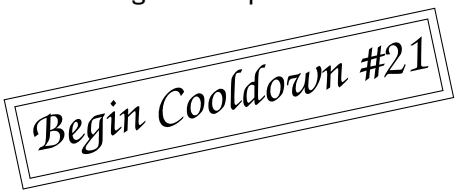
See figures 8 and 7 at the back of this document to see where they are located.

3 Logbook

Somebody else should be able to pick up the log book and be able to fully understand the current state and be able to then operate the machine with no other communication. This is vital for the shared operation of equipment. As such, the use of the logbook is *mandatory* when operating the fridge. It keeps a record of all interactions with the fridge, vital diagnostic values, and thoughts to pass onto other users. The lab book belongs to the fridge; it is not yours to take home, away, or out to lunch. We take ownership of our work to enable a detailed follow up if needed.

Specifically:

- The first entry on a day contains the date, time, and initials. For example:
  2019-06-01 0930 MJS begin warmup procedure
- Later entries of the same day/user only need the time, e.g.
  0932 turn off turbo
- Number the pages and include the cooldown number.
- Make change of samples and cooldowns clear.



- Fill in the cooldown table and dump pressure table at the front of the logbook when needed.
- Leave the logbook at the fridge or on the logbook shelf. You can and should make photocopies, physical or digital, to move the information around.
- The wiring needs to be documented for each run. This can refer to standard wiring or back to the last run.

Generally:

- The use of tables, cartoons, and sketches to communicate clearly is encouraged.
- Record observations of errors and quirks e.g.:
  1513 scroll made strange noise when starting up, but went away. Check out later?
  or
  1614 P6 is high, 10 mBar, but was left low. Leak?
- Record short-term intentions with actions e.g.:
  1707 cleaning up manifold V21-V20 on turbo so I can leak check it soon.
- Taking photographs for documentation is great, write in the location of the files
  0932 fixed the MC heater wire, photos at:
  Transmon/Fridges/1. Ferrari/Maintenance/2019-04-02_MixingChamberHeater/
- Write in-order chronologically with no gaps. Exceptions must be made very clear.
- No loose papers. Glue or tape them in.
- Use strikethroughs for corrections. No deletions.

4 Procedures

4.1 Starting Software

Usually the software is kept running, so you might not have to start the programs. Ensure that all the following are running

- ValveControl. Check that is does not report communication errors with any device, except the Pulse tube compressors (when they are powered off). Make sure it is correctly reading the status of valves, the pressures, and the flow.
- LakeShore Reader. Make sure it reads the temperatures from the LakeShore correctly.
- TeamViewer. Record the ID so you can log in later.
- Fridge tracking. The webpage of the fridge is updated by the Python script `fridge_tracker3.py`. Stop it if it is running in a terminal window (Ctrl+C). Open the script in an editor and set the startdate value (line 13) to the current date (or whenever you want the data displayed on the web to start). Then restart the script by running `python fridge_tracker3.py` in a terminal at the correct working directory.

4.2 Pump on dilution unit

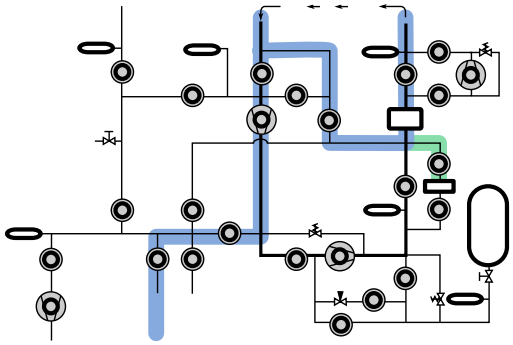


Figure 1: **Pumping the DR and trap.** Using an external turbo connected to AUX.

The fridge is warm, the mix is recovered, and the manual dump valve is closed. All valves on the control panel are closed. Around SCROLL1 and the compressor, a small amount of mixture remains, and these valves should thus never be opened when the fridge is warm. Do not proceed if they were open! While pumping the valve configuration is shown in figure 1.

1. Attach an external pump with turbo to the AUX port.
2. Open V2. Monitor P_2, it should settle at not more than 5mBar.
3. After P_2 has settled, open the gate valve V1.
4. Start the external turbo, open V20 to evacuate the auxiliary unit, then open V18 to start pumping on the dilution unit.
5. When $P_2 < 5$mBar, turn on TURBO1.
6. Open V3, V4 to also pump the condensing side.
7. If the trap is warm, open V7 to also pump it clean.
8. Pump for at least 30 minutes.
9. Close all valves and turn off TURBO1.

4.3 Check thermometers and heaters

The patch panel is located on the right side of the control panel.

1. Check the thermometers. The LakeShore should display around 290 K for T_1, T_2, T_5. T_6 should be over range ("T. OVER"). For Pagani the resistance should read 1.024 kΩ. For Lamborghini the resistance should be around 10 kΩ.
2. Check the heaters. On the right side of the gas handling system control unit is a patch panel with leads that connect to the heaters. Unplug the leads from the patch panel and use a multimeter to probe the heater's resistance. They should be close to the values in the table:

Heater	Channel	Approx. Resistance at RT (Ω)
Heatswitch still **HS-ST**	1	30
Heatswitch MC **HS-MC**	2	50
Still heater **EXT**	3	155
MC heater	4	170
4K Power Heater	n/a	12

3. Turn on **HS-MC**, **HS-ST** and **EXT** on the control panel and use a voltmeter to measure a few volts across the connectors.

When you are sure the devices are fine, leave the patch panel in the configuration as shown in figure 2.

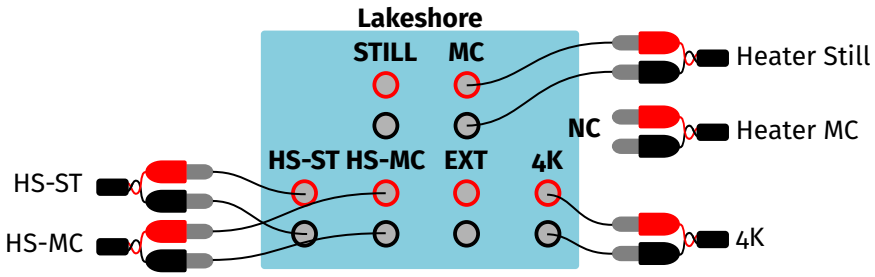


Figure 2: **Heater Patch Panel Wiring.** Note that still and MC are swapped to enable control of the still from the Lakeshore.

4.4 Button up the fridge

The samples are mounted in the fridge and the thermometers and heaters are checked. The state of the inside of the fridge has been documented with photographs and documented in the fridge logbook.

- Close all shields. This requires two people. The shields have a bayonet mechanism, so that no forklift is needed. Pagani has a cold plate shield, while Lamborghini does not.
- Make sure to use the shields belonging to the fridge. Each shield is marked with an “L” or a “P” on the flange, above the seam.
- Make sure all seams are aligned:
  - Due to the bayonets, for most shields, only two orientations are possible:
    * Lamborghini: orient all seams towards the hallway.
    * Pagani: orient all seams towards the window.
  - The cold-plate shield of Pagani has no bayonets. It should have its seam in the middle of the line of sight port ‘AA’ (towards the window, slightly towards Maserati).
- Before mounting each shield, wipe both mating surfaces with IPA to ensure good thermal contact. This is the top inside edge of each shield, and the outside surface of the plates.
- Check for dust in the bottom of the shields, and remove if present.
- The screws for the 50K and 4K shields must not be confused with the slightly longer screws that are only meant to be used for the top of the vacuum can.
- When closing the vacuum can, take each O-ring out of the groove, wipe both the **O-ring** and **groove** with IPA and apply fresh high-vacuum grease to the O-ring until a thin film coats the entire ring. While doing so, you may let the individual shield parts rest on the floor, as they will sit on the bayonet screws, not on the sealing surface.
- The opposing face that mates with the O-ring also needs to be cleaned.
- Double check for any dust on the O-rings just before making the vacuum seal.

4.5 Evacuate Vacuum Can

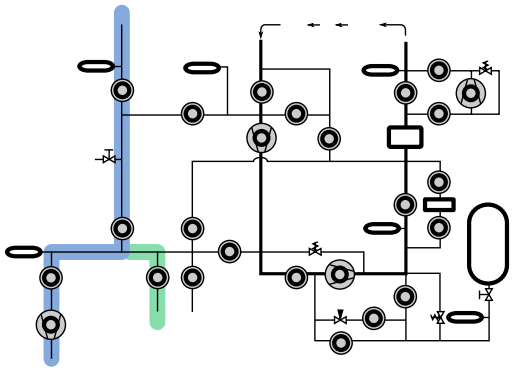


Figure 3: **Pumping the VC.** Using an external turbo connected to AUX.

Thermometers and heaters are checked, all shields are closed, the traps and dilution unit have been evacuated. All valves are closed and pumps are turned off. The trap has been cleaned and is in LN2. While pumping the valve configuration is shown in figure 3.

1. Turn off P_1 on the MaxiGauge ("Sen-off"). The gauge is sensitive to fast pressure changes when active.
2. Start SCROLL2, then open V21, V16 and V14 to start evacuating the vacuum can.
3. Use an external turbo to evacuate the vacuum can further. Attach it to the AUX port, open V20, then start the external turbo immediately, the help from the turbo roughing pump makes quite a difference.
4. The vacuum can is big and roughing takes long, even with both SCROLL2 and the roughing pump of the external turbo. If the external turbo is not set to delay run-up or to idle up to a set point, it might abort run-up. In that case, just restart it.
5. Wait until $P_6 < 0.1$mBar.
6. Turn on the P_1 sensor. Close V21 and turn off SCROLL2.
7. Precooling can now be started. Leave the external turbo pumping until $P_1 = 10^{-5}$mBar.
8. After 1 hour, check that the Turbo is still running, restart if needed.

4.6 Precooling, 300 K to 4 K

1. Open the manual valve to the mixture dump, on the left of the gas handling system.
2. Check whether P_5 reaches the value recorded after the last cooldown.
3. Turn on the main breakers of the pulse tube compressors, wait until they have loaded their firmware, then start them by turning on **PULSE TUBE**.
4. Turn on **HS-MC** and **HS-ST**.
5. The pulse tube compressors run very warm in the beginning of precooling. If the oil temperature reaches over 49°C, they will shut down. If this happens just restart them.
6. Optional: After around 12 hours of precooling, it helps to let exchange gas into the dilution unit. For that,
   (a) Open **V13**, **V9** and **V7**, wait 10 seconds for the pressures to equalize
   (b) Close **V13**.
   (c) Open **V3** to let a shot of mix into the dilution unit.
   (d) Close all valves (**V7**, **V9**, **V3**) again.
7. When $P_1 < 10^{-5}$mBar, close **V14**, **V16**, and **V20**, then turn off and disconnect the external turbo.

4.7 Test method for cooldown

This method is under test, it takes more effort but less time. The vacuum can is evacuated further before starting, at least 10^{-2}mBar or lower. The scroll still does useful pumping above these pressure, and the turbo is left running until P_{aux} goes under range. Do not turn on the heatswitches until T_{still} is below 100K, as above that point they just add heat to the system without benefit. Below 100K start circulation of the mix in **V13V8** and **V13 TANK**, but not the main tank. Circulate this small amount of mixture through the **TRAP** and the normal dilution unit with **SCROLL1** and **TURBO1** but without the compressor. When the pulse tube temperature T_{PT} drops below 5K, open **V13** and the manual tank valve. This lets the mixture begin condensing already. However T_{mc} will still be very hot. When both T_{mc} and T_{still} are below 3.5K, turn off **HS-ST** and **HS-MC**. As the mixture begins to slowly condense in, the T_{mc} will dip below 1K, at this point close **V13** and let the system circulate with this minimal mixture. This configuration should have a column of liquid down to the mixing chamber, providing more cooling power to where is is most needed. Wait until T_{mc} is below 750mK and then open **V13** to condense in more. You still need a hairdryer on the traps at this point. When P_c drops below 500mBar, close **V13** and use the needle valve with **V12** to raise P_4 and P_5 to around 1000mBar. Finally use **V11** to get the rest of the mixture in. The system should already run normally. Apply still heat when T_{mc} begins to fall.

4.8 Pulse precooling, 4 K to 1 K

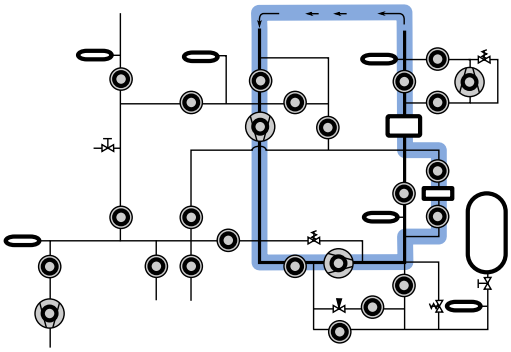
When the still plate temperature T_5 falls below 15 K (after around 30 hours after start of the pulse tubes), pulse precooling, PPC, can be started. This procedure helps to thermalize the dilution unit, and also cleans the mixture. PPC may be omitted if the fridge has already settled to around 4K for more than 5 hours before condensation. PPC is controlled by a computer script, which periodically lets the mixture expand into the dilution unit from the still side, and then pumping it again.

1. Wait until $T_5 < 15$ K. After start of pulse tubes:
    - Lamborghini : ca. 35 hours
    - Pagani : ca. 45 hours
2. Ensure that the manual dump valve is opened.
3. Load and start the script "`Pulse_PreCool_v1_24`". It runs for 2 hours.
4. Monitor the peaks and dips of the dump and still pressure. They should be stable after around 30 cycles.
5. Wait about 30 minutes until T_6 falls below 4 K.

4.9 Condensation, 1 K to base

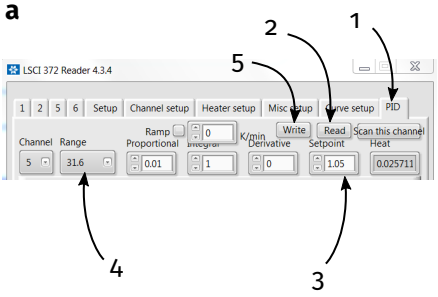
PPC is finished and the fridge is circulating a small amount of mixture. T_6 has fallen to 4 K.

1. Point a blow dryer (with a timer set to 2 h) at the top of the external trap, right below the O-rings. This is to prevent ice forming on the O-rings during the high load of condensation.
2. Condensation is controlled by the script "`Condense_wLN2_v1_24`". Load and run it in the ValveControl Programming tab. Condensation takes around three hours.
3. Wait until condensation is finished. The fridge should now be in a normal circulation mode:



4. Turn off the blow dryer.
5. With lots of mass in the fridge (especially Pagani with extra CP shield), the fridge might enter a phase of lumpy He-3. This leads to large oscillations in P_2, P_4 and flow rate. It might happen that P_4 > 1200mBar; then the safety valve BPV3 should break and let a bit of the mixture back in the tank.
   (a) If you observe a small increase of P_5 (no more than 50mBar), wait until the fridge is stable and then pump the dump empty again by opening V11.
   (b) If P_5 increases above 1 Bar after normal condensation, the condensing lines might be blocked, or the fridge is still too hot. You might wish to wait until the fridge is cooled a bit further, and then run the condensation script again. If normal circulation can not be reached, contact an experienced user.
6. When dilution cooling sets in, T_{MC} below 1 K and falling fast. turn on the still heater by setting the Sample heater range to 120 mW and Setpoint to 1.05 K (Lamborghini) or 1.15 K (Pagani). You can use ether the Lakeshore software on the computer or the front panel.

a



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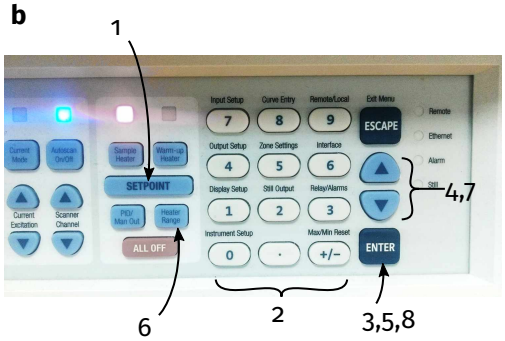


Using the software, shown panel **a**:

1 Open the PID tab in the Lakeshore Reader software
2 Read in the current value from the software
3 Change the setpoint to what is desired
4 Change the range from 'Off' to '31.6'
5 Send the settings back to the device by clicking 'write'.

Using the front panel, shown in panel **b**:

1 Press 'SETPOINT' to begin modifying the PID setpoint

2,3 Key in the setpoint in kelvin (i.e. `1 . 0 5`) and confirm the value using ‘ENTER’

4,5 Use the scroll buttons to select the unit of ’K’, and confirm again with ‘ENTER’

6 To turn the heating on, press ‘Heater Range’

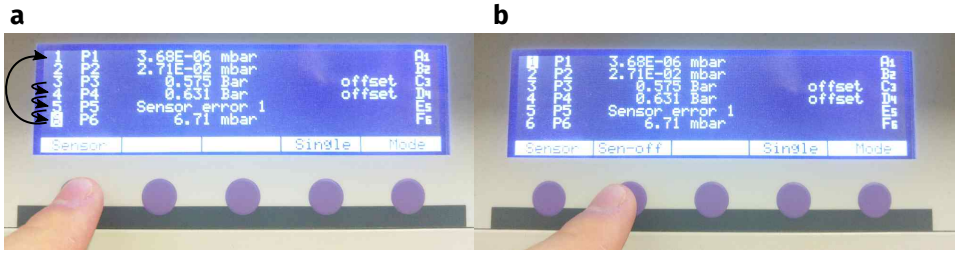
7,8 Use the scroll buttons to select ‘120mW’ and confirm the power with ‘Enter’.

4.10 Warm-up

Warm up is performed manually. **Do not** use the Bluefors supplied warm-up scripts; they let *nasty wet* room air in the VC as exchange gas while the fridge is cold!

These instruction begin assuming the fridge is circulating normally.

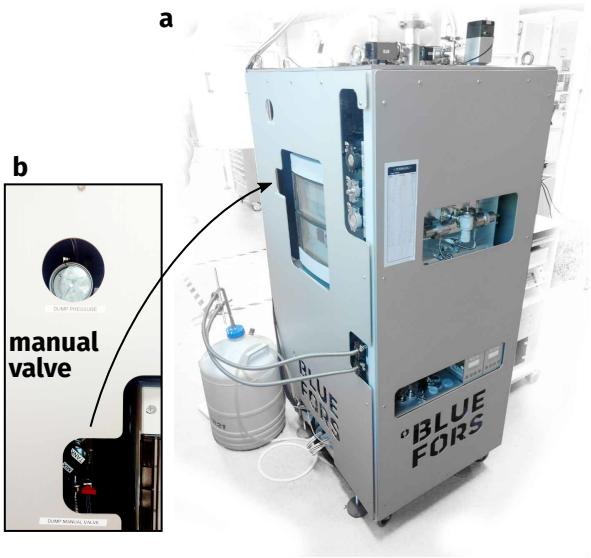
1. Ensure all room-temperature electronics are in a safe state.
2. Record the current temperatures and pressures in the fridge logbook.
3. Turn off sensor P_1 on the MaxiGauge ("Sen-off"). You will later add gas to the vacuum can and this sensor can get hurt by high pressures.



   (a) use the 'sensor' button repeatedly as needed to select P_1, shown in panel **a**.

   (b) use the 'sens-off' button to turn the sensor off, shown in panel **b**.

4. The mixture need to go into the mixture tank. Check that the manual valve, located on the left side of the gas handling system, is open.

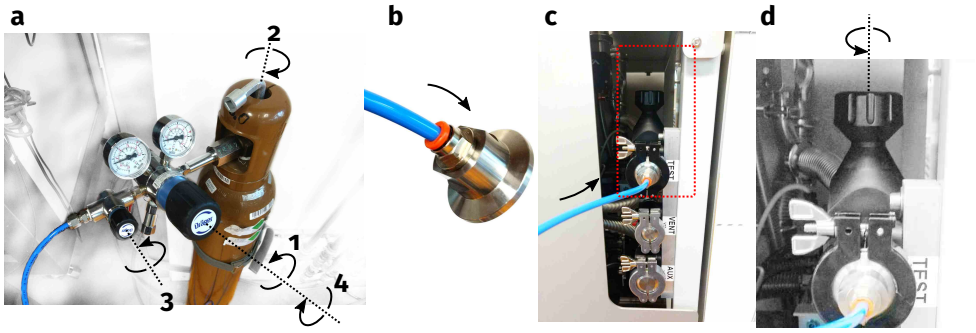


5. Turn off TURBO1. We will soon have P_2 larger than what TURBO1 can handle and it needs time to spin down.
6. Open V13. The mixture is now being recovered to the tank from both the still side and the condensing side. After a few seconds the condensing pressure will equal the tank pressure.
7. Close V9 to direct flow to only As the pressure builds in the tank.
8. Turn on HS-ST and HS-MC. This activates the heat switches to thermally connect the mixing chamber and still to the pulse tube plate causing the liquid helium mixture to boil off and be recovered.

   There will be two additions of helium exchange gas. The first shot of exchange gas will enable full recovery of the mixture from the dilution unit. The second will assist the fridge warming up to room temperature.
9. Prepare manifold $\overline{\text{V14V16V21}}$ to hold the exchange gas:

   (a) Turn on SCROLL2, open V21 and V16, to initially evacuate the manifold until $P_6 < 1$mBar.

(b) Prepare the external helium line (shown in panel **a**):



1 Close-off regulation using the center valve counter-clockwise until gentle resistance.
2 Open the high-pressure helium cylinder valve using the key, about half a turn for fully open.
3 Open the front valve.
4 Dial in a gentle flow using the regulation valve feeling the flow with your thumb.

(c) Using an adapter, attach the helium line to the TEST port. (Panels **b** and **c**)

(d) Close V21 then open TEST manual valve, shown in panel **d**, and *slowly* let about P_6 = 1000mBar of helium in the volume. Watch out: the adapter to the helium line can not be pumped under 1 atm without leaking, so opening the TEST valve too quickly will let in air.

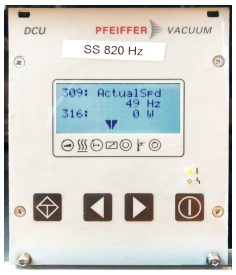
(e) Close the TEST manual valve, then open V21 to evacuate the volume.

(f) Flush the volume two more times, then close V21.

Prepare the first shot of exchange gas

10. Using TEST and V21, let P_6 = 15mBar of helium in the volume $\overline{\text{V14V16V21}}$. You can juggle V16 and V21 to lower the pressure in steps.

11. Wait until TURBO1 is spun down. Less that 30 Hz is acceptable. if the frequency is not visable, use the left and right buttons to navigate to screen 309: Actual Spd.



12. Open V3 and V2 to recover mixture from both sides of the dilution unit and the trap.

13. Open V14 to let the exchange gas into the vacuum can. Wait 5 seconds, then close V14 again. The still, P_2, should increase as the mix begins to evaporate.

14. Wait until P_2 < 10mBar (ca. 10 minutes), This is low enough so that the turbo can run.

15. Turn on TURBO1.
    There is time while the rest of mixture is recovering, so prepare the second shot of exchange gas.

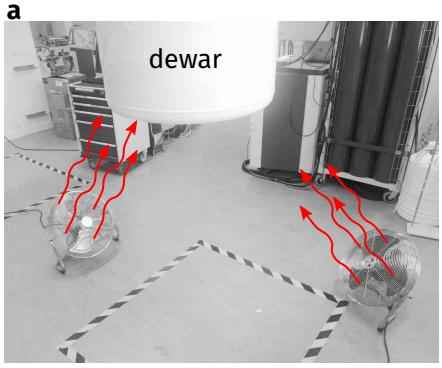
16. Using TEST and V21, let P_6 = 200mBar of helium in the volume $\overline{\text{V14V16V21}}$. You can juggle V16 and V21 to lower the pressure in steps.
    Do not add the second shot of exchange gas yet.

17. Close the helium bottle at the cylinder and at the regulator.

18. Detach the helium line and attach a blank to the TEST port.

19. Set up a fan (or better two) pointed at the vacuum can to prevent condensation for after when the second shot of exchange gas is added. Do not place the fans directly under the vacuum can as there may be dripping water condensate.

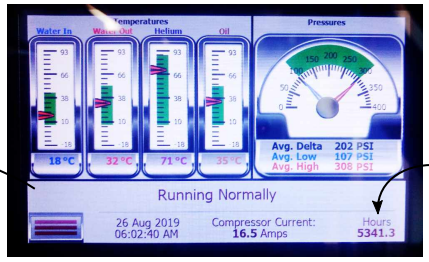
a



20. Wait until $P_2 < 5 \times 10^{-4}$mBar. Despite the low pressure there is still significant flow.
21. Wait until $T_6 > 20$ K. The porous silver inside the dilution unit holds helium on its surface well above the bulk boiling point.
22. Wait an additional 30 minutes to ensure full recovery of the mixture and prevent aggregate losses.
23. Record the values of P_4 and P_5 in the fridge logbook. Check that they are very close to the previous end of run. If not, *do not* proceed to warm up the fridge further, and find an experienced user.
24. Close the manual dump valve.
25. Close all other valves.
26. Turn off HS-ST and HS-MC.
27. Turn off and pumps SCROLL1 and TURBO1.
28. Turn off the PULSE TUBE:

a

b



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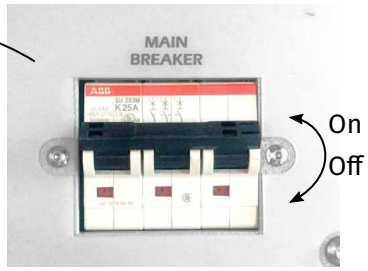


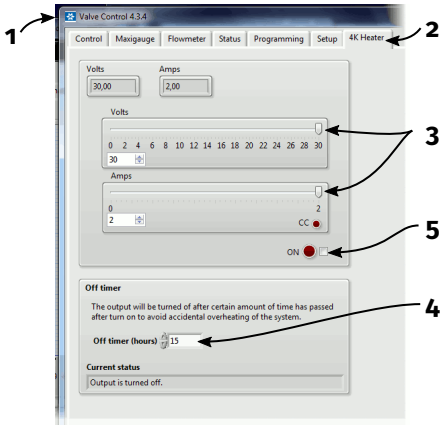
(a) Turn off the PULSE TUBE on the control panel.

(b) Record the PULSE TUBE's runtime in the log book this is shown on the compressor's display, seen in panel **b**.

(c) Then switch off the compressors' main breakers, seen in panel **c**.

29. Let the exchange gas in by opening V14 for about 5 seconds, then close it.

30. Turn on the 4K heater in the software:



1 Open the 'valve control' software.
2 Click the '4K heater' tab.
3 Use the sliders to set current and voltage to their maximums
4 Set the timer to 15 hours.
5 Click the checkbox next to 'on'.

31. Clean the external trap now. If it is forgotten and warms up when the Dewar runs dry, you risk forming an accidental cryobomb. Follow the instruction in section 4.11.

    The fridge has a second internal trap inside the cryostat. When the pulse tube plate gets warm it will release it's contents.

32. Wait until $T_2 > 80$K, this takes about 20 minutes.

33. Check that P_3 is below 300mBar. If not you will also start cleaning this trap immediately.

    Only if $P_3 > 300$mBar:

    (a) Turn on SCROLL2.
    (b) Open V4, V17, and V21.
    (c) Wait until $P_3 < 10$mBar. We are not aiming for clean now. We just need it to be safe for the rest of the warming up.
    (d) Close V4, V17, and V21.
    (e) Turn off SCROLL2.

    The rest of the warm up takes about 24 hours.

4.11 Clean External Trap

These instructions assume that the mix is recovered, and the manual dump valve is closed. All valves on the control panel are closed.

1. Start SCROLL2, then open V21 to evacuate the manifold until $P_6 < 10^{-2}$mBar.
2. Close V21 and open V17.
3. Monitor P_6 to make sure that the path to the trap was evacuated (it should drop further).
4. Open V7
5. Take the trap out of the Dewar and secure it with a clamp stand, Velcro tape, or a cable tie.
6. Observe P_6, in only a minute or two it should start rising.
   It should not rise above 1 Bar, only if it does: open V21 and record "overfull" in the logbook.
7. Heat the trap with a blow dryer, held with a clamp stand to direct heat towards the base of the trap.
8. Monitor P_6 until the trap is warm to the touch.
9. Record P_6 in the fridge logbook as an indication of the gunk that the trap has collected during the last cooldown. Typical values are $10 - 100$mBar.
10. Open V21 to start pumping on the trap. Pump for at least half an hour while heating the trap. In the meantime, refill the Dewar with LN2.
11. Close all valves.
12. Slowly insert the trap back into the liquid nitrogen.

4.12 Opening the fridge

The cryostat is fully warmed up (**all** temperatures around 290 K, ca. 48 hours). Note that T_6 is not calibrated above 100 K, except for a single calibration point at 292 K. All valves are closed.

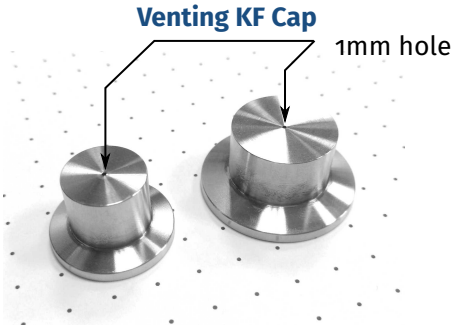


Figure 4: **A cap for venting fridge** This cap has a small hole, about 1 mm diameter, that limits the inrush of air.

1. Check that P_1 is turned off ("Sen-off").
2. Make sure that the VENT port is covered by an impedance (either a KF25 plastic cap with hole, or the metal KF flange with the hole). **Do not vent without impedance**, you can crush the shields! This has happened at TUD.
3. Vent by opening V14, V16, and V19. This takes about 10 minutes.
4. Usually, you only want to access the mixing chamber. In that case you need to
   (a) Lamborghini: Only unmount the lowest segment of each shields.
   (b) Pagani: Unmount the two lower segments of the VC, and both segments of the 50 K, 4 K, and still shields, in order to unmount the CP shield.
5. Before you open the satellite or begin to change wiring and/or samples, have someone with TWPA experience disconnect and terminate all TWPAs. Only do this if you have been *explicitly* instructed to do so – TWPAs are priceless and very ESD-sensitive.

5 Usual Operating Conditions

5.1 Lamborghini

T_1	35 K	
T_2	2.8 K	
T_4	1.05 K (PID)	Still
T_5	11 mK	MC

P_1	3×10^{-6} mBar	VC
P_2	3×10^{-2} mBar	Still
P_3	680 mBar	Condensing
P_4	800 mBar	Trap
P_5	4.5 mBar	Dump
P_6	9 mBar	Aux

5.2 Pagani

T_1	38 K	
T_2	2.9 K	
T_4	1.15 K (PID 22 mW)	Still
T_5	11.5 mK	MC

P_1	3×10^{-6} mBar	VC
P_2	3×10^{-2} mBar	Still
P_3	580 mBar	Condensing
P_4	610 mBar	Trap
P_5	6 mBar	Dump
P_6	2 mBar	Aux

5.3 PID settings

The PID control of the Lakeshore is designed for use with the mixing chamber thermometer, T_6, and heater, however, we use it for control of the still temperature. If the setting were not messed with they will remain correct. Here is our known good settings. Using the LakeShore Reader software on the computer, in the 'Heater setup' tab set the control coefficients P : 0.01, I : 1.00, and D : 0.00. The range of 31.6 mW is sufficient. Control mode: 'closed', control channel: '5' (T_5), heater resistance: 120.

6 Fridge Turnaround Performance

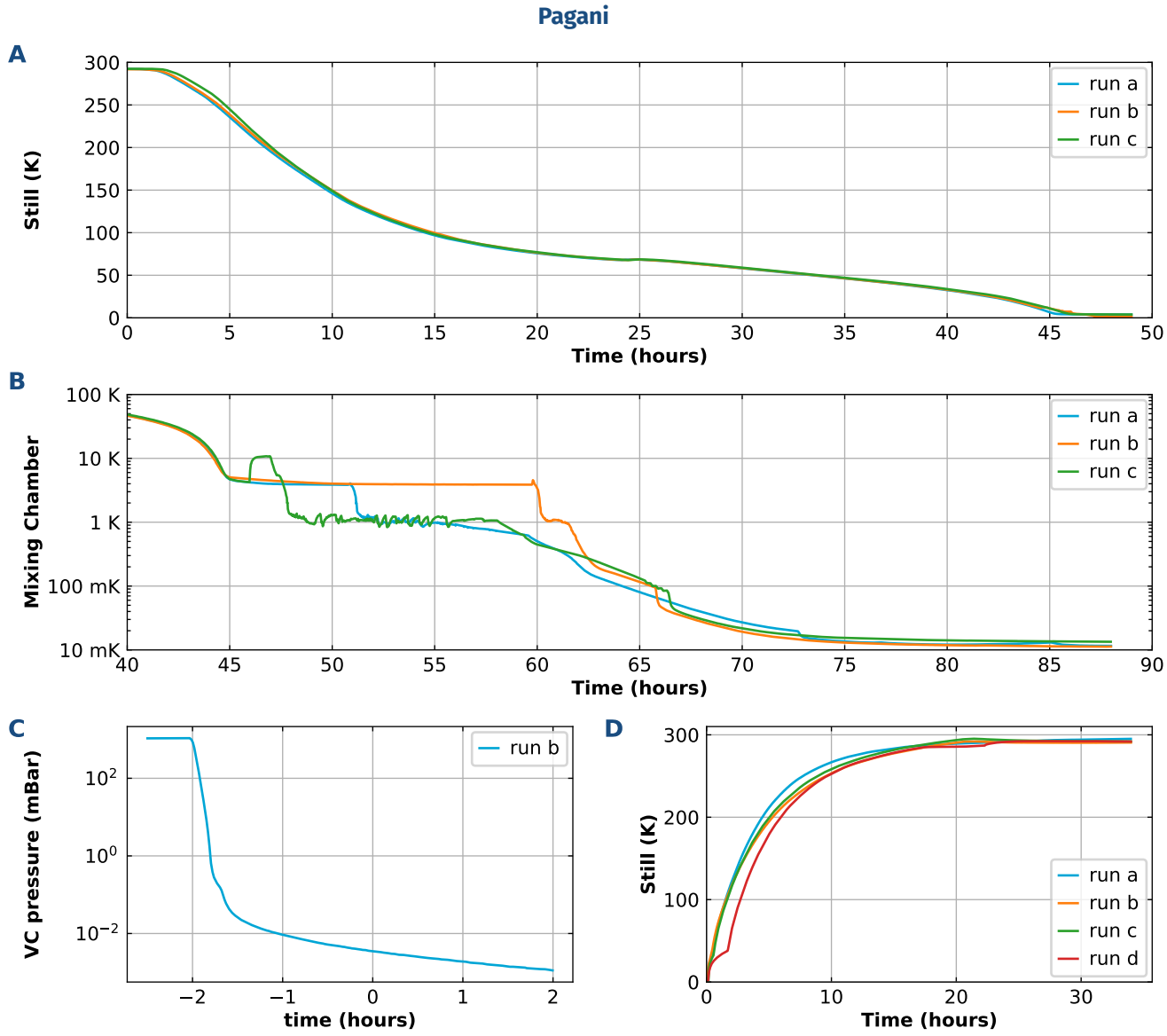


Figure 5: **Pagani Turnaround Performance** (**A**) Initial cooling of the pagani. (**B**) PPC, condensation, and cooling to base temperature. (**C**) Pumping of the VC before cooling. (**D**) Warming up when the run is over.

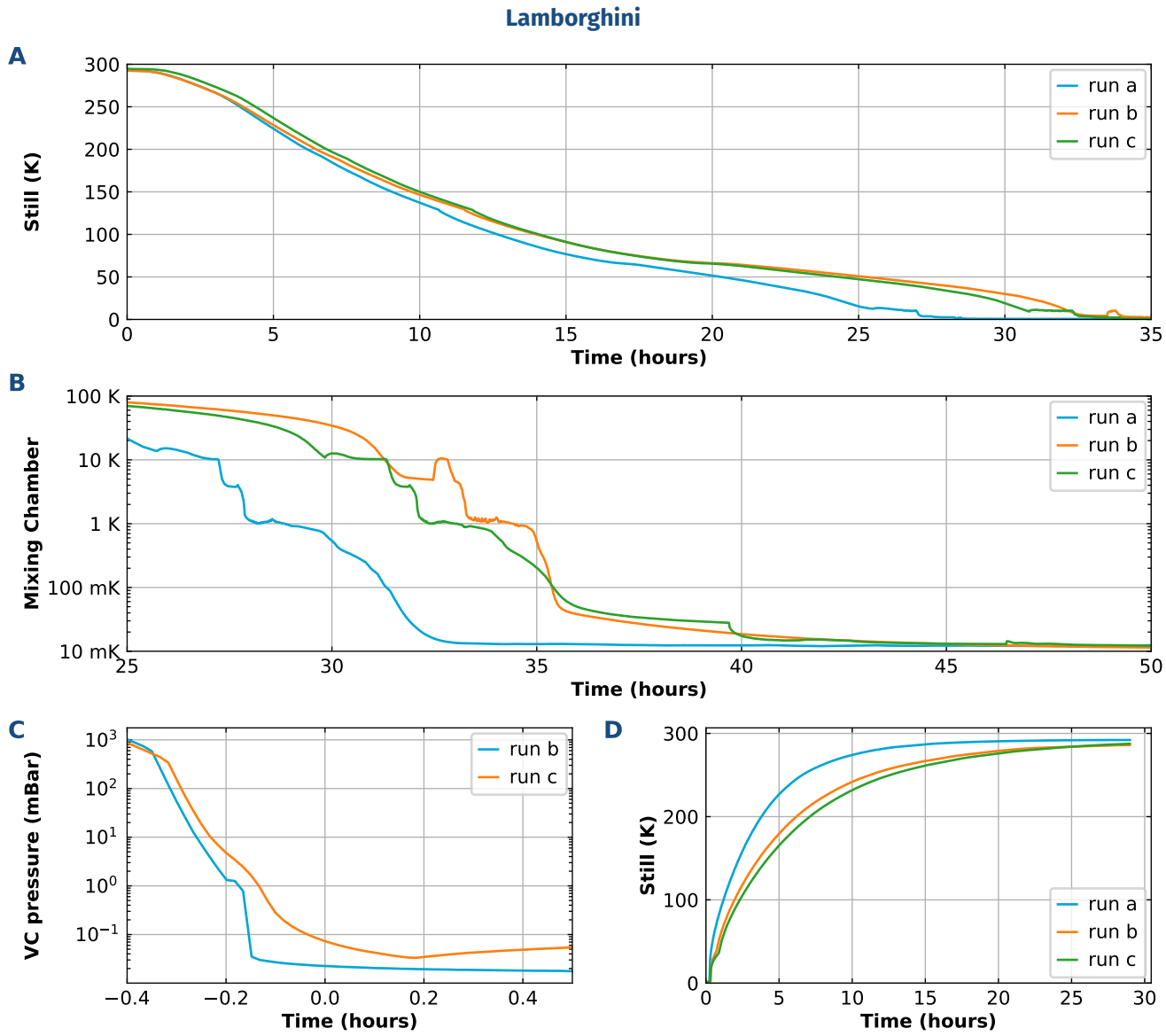


Figure 6: **Lamborghini Turnaround Performance** (**A**) Initial cooling of the Lamborghini. (**B**) PPC, condensation, and cooling to base temperature. (**C**) Pumping of the VC before cooling. (**D**) Warming up when the run is over.

7 General Information

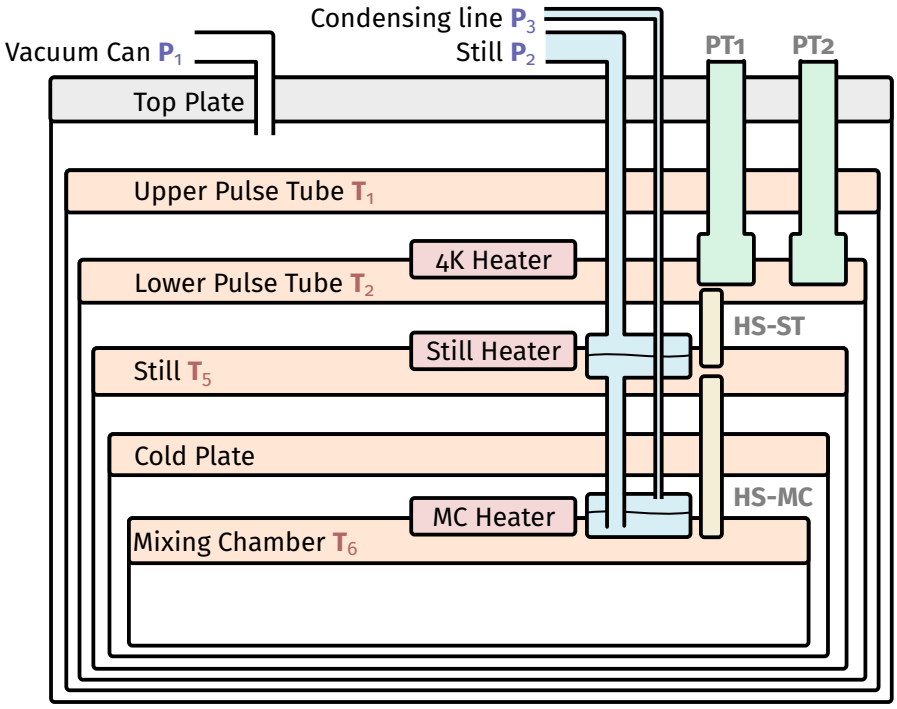


Figure 7: **Fridge layout** Showing the location of thermometers T_1 - T_6 and the fridge pressures, P_1 - P_3. The HS-ST connections the 4K to the Still, HS-MC connects the mixing chamber to the still.

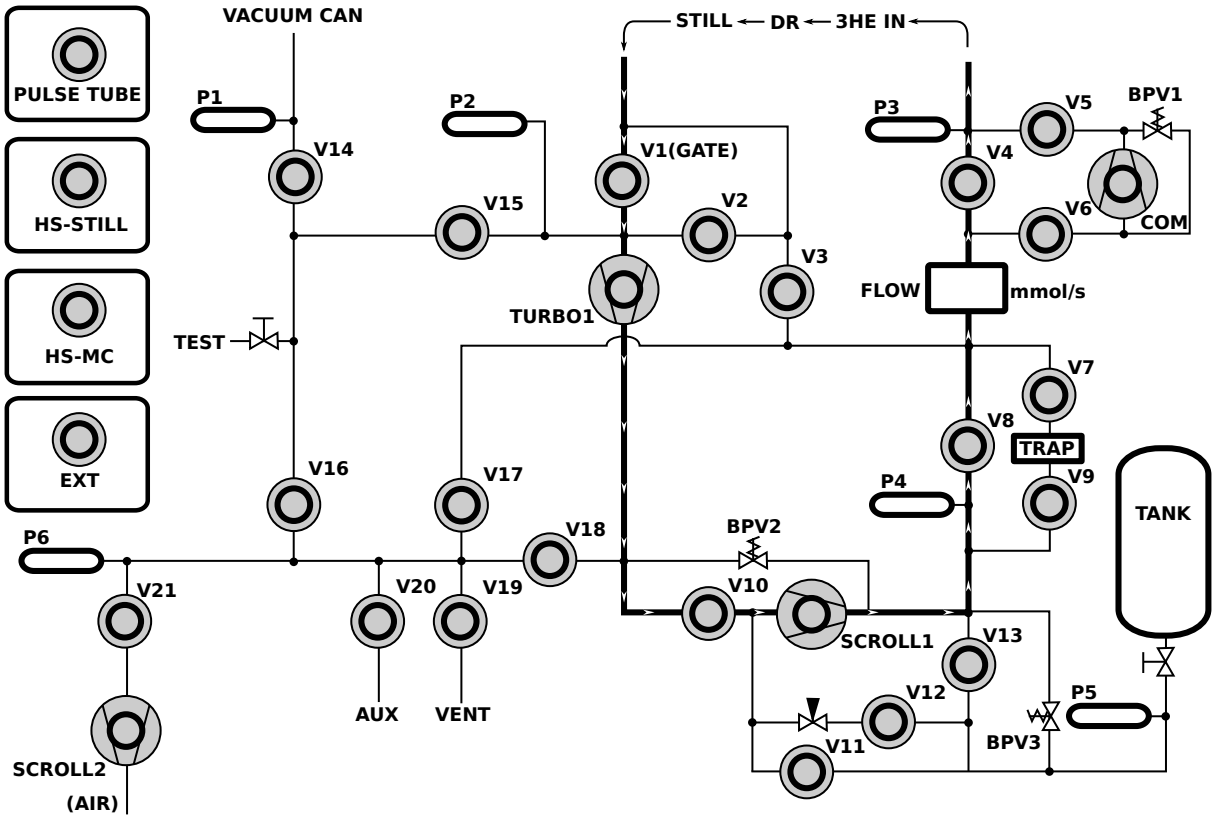


Figure 8: **Control layout.**

8 Photocopy Sheets

8.1 Trap log

Trap Log

Date	Action	Initial