

# Berkeley Bolometer R&D Cryostat Manual

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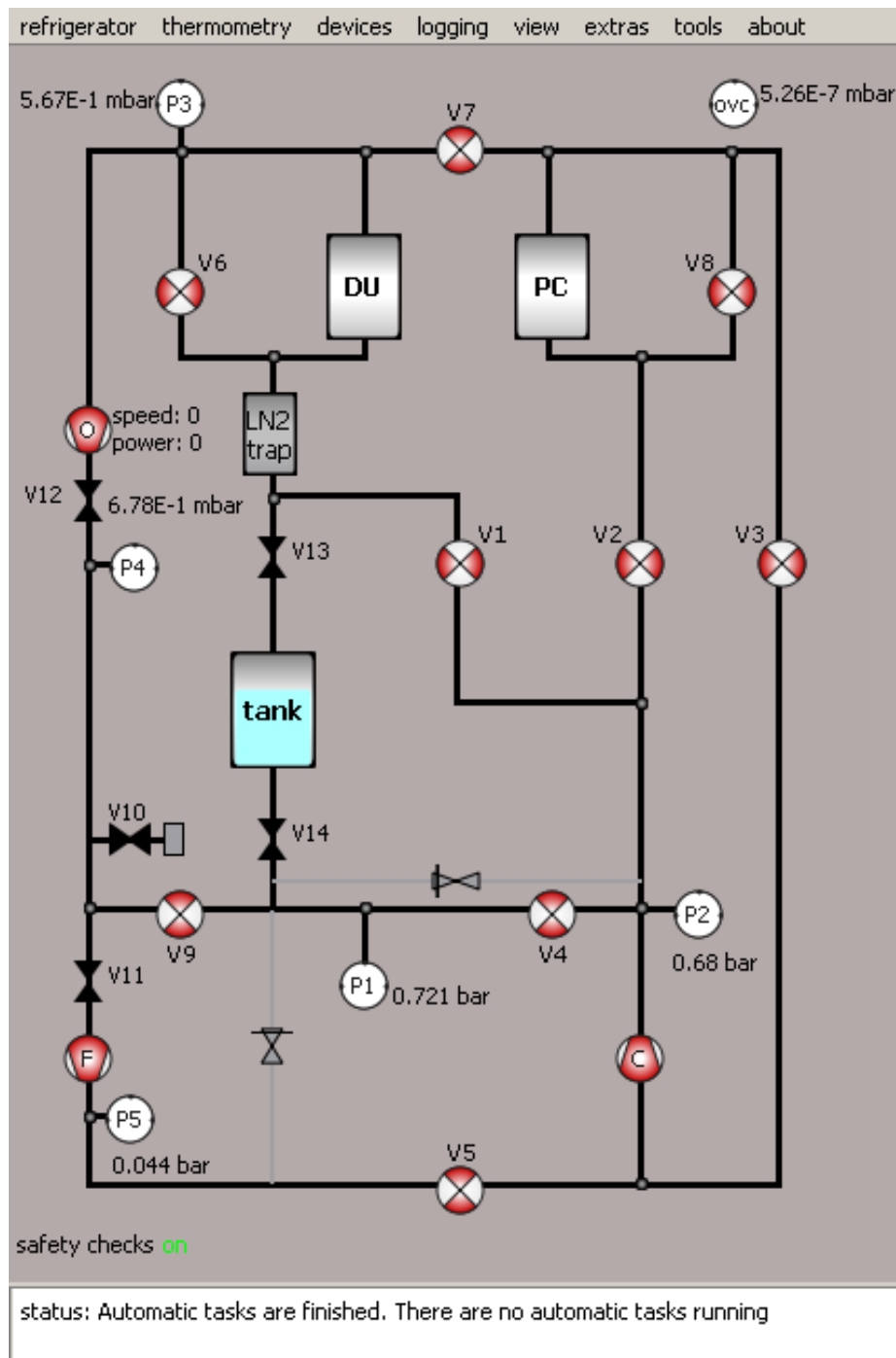


Figure 1: The Triton Dilution Control main panel. (To enable control: *View>Enable.*) The purple lines indicate the flow of the mixture. In this figure, the system is at base temperature. V[N] indicates valve number N, red indicates the valve is closed, green open. P[N] indicates pressure sensors. DU is the Dilution Unit. PC is the Pre-Cool Circuit.

## 2 Warnings and Things to Note

### 2.1 Things that will DESTROY the System

- **Do not open V10.** V10 is the primary valve into and out of the mixture circuit. Opening V10 without serious caution has the potential to lose the mixture. Further, opening V10 will result in a swift kick in the pants from the author.
- **Do not vent the OVC to a pressurized dewar.** Allowing the pressure of the OVC to go above 1 atm can lead to an explosion of the OVC. The OVC can is held on by 8 M4 screws. For every atmosphere of over-pressure, these screws have to hold an extra 5000 lbs of force. Luckily, the OVC has a pressure relief valve, but this should be considered a secondary safety measure. Never vent from a pressurized dewar.
- **Protect the Turbos.** Sudden changes in pressure at P3 while the still turbo is running or in the OVC pressure while the pumpcart turbo is running can cause serious damage to the turbo. Make sure the turbos have spun down before venting them. The program should protect the still turbo from being flooded while its running, however, if during condensing, the still temperature reaches 1K, the mixture can begin to boil and put tremendous stress on the turbo.
- **Leak Check.** Always always always leak check the can before beginning the precool.

### 3 Preparing the System

Because the cryostat has roughly a 48 hour turnaround time, it is very important to properly prepare the system before any cool down experiment. Otherwise, you may find yourself having to wait on a lengthy warm up and subsequent cool down to fix a problem that could have been considered early on.

—————When working with the fridge and shields always wear gloves.—————

#### 3.1 Cleaning the Plates

Before we close the shields, it is always a good idea to clean all the surfaces that have been exposed for a long time or have come in contact with moisture or grease. To do this, you simply wipe down any surfaces with a paper towel dipped in ethanol.

The aim is to prevent any contamination (like fingerprints) from being cooled down, as they can have negative effects on the gold finish of the plates.

Further, moisture inside the OVC will increase the pumping time required to obtain a reasonable pressure. Any moisture remaining on the surfaces after beginning the cooldown will increase the cold mass and increase the specific heat of fridge.

## 3.2 Mounting the Shields

### 3.2.1 Preparing to Mount

————When working with the fridge and shields always wear gloves.————

Before mounting the shields, **make sure that you have not left anything sitting on the fridge**. This can include tools, screws, washers, soda cans, etc. This will add an extra heat load and make it slow (if not impossible) to cool down.

Make sure that there are no wires in contact with a surface they should not be in contact with, (thus creating heat leaks).

### 3.2.2 The Shields

There are 4 shields. From small to large:

- The copper still shield (700 mK).
- The 4K shield.
- The 70K shield.
- The Blue OVC.

The larger three shells are split in half, with a bottom half and a top half. The shells should be mounted as follows:

1. Still.
2. All top halves.
3. All bottom halves.

### 3.2.3 Mounting the Still Shield

1. Using a towel dipped in ethanol, clean off the rim of the shield (the part that will come into contact with the still plate). We want to clean off anything that has stuck to any left over thermal grease from the last mount.
2. Using M3 screws with washers, raise and mount the shield to the still plate. It is easiest to work with opposites: one person holds the shield on one side, while another inserts a screw on the opposite side, and then switch, making sure to always be working with screws 180 degrees apart.
3. Clean the outside of the shield using ethanol.



### 3.2.4 Mounting the 4K and 70K Shields

Notes:

—————When working with the fridge and shields always wear gloves.—————

- These shields require M4 screws with no washers.
- **For the 4K and 70K shields:** clean the rims of each shield with ethanol.
- Clean each of the inner shields with ethanol (both inside and outside).
- Clean the inside of the OVC with ethanol.

#### Procedure:

If the top halves of the shields are already mounted then start at 4.

1. Mount the top half of the 4K shield. This one has many possible orientations, it is important to find one that will allow the welds of the 4K and 70K shields to align. This may take several tries, but it will simplify things later.
2. Mount the top half of the 70K shield, aligning its weld with the weld of the 4K shield.
3. Mount the top half of the OVC shield, aligning its weld with the weld of the 70K shield. See §3.2.5.
4. If you have not already, mount the still shield. See §3.2.3.
5. Mount the bottom half 4K shield, aligning the weld with the top half (and, ideally, the rest of the welds).
6. Mount the bottom half of the 70K shield, aligning the weld with the top half.

### 3.2.5 Mounting the OVC

————— NO VACUUM GREASE —————

Mounting the OVC is significantly more difficult due to the much larger weight of the shield.

1. Clean the rim of the can, making sure that the rubber O-ring is clean and appears intact: no nicks, no discolorations, no gunk stuck in the groove, etc. **Only remove the O-Ring if it needs to be cleaned.** Removing it increases the chances of damage, and there often is not a need.
2. **DO NOT** apply vacuum grease. If the O-Ring is damaged or cracked, replace it.
3. **For the top half:** Aligning the welds raise the OVC and mount with M4 screws with washers from the bottom. **For the bottom half:** Aligning the welds, raise the OVC and mount with M4 screws with washers from the top.
4. **If you are using the automatic lifter:**
  - (a) Strap the OVC to the claw of the lifter so that the can is secure but can still be rotated.

- (b) Rotating the wheel by hand, lift the can a few inches off the ground and by rotating the top horizontal bar adjust the angle of the can so that it is level.
- (c) Using the servo motor, lift the can up all the way. **make sure to stay clear of the 70K shield.**
- (d) The lifter will automatically stop a few inches below the bottom of the upper shield. Use the wheel to lift the can the rest of the way, but do not force it on the upper shield.
- (e) Use the C-clamps to hold the can up while attaching it with the M4 bolts.

Obviously, you do not need to clean the outside of this can (unless you want to).

### 3.3 Pumping Out the OVC

1. Position the red pump cart in a spot where it can easily be connected to the OVC valve. Make sure that the auxiliary valve is also easily accessible.
2. Attach a vacuum hose (bellows) from the OVC valve to the mouth of the turbo on the pump cart. You may need to attach two hoses together.
3. Ensure that the auxiliary valve is **CLOSED** and the roughing valve is **OPEN**.
4. Turn on the pump cart using the green switch on the back of the red panel.
5. If it does not come on automatically, turn on the roughing pump using the switch on top of the roughing pump. You will know the roughing pump comes on when it makes a funny alien-space-craft-taking-off kind of sound.
6. Monitor the OVC pressure on the equipment rack. When the pressure reaches  $\lesssim 10\text{mBar}$ . Turn on the pump cart turbo, by pressing the power switch on the right of the pump cart control panel.

#### Notes:

- It is safe to begin a cool down when the pressure of the OVC reaches  $\lesssim 5 \times 10^{-3}$  mBar (at 300K).
- The longer you pump at 300K, the more gas will boil off from the inner surfaces of the chamber. This will reduce the cold mass and (possibly) noise.

### 3.4 Leak Checking the OVC

It is very important to leak check your system before beginning a cool down. If you do not have time to leak check, then you do not have time to do a cool down.

If air is leaking in while the system is cold, it will begin to condense and freeze on the walls of the chamber, until the walls become saturated, or the cooling power is no longer enough to cool the gas leaking in. At which point it will stay in the chamber as a gas, and act to conduct heat from the inner shields to the OVC. At this point, your system will begin to turn into a snowman. You will overload the pulse tube cooler. You will get water all over the lab. You will certainly look like a fool. So don't be a fool, leak check *before* you cool.

#### 3.4.1 Connecting the Leak Checker

1. Position the leak checker where it can be easily attached to the auxiliary valve of the pump cart. You will probably need to attach two vacuum hoses together to achieve this.
2. While the leak checker is **still capped at the inlet**, turn it on. This will allow the leak checker to spin up its internal turbo.
3. **Note:** If you wish to get a new calibration, leave the leakchecker running for about 20 minutes, before starting a calibration. **You will probably not need to re-calibrate** as the calibration will fix factors of 2 or 3, while we are interested in factors of 10-100.
4. When the turbo has spun up, hold STOP for 3 seconds, to allow the leak checker to vent.
5. **Check to make sure that the auxiliary valve on the red pump cart is CLOSED!** Failure to do this can ruin the pump cart.
6. Attach the leak checker to the auxiliary valve on the pump cart. You may need two hoses.
7. Press start on the leak checker. Wait until the pressure on the leak checker has bottomed out.
8. On the pump cart, **close** the roughing valve.
9. On the pump cart, **open** the auxiliary valve.

#### 3.4.2 Leak Checking

At this point you should see the leak rate jump to a few  $10^{-8}$  mbar·L/s. Anything significantly above this indicates a leak. See §9.1.

10. Using a helium gas bottle, spray some helium around the connected joints. It is often best to start close to the leak checker and work your way back to the OVC.
  - Along the hose from the leak checker to the pump cart.
  - Along the hose from the pump cart to the OVC valve.
  - Around the OVC valve on top of the cryostat.
  - Where the top of the OVC can meets the 300K plate.
  - Where the bottom half of the OVC meets the top.

- Leak check the dilution unit and precool lines. (See §3.4.4).

Any jump in the leak rate indicates a possible leak, see §9.1. Otherwise, if there are no leaks, you are ready to [cool down](#).

### 3.4.3 Disconnecting the Leak Checker

11. On the pump cart, close the auxiliary valve.

**Ensure that the auxiliary valve is fully CLOSED before venting the leak checker.**

12. On the pump cart, open the roughing valve.
13. On the leak checker, press and hold *Stop* for 3 seconds to vent.
14. Turn off the leak checker. And disconnect the vacuum lines from the pump cart. Let it spin down before moving it.

### 3.4.4 Leakcheck the DU

From time to time it is a good idea to leak check the dilution unit and precool lines. If there is a leak from the DU or PC lines to the OVC mixture can leak out and cause a serious problem. If mixture leaks into the OVC you need to recover the mixture from the OVC. (See §??).

While the leakchecker is attached and running. Pressurize the DU with mixture up to  $\sim 0.8$  bar:

1. Open manual valve V14.
2. Open V1, V5.
3. Turn on the compressor and forepump.
4. Toggle V9, until P2 reads about 0.8 bar. This may take some time as the mixture makes its way through the impedance.
5. Close V9.

**If you see a jump in the leak rate collect the mixture immediately. There is a leak in the DU.**

To collect the mixture:

1. Ensure V9 is closed.
2. Close V1.
3. Open V6.
4. Open V4.
5. When P3 gets below 1 mBar, turn on the turbo.

To leak check the precool lines leave the leakchecker attached and running when starting the precool. **If you see a jump in the leakrate, empty the precool circuit immediately. There is a leak in the PC circuit.**

## 4 Cooling Down

After you have [prepared the system \(see §3\)](#), you are ready to begin a pre-cool. For a fully automated cool down see [§4.3](#).

Everything in this system is controlled via the *Oxford Instruments Triton Dilution Control* program, which can be launched from the Desktop.

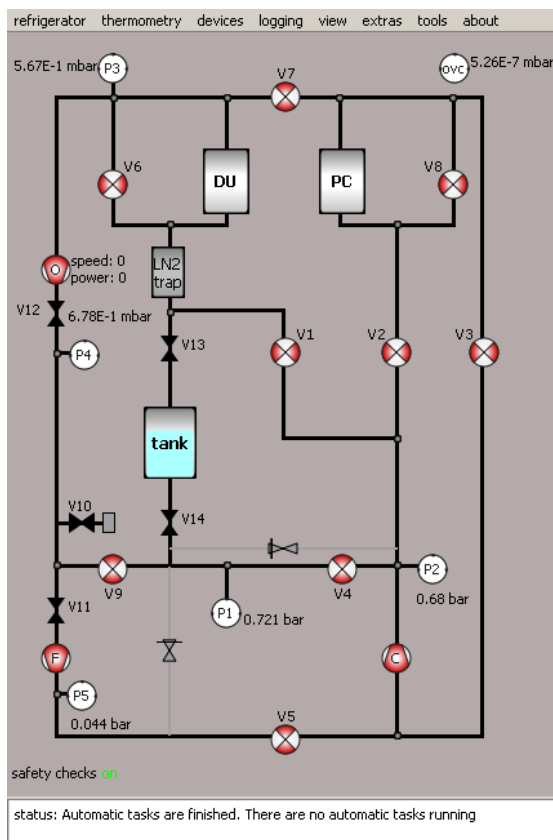


Figure 2: The Triton Dilution Control main panel. (To enable control: *View>Enable*.) The purple lines indicate the flow of the mixture. V[N] indicates valve number N, red indicates the valve is closed, green open. P[N] indicates pressure sensors. DU is the Dilution Unit. PC is the Pre-Cool Circuit.

### 4.1 Pre-Cool

Before beginning a pre-cool, ensure that the safety checks are enabled. This can be done by checking the at the bottom left of the fridge circuit control. If they are turned off, do **NOT** begin a cool down.

#### 4.1.1 Opening all the manual Valves

Begin by opening valves V11, V12 & V14. Ensure that V13 is **closed**.

*Note:* If the Turbo is running when you begin circulating the mixture, the automated pre-cool system will automatically leak a small amount of mixture into the system to slow down the turbo before circulating the rest of the mixture.

— DO NOT OPEN V10 —

#### 4.1.2 Logging

- In the hard copy of the cryostat logbook, record the starting pressure in the tank ( $P_{\text{tank}}$ ). This is read out on  $P_1$ .  $P_{\text{tank}}$  should be in the range of 745 mBar. It can be as low at 740 mBar on a cold day or 750 mBar on a very hot day. This is normal. If  $P_{\text{tank}}$  is significantly higher than this, see §7.4.
- Record temperature of PT1 Head.
- If there is not already an open log file on the cryostat computer, open a new one.
  - Go to *Logging*
  - Select *Start a New Log File*
  - Wait about 5 minutes
  - Go to *Logging*
  - Select *View Current Log File*

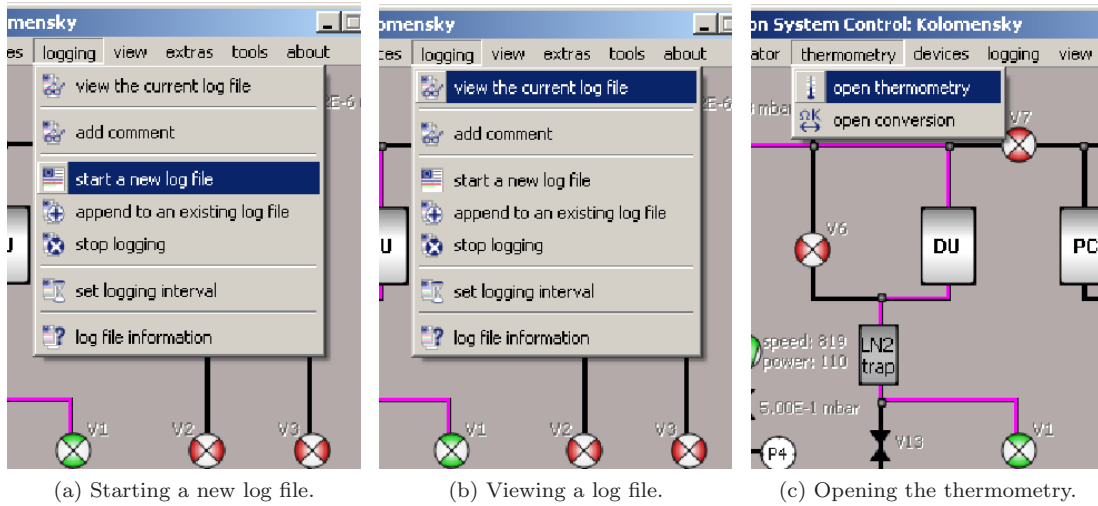


Figure 3: Preparing the system for a cool down.

#### 4.1.3 Thermometry

Open the thermometry.

- Go to *Thermometry*
- Select *Open Thermometry*

- In the Thermometry window, ensure that the following channels are enabled (have either a red or green square):
  - PT1 Head
  - PT1 Plate
  - PT2 Head
  - PT2 Plate
  - Still
  - 100mK Plate
  - MC Cernox
  - MC RuO2
  - MC Cal
- If any are disabled, you can enable them by double-clicking the white square.

#### 4.1.4 Beginning an automated Pre-Cool

At this point, the automation takes over.

- Go to the *Refrigerator* menu.
- Select *Begin the Pre Cooling*.
- You will see a pop up which says
 

*This will pressurize the pre-cooling circuit and start the compressor. It will also start the pulse tube cooler.*
- Press *Continue*

At this point you will hear lots of clicks and whirring. This is expected. From this point on, it takes roughly 16 hours to cool down to 3K, though it can be longer, depending on the mass mounted in the fridge.

Pre-cool is complete when PT2 reaches  $\sim 3\text{K}$ . The still heater and mixing chamber heater will be turned all the way up to prevent condensing in the pre-cool lines. This will result in the temperature of the still, 100mK plate and mixing chamber being roughly 10K. If you plan to head down to base ( $T_{\text{MC}} < 100\text{mK}$ ), you are ready to [empty the pre-cool circuit](#).

By turning down the heater power you can drop the temperature of the MC plate to  $\sim 4\text{K}$ . Though, this may cause the helium to condense in the pre-cool lines, and require boiling off the liquid to empty the pre-cool circuit.



#### 4.1.5 Empty the Pre-Cool Circuit

To empty the pre-cool circuit:

1. Ensure that manual valves V11, V12 and V14 are all open.
2. On the computer control panel, select *refrigerator*.
3. Select *empty the pre-cool circuit*.
4. A pop up will appear which reads:  
*This will start pumping on the cold part of the pre-cool circuit.*
5. Press *Continue*.

It will pump on the pre-cool circuit for  $\sim 2$  hours in order to boil off any helium which has condensed in the pre-cool lines. If this does not boil off, it will act as a heat load later, and may prevent a full cool down.

Once this is complete, you are ready to [begin condensing](#).

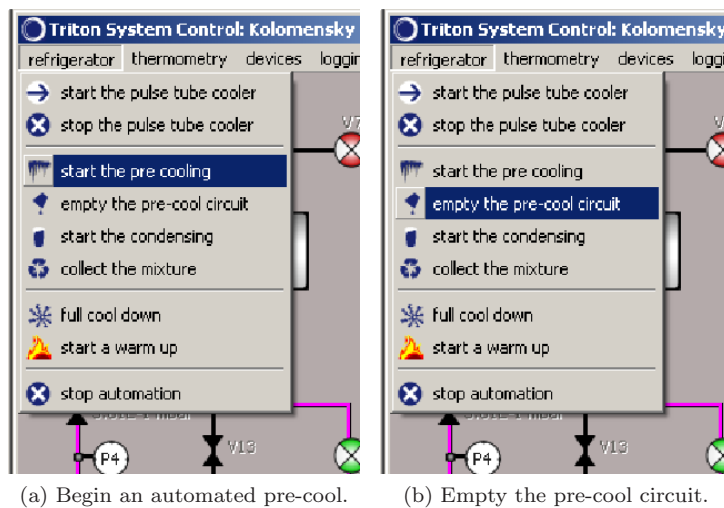


Figure 4: Running a Full Pre-Cool.

## 4.2 Begin Condensing

### 4.2.1 System Status

Before you begin condensing the state of the system should be as follows:

- Manual valves V11, V12 & V14 are **open**.
- Manual valves V13 & V10<sup>1</sup> are **closed**
- Cold trap connected and trap dewar filled.
- $T_{PT1} \lesssim 70\text{K}$ .
- $T_{PT2} \lesssim 4\text{K}$ .
- $T_{\text{Still}} \sim T_{100\text{mK}} \sim T_{\text{MC}} \sim 10\text{K}$ .
- [Pre-cool lines emptied \(see §4.1.5\)](#).

### 4.2.2 Disconnecting the Pump Cart

At this point, it is good practice to close the OVC valve, and turn off the pump cart. Why? Several reasons:

- If a leak occurs in the dilution unit and leaks the mixture into the OVC while the pump cart is connected, all of the mixture will be pumped into the room. If the OVC valve is closed, it will only be pumped into the OVC, and then recovered later (though this is no easy feat either).
- Below 70K, the surfaces inside the OVC begin to act as a more efficient vacuum than the pump cart. And so anything that leaks in may backflow to the cryostat.
- Electrical isolation.
- Vibration isolation.

If you have not already, [disconnect the leak checker, see §3.4.3](#). To disconnect the pump cart:

1. Close the OVC valve.
2. Turn off the pump cart turbo by pressing the power button.
3. Turn off the pump cart roughing pump, by flipping the power switch on the roughing pump.

**IMPORTANT NOTE:** The Turbo pump will spin down to 90% before it vents, (it will sound like an engine spinning down). **DO NOT:** Leave the room with the roughing pump running and the turbo spinning down. If the roughing pump is running while the pumpcart is venting, the roughing pump will continue to pump on atmosphere for 1 hour before the vent closes again.

4. Disconnect the vacuum hoses.

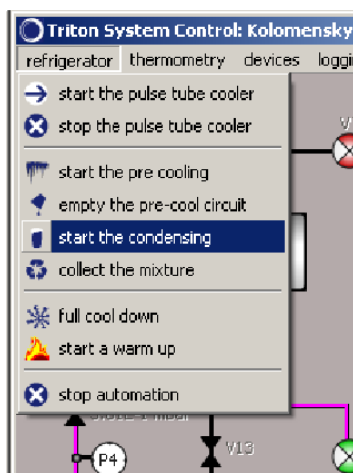
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<sup>1</sup>Remember: YOU SHOULD NEVER OPEN V10!

### 4.2.3 Condensing

1. Select *Refrigerator*.
2. Select *Start the Condensation Cycle*.
3. A window will pop, which says,  
*This will start the condensation cycle.*
4. Press *Yes*.

This will begin condensing the mixture into the dilution unit, and start the cool down to base. It takes roughly 3 to 4 hours to reach base temperature, depending on the cold mass.



(a) Begin Condensing.

Figure 5: Heading down to Base.

### 4.3 Full Cool Down

A full cool down can be achieved using the fully automated functionality of the fridge control program. However, care should be taken that the system is monitored during the beginning of mixture condensation. To run the full cool down:

1. Prepare the system, (see §3).
2. Ensure that V10<sup>2</sup> & V13 are **closed**.
3. Ensure that V11, V12 & V14 are **open**.
4. Ensure that the cold trap is connected and the cold trap dewar is full.
5. On the fridge control program, select *Refrigerator*.
6. Select *Full Cool Down*.
7. A pop up will state,  
*This will start a full cool down.*
8. Press *Yes*.

It will take roughly 20 hours to reach base temperature. If possible, close the OVC valve during the *Emptying the Pre-Cool Circuit* phase of the cool down. Then you can [disconnect the pump cart](#), (see 4.2.2).

—— DO NOT OPEN V10 —— DO NOT OPEN V10 ——

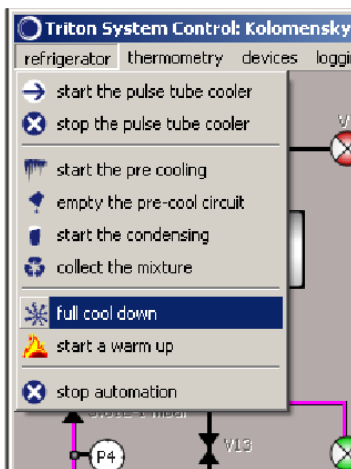


Figure 6: An automated full cool down.

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<sup>2</sup>Remember: YOU SHOULD NEVER OPEN V10!

## 5 Low Temperature Operation

### 5.1 Closed Loop Temperature Control

The software can hold the temperature of the MC plate stable using a closed PID loop. To utilize this

### 5.2 Reaching Base

The base temperature of this system is  $\sim 7\text{mK}$ , depending on the cold mass.

To reach base temperature turn off the heat load on the Mixing Chamber, and keep the heat load on the still around  $4\text{mW}$ . The heat load on the still is required to keep the cooling power high. The optimal heat load on the still to reach base temperature will depend on the cold mass. For an unloaded MC, it was found to be  $\sim 4\text{mW}$ , but you may need to tweak this value to find the true base.

The  $\text{RuO}_2$  thermometers will lose accuracy around  $50\text{ mK}$  and will bottom out completely at  $\sim 20\text{mK}$ . Below this, you will need an alternate measure of the temperature.

## 6 Warming Up

Warming up is fairly straight forward.

### 6.1 Collecting the Mixture and Starting a Warm Up

#### 6.1.1 Automatic

1. Go to *Refrigerator*.
2. Select *Start a Warm Up*.
3. You will see a pop-up which says  
*This will collect the mixture into the tank.*
4. Press *Yes*.
5. Wait for the mixture to be fully collected ( $\sim 2$  hours).
6. Close V14. (This will lock the mixture safely in the storage tank.)

This will collect the mixture into the tank, turn the heaters on full blast and turn off the pulse tube.

#### 6.1.2 Manual

To manually do a warm up:

1. Close V1 and open V4. This will redirect the mixture into the dumps.
2. Turn off the forepump and compressor.
3. Turn off the turbo, and wait for it to spin down. This can be done faster by leaking about 50mbar of mixture from the dumps through V9.
4. Wait for the turbo to spin down to  $\sim 200$ Hz.
5. Turn the forepump and compressor back on.
6. Turn the heaters on full blast, and turn the pulse tube cooler off.
7. Pulse V6 open and closed until you can leave V6 open without overwhelming the forepump.
8. Once P1 reads  $\sim 700$  mbar, open V7 and V8.
9. At this point, V1, V2, V3 & V9 should be closed. V4, V5, V6, V6 & V8 should be open. The compressor and forepump should be on. P1 should be  $\sim 730$  mbar.
10. Turn on the turbo for  $\sim 1-2$  hours to collect the last of the mixture.
11. Close V4. Close V14. Close all valves. Turn off all pumps.
12. Record P1 in the log book.
13. Wait for MCCernox to read  $\sim 300K$ .

## 6.2 Speeding Up The Warm Up

A full warm up will take  $\gtrsim 3$  days. But this can be made faster by circulating warm mixture or softening the vacuum.

### 6.2.1 Softening The Vacuum with $N_2$

- **How Long:**  $\sim 16$  Hours.
- **Thermal Shock:** Very High.

Softening the vacuum will add gas to the OVC to allow conduction from the room directly to the cold mass. Depending on what is in the cryostat this may or may not be possible, as the accelerated warm up will result in thermal gradients across the cold mass.

To soften the vacuum:

1. Attach one end of a vacuum line to the OVC valve and place the other end submerged in  $LN_2$ . Use a dewar that is open to atmosphere, this will ensure that the OVC doesn't overpressure. Wait about 5 minutes before proceeding. This will allow the moisture in the lines to condense into the  $LN_2$ .

**DO NOT VENT FROM A PRESSURIZED DEWAR.**

2. Crack the OVC valve open just enough to hear a faint hissing. You should see the OVC pressure jump to  $\sim 2$ mBar. After about 5 to 10 minutes the OVC pressure will climb to 1 bar. Once the hissing fully stops, open the OVC valve completely.

**Do not close the OVC valve until you have reached room temperature.**

3. Make sure that the  $LN_2$  does not run dry to ensure that no moisture gets into the OVC.

This faster process will allow conduction from the environment to warm the fridge up in about 16 hours. The fridge will collect a lot of condensation in this process, and will drip lots of water. Remove all electronics from the area.

### 6.2.2 Softening the Vacuum with He

- **How Long:**  $\sim 24$  hours.
- **Thermal Shock:** Moderate.

The previous section softened the vacuum to atmospheric pressure, keeping  $P_{\text{OVC}}$  constant. Alternatively, you can keep the mass of gas in the OVC constant, by softening with He. This will slow the warm up and result in less of a thermal shock to the cold mass.

To do this:

1. Wait until all parts of the fridge are warmer than 5K. To prevent condensation of He.
2. Adjust the pressure regulator of a He gas cylinder so that the absolute pressure is just slightly higher than 1 atm (the regulator will read  $\sim 1$  bar). And adjust the flow rate to be very low.
3. Purge the line with He, and then attach the line to the OVC valve.
4. Very slowly, crack the OVC valve open.
5. Leak He into the OVC until the pressure reads  $\sim 20$  mbar. Then close the OVC valve.
6. Disattach the He bottle.
7. As the cold mass warms, the gas will slowly expand. Monitor the OVC pressure to ensure that it does not rise above 500 mbar.

### 6.2.3 Circulating Warm Mixture

- **How Long:**  $\gtrsim 1$  Days
- **Thermal Shock:** Low to None.

This results in the least thermal shock to the cold mass, but is also slower than softening the vacuum.

To accomplish this:

1. Wait until the MC, 100mK and still plates are warmer than 5K.
2. Turn on the forepump and condenser.
3. Open V5 and V2.
4. Pulse V9 until P2 reads about 1 bar.
5. Close V9.
6. Turn off the forepump.
7. Open V3.
8. Until the system is warm, periodically check that P2 is less than 2 bar. If P2 exceeds this, then pulse V4 to leak mixture back to the dumps.
9. Once the system is warm. Recollect the mixture.



### 6.3 Once Warm

- If not already vented, vent the OVC with N<sub>2</sub> from an open to air LN<sub>2</sub> dewar. **DO NOT** vent from a pressurized dewar.
- Close all the manual valves (V11, V12, V13 & V14).
- Clean the 70K trap if required, ([see §7.2](#)).
- Stop logging, if desired.

## 7 Maintenance

### 7.1 Filling the Trap Dewar

- **HOW OFTEN:** Every 2 to 3 weeks (depending on use.)
- **SYSTEM STATUS:** Any.

The trap dewar needs to be filled roughly every two weeks. It is important that it not run dry while the refrigerator is at base temperature. Otherwise, gasses from the trap will be allowed to boil out and contaminate the system, clogging the dilution unit, and requiring the 4K trap to be cleaned.

You can check the nitrogen level in the trap dewar by raising the trap out of the dewar briefly and looking for a line in the condensation, there will be no condensation below this line initially, but will quickly form as it pulls moisture out of the air.

To refill the trap dewar, simply connect the LN<sub>2</sub> line from the liquid out phase of a storage dewar to the flange on top of the trap dewar.

Fill until liquid begins to overflow out of the vent. It will take roughly 20-30 minutes.

### 7.2 Cleaning the 70K Trap

- **HOW OFTEN:** As needed or after scrubbing the mixture.
- **SYSTEM STATUS:** The mixture closed in the tank.

1. Disconnect the self sealing hoses from the top of the 70K trap, by pushing the largest ring along the hose and pulling the body of the hose away. Do this as quickly as possible, to minimize the chance of contamination from the air.

——**Be careful not to touch the needle tip of the self sealing hoses.**——

2. Connect the hoses together to protect them from leaking.
3. Remove the cold trap from the cold trap dewar.
4. Next attach the quick connect-KF adapter to the end of a vacuum line, and the other end of that line to the red pump cart. **DO NO ATTACH THE COLD TRAP YET.**
5. Turn on the roughing pump and pump out the vacuum line.
6. Then attach the cold trap to the pump.
7. Allow several hours for the cold trap to warm up to room temperature.

8. Heat the trap using a heat gun, but do not exceed 100°C.
9. *While still under vacuum*, disconnect the trap from the vacuum.
10. Place the cold trap back in the LN<sub>2</sub>.
11. Wait two hours for the trap to cool and reconnect it to the mixture lines. **Avoid touching the needle tip of the self sealing hoses.** Make the connections as quickly as possible, to avoid leaking in air.

———**Be careful not to touch the needle tip of the self sealing hoses.**———

12. Scrub the mixture remaining in the lines, (see §7.4.1).

### 7.3 Cleaning the 4K Trap

- **HOW OFTEN:** As needed.
- **SYSTEM STATUS:** Cans fully removed.

Cleaning the 4K trap will involve dropping the full shields. Strictly speaking, the 4K trap sits at about 40K and is there to filter any boil off from the 77K trap. This trap should empty when the system warms, and shouldn't need to be cleaned. But if you are going to clean it, follow this procedure. Begin with all automatic valves closed.

1. **Dismount the lower half of the OVC, the 70K and the 4K shields.** If you have no reason to remove the still shield, you can leave it in place. To do this, simply reverse the process laid out in §3.2.5 and §3.2.4.
2. **Remove the top half of each shield.** This is done exactly like the lower halves, but must be done *after*, so that the shields have clearance. Make sure to set the top half of each shield **gently** on top of its lower half, and not on the floor.
3. **Make sure that the 77K trap is attached and cold.**
4. **Open** manual valves V11 and V12.
5. **Open** automatic valves V1 and V5. (V2, V3, V4, V6, V7, V8, and V9 should be **closed**).
6. **Turn on** the condenser and fore pump.
7. **Locate the 4K trap.** See photo.
8. **Using a heat gun**, carefully heat the 4K trap for a period of 15-20 minutes. The 4K trap should be just slightly too hot to touch. **USE CAUTION:** Close to the 4K trap are many wires which don't respond well to excessive heat.
9. Replace the top half of the shields. [CITATION]

10. Replace the bottom half of the shields. [See §3.2.](#)
11. Clean the 77K trap. [See §7.2.](#)

## 7.4 Scrubbing the Mixture

Scrubbing the mixture will circulate the mixture through the 70K cold trap, trapping much of the unwanted junk in the lines. If the amount of contamination in the lines is small, say from re-connecting the cold trap, then the cold trap will not have to be cleaned afterward. If, however, you are performing a full scrub, it is a good idea to clean the cold trap afterward.

### 7.4.1 Scrubbing the Mixture in the Lines

- **HOW OFTEN:** After cleaning the cold trap or as needed.
- **SYSTEM STATUS:** Fridge warm. Mixture locked in the tank. Cold trap installed and cold.

If you are confident that the contaminants are in the lines and not in the tank with the mixture, then you may only need to scrub the mixture remaining in the lines. This might occur if a small amount of air leaks into the mixture circuit when connecting or disconnecting the cold trap. If the mixture is closed in the tank, (as it should be whenever connecting or disconnecting the cold trap), then you can get away with a small scrub.

1. Make sure V13 and V14 are **closed**.
2. Open V11 and V12.
3. Open V1 and V5.
4. Turn on the compressor.
5. Turn on the fore pump.
6. Turn on the turbo pump.
7. Let sit for 30-40 minutes.
8. Turn off the turbo pump, fore pump, and compressor.
9. Close V1 and V5.

Keep in mind, when you've finished, the turbo will continue to spin for  $\sim 30$  minutes after you've turned it off. Filling the lines with mixture while the turbo is at full speed can damage the turbo.

### 7.4.2 A Full Scrub

Though this should not happen, you might find that the mixture in the tank has become contaminated. In this case, you will need to perform a Full Scrub of the mixture.

- **HOW OFTEN:** Only as needed.
- **SYSTEM STATUS:** Fridge warm. Cold trap installed and cold.

1. Open manual valves V11, V12, V13 & V14.
2. Open automatic valves V4 & V5.
3. Turn on the compressor.
4. Turn on the fore pump.
5. Turn on the turbo pump.
6. Let sit for 2-3 hours.
7. Close V13.
8. Let sit until P3 reads  $< 10^{-3}$ mBar. This will push the mixture back into the storage tank.
9. Close V4.
10. Turn off compressor, fore pump and turbo.
11. Close V14.
12. Close V5.

At this point, the mixture should be locked in the storage tank, V13 & V14 closed. All the pumps turned off. All the automatic valves closed.

13. Clean the 70K trap, ([see §7.2](#)).

Keep in mind, when you've finished, the turbo will continue to spin for  $\sim 30$  minutes after you've turned it off. Filling the lines with mixture while the turbo is at full speed can damage the turbo.

## 7.5 Replacing the Impedance

- **HOW OFTEN:** As needed.
- **SYSTEM STATUS:** Cans fully removed.

To clean the impedance, you first need to evacuate the mixture from the lines for a LONG time. Pump on *both* sides of the dilution unit by opening V6. Once you have collected all of the mixture into the dumps, make a note of the pressure in the dumps, then close all valves.

**You will need:**

- Two stainless steel gaskets.
- The impedance.
- Wrenches.

**Instructions:**

1. Collect the mixture for a long time (2 days is sufficient). Pump on the circuit with the turbo, forepump, compressor ON, and V4, V5, V6, V7, V8, V11, and V12 OPEN. The rest closed.
2. Close all automatic valves. Turn all pumps off.
3. Make a note of the pressure in the dumps.
4. Close V13, V14, and V11.
5. Get a pony bottle of ultrapure helium, and attach a regulator and adaptor to KF fittings.
6. Set the regulator, so that the maximum pressure is 3-4 PSI. Flow helium through the lines to clear the lines of other gasses.
7. Attach the bottle of pure He to the external valve attachment, V10.
8. Open V6.
9. Once the bottle is attached, slowly begin to leak helium into the system.
10. Watch the turbo pressure, P3. Make sure that the pressure doesn't go too far above 1 bar, as this can damage the system.
11. Keeping the pressure slightly above 1 atm, remove the old impedance by loosening the bolts on either side.
12. Put the new impedance in place with new stainless steel gaskets and tighten it down.
13. Close V10, and remove the helium bottle.
14. Attach the red pumping cart to V10. And vacuum out the lines using the roughing pump. Then turn the roughing pump off.

15. Open V10, and begin pumping on the system again. When the pressure gets low enough, turn on the turbo, and pump on the system for an hour.
16. Close V10. Turn off and remove the pump cart.

Now to leak check the new impedance, close and evacuate the OVC with the red pump cart. Attach the leak checker, and leak check the OVC. Once the OVC passes the leak check, perform a throughput test while watching the leak rate, (see §8.3). If you see a leak while performing the throughput test, it must be coming from the impedance, quickly collect the mixture, open the OVC and tighten the impedance. If the impedance passes the throughput test, perform the test again at 10K.

## 7.6 Servicing the KNF compressor

Generally this is done by the Oxford technician, during routine maintenance. Service requirements:

Service	Frequency
Replace Outer Diaphragm	Every 8,000 hours or annually.
Replace Inner Diaphragm	Every 16,000 hours.
System Status	Warm.

Procedure:

### Remove the KNF Compressor from the circuit:

1. Collect all mixture. Lock in dumps. Close V14.
2. Close all automatic valves. Turn off all pumps.
3. There remains a small amount of mixture in the KNF compressor. So we remove it.
  - (a) Close manual valve V12. Open manual valve V11.
  - (b) Turn on forepump.
  - (c) Open V4.
  - (d) Toggle V9, watch P5 to make sure the pressure never exceeds 1bar.
  - (e) Open V9, leave open.
  - (f) P1 and P2 should go to 0 bar. P5 should be about 700 mbar.
  - (g) Close manual valve V11.
  - (h) Turn off forepump.
4. All mixture should now be closed between V11 and V5.
5. The KNF is connected to the mixture circuit by two quick release valves. Undo these and be very careful of the tips. Connect them together while KNF is being serviced.
6. Remove the nuts holding the KNF to the rack.
7. Remove the KNF.



## 7.7 Verticalization and Noise Damping

The fridge is mounted on air bumpers intended to dampen vibrations and keep the fridge level. Occasionally these go flat and need to be refilled. When the dampers are empty, the fridge will tend to rise up too high rather than bottom out. This is because the still line is under vacuum and the weight of the fridge rests on the still turbo and PT cooler.

- **HOW OFTEN:** As needed.
- **SYSTEM STATUS:** Any.

You will need:

- Air pump/Bicycle pump with long hose.
- Bubble Level.

### **Procedure:**

The bumpers on the bottom of the fridge pull the fridge down, while the ones on the top pull the fridge up.

1. Pump air into each of the bottom four bumpers until the support plate is almost touching the stops on the bottom. (So the fridge should be nearly bottomed out.)
2. Next, add air to the top and bottom bumpers so that there is a reasonable amount of air in the top bumpers but the fridge is still floating above the bottom bumpers.
3. Finally, go around with a level and adjust the bumpers – adding or removing air – to get the fridge plate level.

When done, the support plate should be floating level a few mm above the bottom bumpers. This may take some time.

## 8 Tests

Occasionally, problems with the fridge will require a few tests to diagnose. Before contacting Oxford technicians, you should conduct these tests, since they will ask you for these numbers anyway.

First of all, you should prepare the system:

- Perform a full scrub of the mixture. (See §7.4.2).
- Clean the 77K trap. (See §7.2).
- Clean the 4K trap. (See §7.3).

### 8.1 Cooling Power Test

A cooling power test is a measure of the cooling power at 100mK. This is accomplished by finding the maximum power placed on the mixing chamber while maintaining the mixing chamber temperature at 100mK. The two parameters to adjust are the powers applied to the mixing chamber and to the still. The spec on the fridge is  $400\mu\text{W}$ , though upon delivery we only achieved  $350\mu\text{W}$ .

*Note:* For the most accurate measurement, the test should be done with nothing attached to the mixing chamber plate.

1. Once the system is at base temperature, begin stepping the mixing chamber heater up until the mixing chamber temperature *stabilizes* at 100mK. It may take several minutes to stabilize, and the system may over shoot before settling.
2. Once the system has stabilized, adjust the power on the still heater to lower the temperature on the mixing chamber. You will need to determine if the still power needs to go up or down. Continue adjusting the power until the mixing chamber temperature is at a minimum.
3. Repeat the above two steps, until you reach a setting where adjusting the still power either up or down only *raises* the mixing chamber temperature.

*Notes:*

- This process can be quite time consuming, so finding a good place to start is key. At the time of delivery the settings used were  $350\mu\text{W}$  on the mixing chamber and  $27\text{mW}$  on the still.
- A good step size is  $3\text{mW}$  on the still and  $25\mu\text{W}$  on the mixing chamber for gross tuning, and  $1\text{mW}$  on the still and  $10\mu\text{W}$  on the mixing chamber during fine tuning.
- The mixing chamber should be stable at close to 100mK in the final settings.
- **Never** allow the temperature of the still to reach 1K. This will cause the mixture to begin to boil and cause a catastrophic shut down of the system. The safety checks will protect the system from permanent damage.
- The mixing chamber temperature should not get above 300mK during this process. While the system is stabilizing, the temperature may overshoot, but never by more than a few tens of mK.
- Record the new numbers in the Cryostat log book. Keeping track of these values can give important insight into the development of problems within the system. See §10.3.

## 8.2 Base Temperature Test

A base temperature test requires mounting the Cobalt thermometer. It is most effectively accomplished with nothing else mounted on the mixing chamber plate.

### 8.2.1 Mounting the Cobalt

#### Notes:

- If desired, perform a measurement of the background rate *before* mounting the Cobalt. See the  $^{60}\text{Co}$  Thermometer manual.
- Keep in mind, the cobalt crystal is **radioactive**. The radioactivity is extremely low, but you should still minimize the time you spend handling it.
- More importantly, the cobalt is a SINGLE crystal. DO NOT drop, hit, fracture, or shatter it. Its expensive.

#### Procedure:

1. The cobalt is mounted on a copper puck with a threaded M3 hole on the bottom.
2. Clean the bottom of the copper puck, (the side that will come into contact with the MC plate) and spread an ultra thin layer of vacuum grease on the bottom. *During this process, take care not to damage the cobalt crystal.*
3. Attach the copper puck to the center of the mixing chamber plate by passing an M3 screw through a washer and then through the larger M4 hole. Attach the puck to the end of the screw.
4. Align the cobalt with a fixed object *outside* the cryostat, and away from any of the four legs of the cryostat. And measure the height of the crystal from the floor, the height should be about 40.5". This can be most easily done by mounting a laser to the fixed object and leaving it there until the system begins to cool.
5. Holding the alignment, tighten down the cobalt to get good thermal contact.

### 8.2.2 Mounting the PMTs

You will now need to mount two PMTs: one aligned along the long axis of the crystal and one perpendicular to the long axis. Use the height and alignment fixture that you used when mounting the cobalt to determine the position and direction of the cobalt crystal. (Having a fixed laser pointer makes this rather trivial.) Create some type of marking on the side of the can to specify the center of the PMT.

Attach the L shaped brackets to the OVC can using the blue strap, and align them before tightening down the strap. You do not need to tighten the strap too tight.

Set the PMTs on the L brackets and secure them. One method is to secure them to the L-bracket by wrapping the PMT in a paper towel and then strapping the whole thing down using duct tape.

Attach the power and signal BNC cables. Take note of which PMT is aligned to the long axis ( $0^\circ$ ) and perpendicular ( $90^\circ$ ) to it.

### 8.2.3 Measuring Base

A warm count rate can be taken at any temperature above 200mK.

To reach base, turn off all power to the MC heater. Leave about 4mW on the still heater.

Once the system has stabilized at base. Take a cold count rate (for each PMT). The ratio of the cold to warm count rates can be used to find the current temperature. The two PMTs should be in agreement.

To find the true base temperature, adjust the still heater until the lowest temperature is found. Record this value in the log book.

For a detailed guide on how to use the  $^{60}\text{Co}$  Thermometer LabView program, see the manual.

## 8.3 Throughput Test

Measuring the throughput of the system is a way of measuring the end to end impedance of the dilution unit. This will depend heavily on temperature, and so is often measured at both room temperature and  $\sim 10\text{K}$ .

To measure the throughput we will put 3 bar on one side of the dilution unit and vacuum on the other side and observe the pressure rise at P3.

The throughput at 10K is fairly high, which means that the mixture will flow through and cause P3 to increase significantly while you are putting 3 bar on P2. This is unavoidable, but try to minimize it by increasing P2 as quickly as is safely possible. Starting at step 4 below, the mixture will begin to flow across the DU.

**Important:** Make sure that the turbo is **TURNED OFF!**

**To begin:**

- Close all automatic valves.
- V13 **closed**.
- Turbo **stopped**.
- All pumps and compressors turned off.
- V11, V12 and V14 **open**.

**Procedure:**

1. First make sure that P3 is under vacuum. Less than 20 mBar is probably sufficient. If not, evacuate the line using the fore pump.
2. Once P3 is sufficiently vacuumed, **close V12**.
3. Open and close V4 to equalize the pressures.
4. Open V1 and V5.
5. Turn on the compressor and fore pump.
6. Toggle V9 until the pressure at P2 reads about 3bar. Make sure not to leave V9 open for too long and overwhelm the compressor. P5 should never go above 1 bar.
7. Once P2 reaches 3bar, close V9.

8. Hover the mouse over P3, and observe the change in pressure per minute. It may take a minute or so to stabilize. This number is the throughput. Record it in the logbook.
9. Recollect the mixture: close V1, open manual valve V12, then open V4 and V6. After most of the mixture is back in the tank, turn on the turbo to collect the last of it.

## 8.4 Single Shot Test

A single shot test will tell you how much  $^3\text{He}$  there is in the mix. It takes advantage of the fact that during the dilution cycle the  $^3\text{He}$  is circulating and the  $^4\text{He}$  is more or less stagnant.

Start this test while the system is  $\lesssim 50\text{mK}$ . Close V1 and open V4. This will divert the  $^3\text{He}$  from being pumped back into the MC and into the dumps. The fridge will continue to stay cold for the duration of the test. When the  $^3\text{He}$  runs out, the cooling power drops, and the MC temperature will spike and hold around  $\sim 300\text{mK}$ , the pressure in the dumps will rise much more slowly until the  $^4\text{He}$  runs out as well.

The value of P1 when the slope decreases suddenly and the temperature rises rapidly, gives the amount of  $^3\text{He}$  in the system.

To end this test, you should collect the rest of the mixture.

## 9 Troubleshooting

### 9.1 A Leak

The following things may indicate a leak:

- The roughing pump has been running for several hours and has not gotten the pressure below  $\sim 1$  mBar.
- The turbo pump has been running for several hours and has not gotten the pressure below .1 mBar.
- When you stop pumping on the system, after a long time of pumping, the pressure rises very quickly.
- While leak checking, you detect a leak of order a few times  $10^{-6}$  L·s $^{-1}$ ·mBar $^{-1}$  or higher.

Finding a leak can be extremely time consuming, especially when the system is enclosed in a small space and the helium eventually gets into the system regardless of where it was sprayed. It is a good idea to hunt for a leak in sections.

Typical locations for a leak are:

- The hoses attaching the leak checker to the pump cart or the pump cart to the OVC valve.
- The OVC valve.
- The pressure release cap on top of the OVC valve.
- The seal where the OVC can meets the 300K plate.
- The seal where the lower OVC can meets the upper OVC can.

Usually, a leak can be fixed by tightening a KF flange clamp, tightening flange bolts, or cleaning/replacing an O-ring. In the case of the large OVC O-ring, its best to take it out, inspect it for cracks/drying/damage, and clean it with ethanol.

More specialized leaks may require more technical fixes.

### 9.2 Trouble During Pre-Cool

Problem	Symptoms
<a href="#">Software Triggering</a>	MC stalls between 15 and 50K.
<a href="#">Poor Circulation</a>	PT2 cold, DU unit cools unreasonably slowly, P2 low.
Poorly Thermalized Cold Mass	MC gets to 10K, but cold mass cools unreasonably slowly.
<a href="#">Misc. Heatload</a>	A stage will not cool.
<a href="#">OVC Pressure Gauge</a>	OVC pressure bottoms out at $10^{-3}$ .

### 9.2.1 Software Triggering

The computer software maintains the pressure in the pre-cool lines to keep the pulse tube cooling power high. Occasionally, the pulse tube cooling power will drop to zero before the temperature gets low enough to trigger the software to lower the pressure in the pre-cool lines.

To solve this, pulse either V4 or V7. The temperature should fall very quickly, and the software should pick up automation again.

### 9.2.2 Poor Circulation

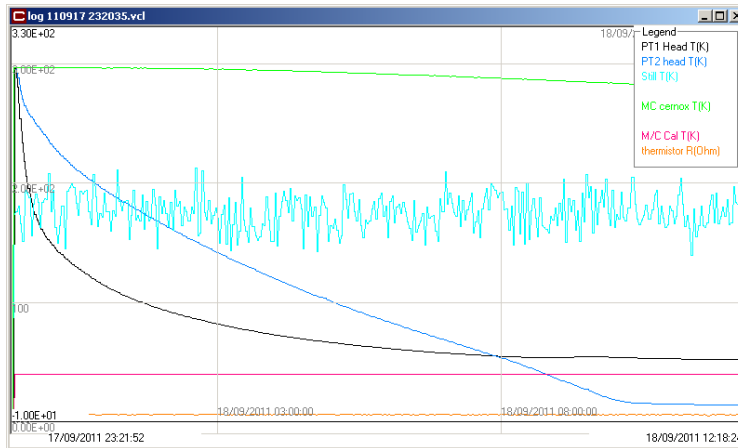


Figure 7: The temperature graphs when the MC chamber takes unreasonably long to cool. Notice that both PT1 and PT2 cool down normally, while the MC cools *very* slowly.

If the mixture in the pre-cool circuit does not circulate, heat is not carried from the MC plate to the pulse tube. The result is that PT1 and PT2 cool down as usual, but the MC plate cools unbearably slowly.

Possible reasons this might happen include:

- Compressor bypass open.
- Compressor circuit breaker open.
- Pre-cool lines clogged.

Both the compressor **bypass** being open and a flipped **circuit breaker** can be seen remotely by looking at the pressure gradient across the compressor while its running. No gradient means no compressor. If you are on site, both of these are easily fixed.

A **clog in the pre-cool lines** can be diagnosed by warming up, and collecting the mixture. If you see more than the expected pressure in the dumps, there might be a leak. Scrub the mixture (see §7.4.2).

### 9.2.3 Poorly Thermalized Cold Mass

If the MC temperature reaches 10K, but the sample you are trying to cool fails to reach base, this is indicative of a poor thermalization. To correct this, you will have to open the cans and fix the thermalization.

- Make sure all bolts are tight.
- Make sure the cold mass is thermalized with a conductive material – note that when materials go superconducting, they become poor thermal conductors.

### 9.2.4 Misc. Heatload

Other miscellaneous heat loads include loose parts, forgotten screws, wires bridging stages, etc.

### 9.2.5 OVC Pressure Bottoms Out at $10^{-3}$

During the pre-cool, the OVC pressure should drop to  $\lesssim 10^{-6}$ mbar as  $N_2$  condenses. Occasionally, a problem arises where the pressure will bottom out at  $\sim 10^{-3}$ mbar and sit there indefinitely.

**Symptoms:** OVC pressure bottoms out at  $\sim 10^{-3}$ , even while pumping with the pump cart or temperature less than 70K.

**Diagnose:** Pump directly on the OVC pressure gauge with the pump cart. Pressure should drop below  $10^{-6}$ mbar easily. If pressure bottoms out around  $10^{-3}$ mbar, pressure gauge needs cleaning.

**Solution:** Clean the OVC pressure gauge.

## 9.3 Trouble Near Base

Problem	Symptoms
Excess Orthohydrogen	Poor base temp, temperature change slow (high heat capacity).
Poorly thermalized cold mass	Poor base temp, slow temperature changes.
Heat leak	Poor base temp, high heat capacity, two stages at similar temperatures.
Clogged Impedance	Low cooling power, poor base temp, low throughput at 300K and 10K.
Unbalanced Mixture	Poor base temp, low cooling power, abnormal single shot test results.

### 9.3.1 Excess Orthohydrogen

A problem occurs when one uses copper that contains a lot of dissolved diatomic hydrogen ( $H_2$ ). Diatomic hydrogen has two states, ortho and para, corresponding to the spin-1 and spin-0 states. At room temperature the ratio is 3-1 corresponding to the state degeneracy. At zero temperature, the hydrogen will fall into the parahydrogen state, however, the conversion process is slow.

This poses a problem at base because the heat capacity of orthohydrogen is considerably higher than parahydrogen, and the latent heat release in the conversion can cause heating.

To solve this issue, warm the cold mass up to about 15K, where the conversion from ortho to parahydrogen is faster. Hold here for several hours (depending on the mass and the concentration of diatomic hydrogen). Then cool back to base.



### 9.3.2 Poor Thermalization

Generally, thermalization issues will be discovered during the pre-cool. Because the cool down time depends on  $C(T)/k(T)$  (which goes as  $\sim T$  at lower temperatures), the time to cool a poorly thermalized mass from 300K-10K will be much longer than from 10K-10mK.

However, if you do not monitor the temperature of the poorly thermalized mass, what you may find is that the system *seems* to get cold, but then fails to reach base. This may be because the poorly thermalized mass is still  $> 1\text{K}$  and is warming the rest of the system.

In either case, you will need to thermalize the cold mass better.

### 9.3.3 Heat Leak

Occasionally, problems can occur from heat leaks. Solutions depend on what causes the heat leak.

- Make sure there are no bridges between stages: loose parts, stray wires, etc.
- Make sure that electrical wires are well thermalized so as not to carry heat between non-adjacent stages.
- Make sure there are no line of sights for radiative heating from  $> 2\text{K}$  to the MC.

### 9.3.4 Clogged Impedance

Less common problem is when ice, dust or other particulates make their way to the impedance and get stuck. This manifests itself as a higher base temperature, lower cooling power, and lower throughput.

In the case of **ice**, this is indicative of contaminants in the line, and can be confirmed by warming up, collecting the mixture and comparing the pressure in the dumps to what's expected.

In the case of **dust and particulates** clogging the impedance, the best solution is to replace the impedance (see §7.5).

### 9.3.5 Unbalanced Mixture

Least likely, is that the mixture could be disbalanced. If the phase boundary between the  $^3\text{He}/^4\text{He}$  liquids is not inside of the mixing chamber, the cooling power will plummet. This will only occur if there is too much, too little of  $^3\text{He}$ ,  $^4\text{He}$ , or both.

Perform a single shot test and collect the mixture into the dumps and close V14. Record the results of this test. If the results of this test are markedly different than expected, it may be indicative of a change in the mixture. Get help.

## 10 Specifications

### 10.1 History

Date	Info
Dec 2011	Problem with cooling power. Throughput down. Base temperature up.
Feb 9, 2012	Replaced clogged impedance. Switched impedance from 7 to 9.
Feb 9, 2012	Serviced KNF compressor @ 4000.5 hours of runtime. Replaced diaphragm.
Oct 2012	Cernox Thermometer stopped working.
Nov 2012	Cernox Thermometer fixed.

## 10.2 Throughput

The throughput is measured at room temperature and 10K. It has units of mBar/min.

Date	300K	10K
Dec 2011	-	5.5
Feb 9, 2012	.6	-
Feb 17, 2012	1.5	24
Nov 14, 2012	2.5	>25

## 10.3 Cooling Power

Date	Still Power (mW)	Cooling Power ( $\mu$ W)	$T_{MC}$ (mK)
Mar 2011	27	355	105
Dec 2, 2011	20	73	110
Feb 20, 2011	30	400	100.6

## 10.4 Base Temperature

Base temperature is measured using the Cobalt 60 source.

Date	Still Power (mW)	$T_{MC}$ (mK)
Mar 2011	4	7
Dec 2011	3.5	12
Feb 2012	3.5	8.5
Nov 2012	3.0	7.75

## 10.5 Lessons Learned

This section is a collection of lessons learned while operating the Fridge.

- **Do not use steel screws.** Steel screws have a contraction coefficient much smaller than copper. Thus, as the structure cools, anything held together by steel screws becomes loose. Resulting in poor thermal conduction. Stainless Steel is the way to go.
- **Pausing in the Pre-Cool.** This is a very common problem. It is caused because the mixture in the pre-cool lines begins to condense. The pre-cool initially starts the circulation with 3 bar of mixture. As the temperature drops, it begins to condense, so the program automatically drops the pressure to keep it gaseous. Sometimes, the mixture begins to condense before the temperature trigger is reached and the pre-cool stalls. The fix is to release some mixture from the pre-cool circuit.
- **Clogged Impedance.** We once encountered the problem that our base temperature was much too high. Our cooling power was much too low. Throughput at 10K was low. We determined that this was a clogged impedance. We replaced the impedance and everything worked much better.
- **Dodgy Cernox.** The cernox thermometer occasionally stops working. This is caused by a dodgy cable connecting the 50 pin D on the top plate to the Oxford breakout box.