# The Gospel on pumping
## Or how to become good at making nothing!

Please also look below for specific links to procedures that are required for some detector cryostats.

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Special attention is required for these cryostats. Please read the relevant page.

1. Pumping the INT WFC
2. Pumping INGRID

**Basic reasoning**.

The only reason that a vacuum is required inside a cryostat is to provide an effective insulation to the cooling system against unwanted ingress of heat. A cooling system is needed for all science detectors currently in use. This cooling system is usually just a reservoir of liquid nitrogen that extracts heat from the detector and, while transferring the heat to the nitrogen, causes the nitrogen to evaporate, taking the heat out through the filling port with the gas.

Without an adequate vacuum, the nitrogen also extracts heat from the calorific interchange between gas molecules in the cryostat as they carry energy from the cryostat walls at ambient temperature to the liquid nitrogen reservoir at 77 Kelvin. This then augments the consumption of liquid nitrogen, up to the point where the autonomy of the cryostat becomes a matter of minutes instead of in the order of 10 hours.

When the vacuum detereates and the cryostat is not filled in time to prevent the reservoir wall from warming up, molecules of gas that were stuck on to, or frozen out, on the reservoir walls release and look for somewhere else to settle. This has two effects. Firstly it increases the cryostat pressure dramatically thus adding to the problem by reducing the thermal isolation further. Secondly, the cold gas thus released will tend to condense out onto anything that is cooler than the reservoir. Since the reservoir cools first and heats first in a thermal cycle, this usually leaves the detector itself as the coldest part inside the cryostat. Under these conditions condensing gas forms liquid (and possibly ice) on the detector which is going to make the detector people *really unhappy*.

So a good vacuum will enhance the autonomy of the cryostat and be quicker to refill because of the reduced liquid nitrogen consumption. In addition a good vacuum minimises the risk to a detector by reducing the likelihood of contamination by condensates.

**Requirements for a good vacuum**.

Cleanliness and Patience…. Most materials, including dirt and grease (the bane of vacuum systems) will 'outgas' at a certain rate. This is either a process of evaporation as the very low pressure inside a cryostat promotes molecules to a gas state because of thermal agitation (Brownian motion) or through the release of gas molecules trapped in the surface of materials. The most likely contaminant in vacuum systems used here is finger grease. On the pumping side, i.e. the vacuum pump and pipe work up to the cryostat valve, this is not so much of a problem as the volumetric capacity of the pump overcomes any gas produced this way. However, *any source* of gas in the vacuum system will slow pumping speed down and hence prolong the process. The working rule is “If in doubt, clean it”. Cleaning pipework and seals is done by wiping down with a lint free cloth or wiper soaked in Proponol. Air dry the part thoroughly before applying Fomblin grease if needed.

Since I mentioned grease it is appropriate to say that the special vacuum grease possesses properties that make it more stable in a vacuum, however, it will still tend to evaporate and so when grease is needed to create a gas tight seal, it must be used very sparingly. The grease itself will not block any holes, its only purpose is to lubricate the Viton or nitrile seals so that these will conform to surface irregularities more closely. Use only Fomblin YVAC-3 grease from ROCOL for this purpose.

Patience is a major asset when assembling the pipework and during the pumping. Gas flow in a vacuum system follows two main flow models. These are fluid flow while the pressure of the overall system is somewhat above $1^{10-3}$ millibar and molecular flow below this pressure. Under fluid flow conditions, adjacent molecules drag one another from a high pressure area towards a low pressure area of the system. This results in a high flow rate because of the coherent mutual interaction amplifies the energy available on each molecule to move it. In a molecular flow regime, molecules interact with each other only occasionally and the first order flow is derived by the differential pressure across the molecule itself. Thus the energy available to move each molecule is very small. If friction is encountered in a molecular flow of gas (e.g. against pipe walls), the friction is very large compared to the inertial and differential energies and the molecule will stop. In fact statistically the molecule moves only as a result of its own Brownian motion being biased by the pressure differential across the molecule. What I’m leading up to here is that to achieve good pumping speed (i.e. the time it takes to reach a certain acceptable pressure) is very dependent on how easy the molecules can find their way to the pump vanes and the pressure differential across the high to low side of the system. This means planning for and using short, large bore pipework with a minimum of bends and efficient pumps. As you can appreciate, as the pressure of the system reduces the pumping rate decreases as there is now less differential pressure to drive the molecular flow. This means that in planning to pump a cryostat, adequate time must be allowed for a slow drag (or suck) down. Patience can only be practised where there is time enough to allow for it.

**Vacuum pumps**.
There are two types of vacuum pump systems used by the observatory at present. These are classified as ‘dry’ and ‘oil’ types. One major concern at any time that a cryostat is under pump is the contamination that may occur in a back flow situation. This occurs when the golden rule is broken and may be caused by pump failure, loss of power to the pump, or incorrect procedures being used in the pump down. To minimise the risk of such contamination a dry pump it is preferable to use a dry type pump. In addition, these pumps have a greater pumping speed that equates to a shorter pump time. These dry pumps use a ‘plastic’ diaphragm as the second stage i.e. the stage that vents to atmosphere. This stage (of both types) is responsible for creating a pressure differential across a first stage turbine pump by transporting a volume of gas. This first stage is a turbine type that works as a mass transporter when operating in the molecular flow regime. The oil type pumps have a piston or displacer second stage that uses oil for lubrication. It is the danger that this oil is sucked back through the first stage and into the cryostat via the pipework that makes them dangerous. Never the less, if the procedures outlined below are adhered to then the golden rule should never be broken and the danger thus minimised.

Some possibly useful tips:
With the dry type pumps it is possible to display the first stage motor current draw. Toggling the cursor button on the control unit (left most button) accesses this. The starting current is quite high (7 amps or so) but as the transition is made to molecular flow, the current will drop to around 1 amp. From this point on the load that the motor is feeling indicates the amount of gas being transported. This is reflected in the current draw and so an indication is available to guide you in determining when a cryostat is sufficiently pumped.

If using an oil pump to pump a large volume of a cryostat from atmospheric pressure, then there is a gas balance valve located behind the displacer head that can be opened. This helps ‘rough pump’ down times in only a single displacer is used and avoids gas pressure build-up between the first and second displacers of the pump. Don’t forget to close it after molecular flow has started as it will influence the final pump pressure.

**Connecting the pipework**.

So, let’s get practical. By combining the above-mentioned criteria (cleanliness, planning and patience) the connection to the cryostat can be made with the aid of seals and flexible pipes. I’ve found the best way is to position the cryostat to the pump or the pump to the cryostat (which ever is easier) so as to allow the shortest and most direct route *and then* connect the two with a short pipe. An important requirement is that the cryostat is steady and safely supported. If possible handle the cryostat only by the housing. Never lever or apply pressure to the filling neck, the valve, the cable connectors, or any other ancillary equipment attached to the cryostat. Always protect the entrance window with either a plastic cover or a soft wipe and tape. Don’t let cables drag on the ground or leave them were they may be tripped over. Make sure that the static protection cap fitted to the end of the cable is used. Be careful to choose clamp fittings and seal supports that are the correct size. There are some clamps that look like the real thing (KF40’s) but are in fact for a different flange type and will not seal without over tightening them. They can be identified the way that they do not seem to fit quite right! The normal black seals (nitrile) or Viton (green) seals can be used. The seal must be supported by a metal ring and be roughly circular or oval in cross section. Over tightening seals will not improve the pipework joint quality and leads to seals with flat sides and low conformance that will leak when next used. Again the working rule is “If unsure about the quality of a part, replace it”. The correct tightness on clamps is that required to just support the seal in place and remove any off axial loads from them: As a rule of thumb, just tight then another half turn. Before making a joint, inspect the flange flats and seal for dirt, cuts, or hairs, etc. Make it gleam with cleanliness. Just before tightening the clamp it is good practice to lightly twist the to flats with the seal between against each other to bed in the seal.

Once the pipework is in place, stand back and think. Plan through the next few stages of the procedure. The pump down will take a long time and you need to plan to not interfere with the system. Will the pumping system interfere with access to something that will be required in the next two days? Is the pump power supply a UPS supply? Can you access the nitrogen fill port to pre-cool with the pipework attached?

The Golden Rule!
This is it … The single most important rule for any good vacuum mechanic…
If you master this you’ll be a happy pumper … Ready?

Gas flows from high pressure areas to low pressure areas right? **The rule is: Always make sure that the *pressure outside the cryostat is lower, much lower, than the pressure inside* the cryostat. This means that gas will always flow from the cryostat to the pump and never from the pump to the cryostat**.

**Pumping a cryostat that has been opened to atmospheric pressure**.

1. Connect the required pipework as described above.
2. Open the vacuum pump valve.
3. Open the cryostat vacuum valve by unscrewing the knob until the thread jumps at the end of travel and then screw the knob in by one turn.
4. Connect the pump to the power, the trap heater supply to the cryostat connector, the vacuum gauge meter to the cryostat gauge head if fitted.
5. Power up the vacuum pump and watch the pump pressure. This should reduce fairly quickly down to around 5 $^{10-2}$ millibar or lower. At this pressure the pump should be at or close to full speed. The pressure drop will then slow down but keep dropping. If a cryostat gauge is fitted it will show a rather higher pressure than the pump (the golden rule!).

6. Monitor the pump pressure until it drops into the $^{10-4}$ millibar regime. At this point you can be sure that there are no significant leaks and the pump down will proceed normally. If a cryostat gauge is fitted it is normal to see a one magnitude or greater pressure difference between the pump and cryostat.
7. Before leaving the system, start a trap heater cycle by cycling the power to the trap power supply. This begins a twenty-minute heat cycle of the cold gas trap that will rejuvenate the traps' capacity to absorb gas when cold.

**Pumping a cryostat that has unknown vacuum quality**.

1. Connect the required pipework as described above.
2. Open the vacuum pump valve.
3. Connect the pump to the power, the trap heater supply to the cryostat connector, the vacuum gauge meter to the cryostat gauge head if fitted.
4. Power up the vacuum pump and watch the pump pressure. This should reduce fairly quickly to 1 $^{10-4}$ millibar or better.
5. At this time and with great care, *very slowly* open the cryostat vacuum valve while monitoring the pump pressure. If the pump pressure suddenly drops the close the cryostat valve and wait until the pump pressure drops further. Normally the pump pressure will rise as the gas begins to flow from the cryostat, then recover and begin to fall again as the valve reaches the open position.
6. Monitor the pump pressure until it drops into the $^{10-4}$ millibar regime again. At this point you can be sure that the pump down will proceed normally. If a cryostat gauge is fitted it is normal to see a one magnitude or greater pressure difference between the pump and cryostat.
7. Before leaving the system, start a trap heater cycle by cycling the power to the trap power supply. This begins a twenty-minute heat cycle of the cold gas trap that will rejuvenate the traps' capacity to absorb gas when cold.

**Pumping a cryostat that is cold** (only in emergencies!)

Pumping a cold cryostat will not achieve very much and is to be avoided if at all possible. This practice will save at most three or four hours and cannot be considered anything except a temporary cure for low autonomy. If the reason for considering this action is an unforeseen thermal cycle during the night then the detector should be visually checked for contamination products. The normal procedure is to warm up the entire cryostat to ambient temperature by forcing dry air or nitrogen into the nitrogen reservoir and then using the procedure for 'Pumping a cryostat that has unknown vacuum quality'.

Use only a dry bellows vacuum pump. Never use any pump that uses an oil-based roughing pump.

If possible contact a detector group engineer to carry out this procedure.
If this is not possible then use the procedure as outlined for 'Pumping a cryostat that has unknown vacuum quality'. However, in step 4 wait for the pump pressure to drop to at least 3 10-6 millibar. Keep the nitrogen reservoir cold and do not use the trap heater. Advise the detector group about the problem.

**Is it leaking?**

The object of the game is to get down to an acceptable pressure in the quickest time possible. If an acceptable pressure (see below) is not achievable then the pumping system must be at fault somewhere. There are three contributions that generally determine pumping rate i.e. how fast a system pumps down. These are:

a) Leaks
b) Outgassing
c) Pump condition

When a leak is present of such magnitude as to make an acceptable pressure unobtainable, it will most always be indicated by a high and stable pump pressure of above 1 $^{10-3}$ millibar. If pumping is started then this pressure should be obtained within the first ½ hour of pumping. If it isn't then a leak should be suspected. While the system is pumping, close the vacuum valve of the cryostat. If the pressure plummets then the leak is in the cryostat itself. If there is very little change however, next close the valve on the pump. If the pressure now plummets then

the leak is in the pipework. If the pressure still remains high then the leak is obviously after the pump valve or your using a duff pump.
Having isolated the part of the system with the leak, open that part of the system to the pump again and try tweaking the pressure on any clamps that
Section. If this doesn't cause the system to respond then make sure the cryostat and pump valves are closed, power off the pump, wait for the system to come back up to ambient pressure, and disassemble the offending section while inspecting for dirt or hairs in the seals.
In summary, if the system reaches a pressure of $1^{10-3}$ millibar, you don't have a leak.

Outgassing will slow down the pumping speed but will generally never prevent an acceptable pressure being reached. Outgassing will be significant in systems that have been exposed to ambient pressure and be reflected in the longer time it will take to reach $1^{10-3}$ millibar after pumping is started. The rule of thumb is "If the pressure is still dropping, be patient and leave it alone"

If the pump is overdue for a service or has been damaged then it may appear that that there is a leak present by showing the same symptoms. You should have eliminated the possibility of a leak by the first procedure and so the only alternative is to look for another pump. Please inform the a detector engineer if you find a duff pump so as to prevent someone else from making the same conclusion next time the pump is used.

### How long to pump?

You need to pump until the cryostat reaches an adequate internal pressure. This corresponds to a maximum number of molecules left within the cryostat once the pump is removed. The limit on the number of molecules is in turn a factor of the cold surface area of the inside of the cryostat. This is because, as the cryostat is cooled down, space is needed so those individual molecules can stick to and be trapped by the cold surface. In this way the internal pressure will drop when the cryostat is cooled. This is called cryo-pumping and begins when the nitrogen reservoir reached liquid nitrogen temperature (77 Kelvin).
In addition, and by similar means, there is a box of material (usually carbon) attached to the cold reservoir wall which when cold will 'absorb' gas molecules into the surface pores and trap them there until heated again. So minimum acceptable pressure corresponds to maximum number of gas molecules, which corresponds to surface area. It is obvious that it is highly desirable to go lower that the minimum acceptable pressure as this leaves fewer molecules inside the cryostat that might glue themselves onto the detector. This occurs because the detector is the last to cool down when cooling a cryostat (and so is not a target for molecules to stick onto) but the last to warm up (where molecules will be released from the reservoir and then stick on the surface of the detector.  Okay, Okay, so what is the minimum acceptable pressure? For all CCD cryostats, except the INT WFC, a pump pressure of at least $5^{10-5}$ millibar must be obtained before cooling is commenced. For the INT WFC and INGRID (which have larger cold surface areas) a minimum pump pressure of $1^{10-4}$ millibar must be obtained before cooling is attempted. These values assume that there is, at these pressures, slightly less than 1 magnitude of pressure difference (assuming good pipework) between the pump and cryostat. If a cryostat gauge is fitted then this should reflect this assumption. For cryostats that have not been vented to atmosphere, the time to pump down to a good vacuum is usually around twenty-four hours. If a cryostat has been vented then this time will be increased to about three days.

### Shutting down the pumping procedure

Once the acceptable pressure has been achieved and if time permits then the trap heater should be cycled once again. This is approximately a twenty-minute cycle but give the cryostat another hour if possible to reach equilibrium once more. There are two versions of shut down procedure that can be used. The first is more convenient and simple but results in a higher final cryostat pressure. This is only important if the cryostat is expected to maintain good vacuum for a long period of time (i.e. >three months) where the second version should be used if possible.

Simple procedure.

1. Shut the cryostat vacuum valve.

2. Note that the pump pressure reduces dramatically. This assures you that the pump still has more capacity to pump and that it is still serviceable.
3. Close the vacuum pump valve and switch off the pump power.
4. Disconnect the cryostat from the pump pipework.
5. Using the same seal, replace the blanking flange onto the cryostat vacuum port.
6. Remove any air lines, trap heater cables, or gauge head cables from the cryostat.
7. Let the pump spin down and the then switch off the pump.
8. Make sure that the correct fill tube is fitted for the instrument.
9. Take the cryostat to a convenient liquid nitrogen dewar and fill to capacity.
10. Refill the cryostat after 1 ½ to 2 hours of the initial fill.
11. Inspect and clean if necessary the cryostat window.

Favoured shutdown procedure.

1. Bring a liquid nitrogen dewar to the pump area.
2. Make sure the correct fill tube is fitted for the instrument in use.
3. Fill the cryostat to the limit with liquid nitrogen. While filling is progressing, monitor the pump, or better yet, the cryostat pressure gauge. At some certain point the pressure will begin to drop rapidly. This indicates the onset of cryopumping. At this point close the cryostat vacuum valve.
4. Note that the pump pressure continues to reduce. This assures you that the pump still has more capacity to pump and that it is still serviceable.
5. Close the pump vacuum valve. Switch off the pump.
6. Disconnect the cryostat from the pump pipework.
7. Using the same seal, replace the blanking flange onto the cryostat vacuum port.
8. Remove any air lines, trap heater cables, or gauge head cables from the cryostat
9. Let the pump spin down and the then switch off the pump.
10. Refill the cryostat after 1 ½ to 2 hours of the initial fill.
11. Inspect and clean if necessary the cryostat window.

**Last (and important) acts.**

You probably have more important things to do but these few last rites make the difference between a nominal pump mechanic and a master of empty space.

1. Do make sure that the vacuum blanking flange is fitted to the cryostat vacuum port. It prevents damage to the sealing surface and acts as a safety precaution against someone opening the vacuum valve.
2. Disassemble the pipework and cap all flanges with plastic protection caps.
3. Put the top back on the vacuum grease tube!
4. Put the vacuum pumps fittings back where you found them. It makes it so much easier to do work when you know where all the pieces are.
5. Please update the CCD status white board in the operations room to reflect your work.

**Vacuum resources i.e. where's it all at?**

Pumps.

1. There are currently four vacuum pumps on the mountain and one at sea level.
2. The dry pumps are at the sea level office and in the detector laboratory in the WHT.
3. There are oil pumps in the INT pump room (adjacent to the observing floor), in the JKT cleaning room (ground floor old photo lab), and on the WHT nasmyth floor.

Vacuum fittings, pipes, and grease.

There is a nominal amount of equipment kept at each pump. In addition there is a 'fishing tackle' box in the pump room of the INT and a 'floppy disk' type box in the WHT detector lab pump room. A supply of spares is kept on the second shelf of the left blue cabinet in the WHT detector lab pump room.

The 'nominated person' responsible for vacuum equipment is Roberto Martinez (ext. 627 / intercom 14). The second in charge is me, Peter Moore ( ext. 556 / intercom 75). Please report any equipment failures or shortages to us.

Peter Moore 10/07/00