CHASE RESEARCH CRYOGENICS LTD.

WORLD LEADERS IN SUB-KELVIN CRYOGENICS

TWO-STAGE SUB-KELVIN ^{4}He CRYOCOOLER

TYPE GL4 (Helium 4)

GENERIC INSTALLATION AND OPERATING INSTRUCTIONS

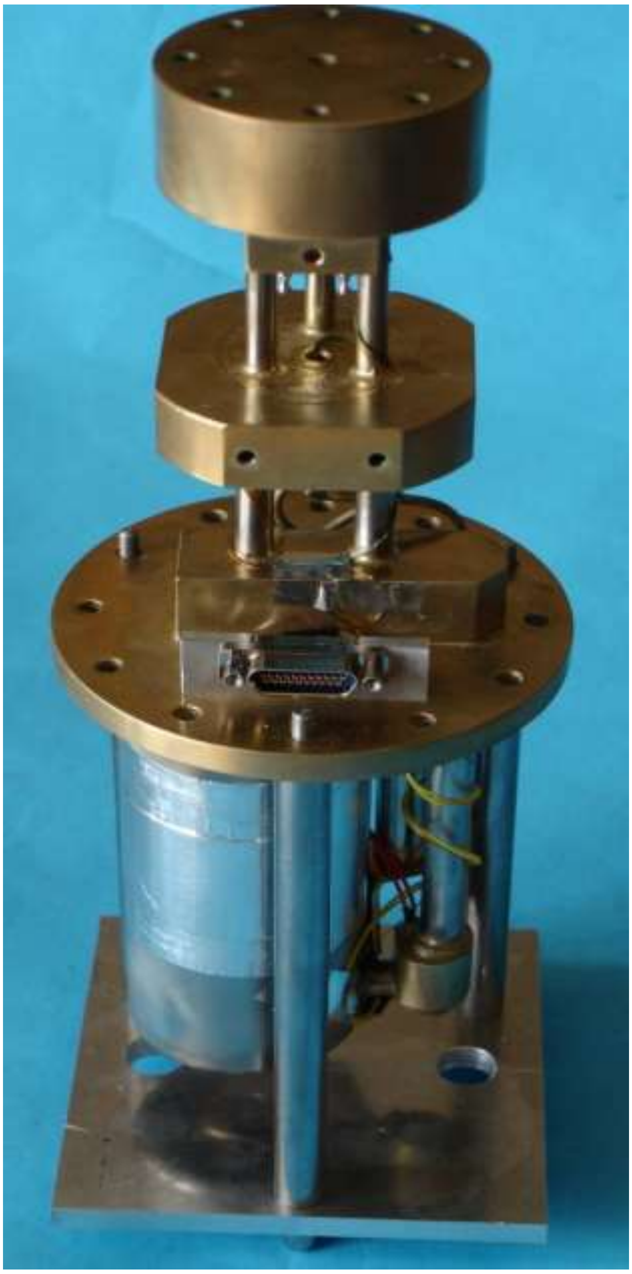

Photo shows a typical CRC GL4 cryocooler

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Contents

THIS GENERIC OPERATING MANUAL describes how to install and operate a CRC GL4 cryocooler. It is accompanied by an Excel file that contains the validation test data and the calibration files that are **specific** to the cryocooler unit that you have purchased.

You are advised to make a note below of the location of the Excel file specific to your cryocooler unit.

This revision of the manual was created in April 2019.

1. GENERAL HANDLING

WARNING!

CRC CRYOCOOLERS CONTAIN HELIUM GAS AT HIGH PRESSURE.

Do not crush, twist or bend the unit. Avoid applying mechanical stresses. Do not heat the unit above room temperature. Keep in a sealed cryostat, or in the shipping box and brace in which it came.

Do not hold or lift the unit by the cold heads.

Do not tamper with the copper capillary fill tubes.

Avoid the use of acid fluxes when soldering near the cryocooler. Chloride based fluxes will corrode stainless steel and could damage your cryocooler.

After unpacking the cryocooler according to the instructions supplied, the cryocooler should be immediately transferred into the host cryostat. The shipping brace doubles as a stand for the cryocooler, though when used as a stand, the screws through the aluminium plate into the cold heads should NOT be in place. When picking the cryocooler up, it should be held by the main plate.

2. SAFETY OF CHASE RESEARCH CRYOGENICS PRODUCTS

2.1. Pressure Equipment Directive 2014/68/EU.

This CRC cryocooler unit is manufactured in accordance with Sound Engineering Practice. The volume and gas pressure within the cryocooler are such that the equipment falls below the lower classification limit in Annex II of the Pressure Equipment Directive. Hence the requirements for Conformity Assessment do not apply and no Declaration of Conformity can be made, or CE marking applied.

The cryocooler is covered by Article 4 Paragraph 3 of the Pressure Equipment Directive, which states:
"Pressure equipment and assemblies below or equal to the limits set out in points (a), (b) and (c) of paragraph 1 and in paragraph 2 respectively shall be designed and manufactured in accordance with the sound engineering practice of a Member State in order to ensure safe use. Pressure equipment and assemblies shall be accompanied by adequate instructions for use. Without prejudice to other applicable Union harmonisation legislation providing for its affixing, such equipment or assemblies shall not bear the CE marking referred to in Article 18."

2.2. Pressure Equipment (Safety) Regulations 2016.

The pressurized modules making up this cryocooler unit have internal volumes much lower than 1 litre, and pressure x volume much lower than 200 bar-litres, hence the cryocooler is exempt from the Essential Safety Requirements set out in Schedule 2 of the PESR Regulations 2016. This means that the cryocooler does not require a written scheme of examination. The cryocooler complies in all respects with the requirements of Regulation 8 of PESR 2016. The *owner* has duties under the PESR regulations to ensure that a) the safe operating limits are not exceeded; b) the unit is operated in accordance with these instructions; c) the unit is returned to Chase Research Cryogenics Ltd in the event that any maintenance is required. The cryocooler contains no user-serviceable parts.

2.3. Safe Operation

The safe operating temperature range of this cryocooler is 0 to 320 K.

2.4. Risk Assessment

CRC cryocoolers contain Helium gas under pressure. The stored energy of the system is less than 50 bar litres. All system components are integrity tested during manufacture; the slightest leak will make the cryocooler lose its stored gas and cease to function. A unit that has leaked presents no risks whatever to the user; the following risk assessment applies therefore only to functional units.

Hazards and consequences
Accidental damage to the cryocooler unit could result in the sudden release of pressurised gases, causing mechanical failure of the unit and potential injury (or damage to surrounding instruments) from ejected debris.

Possible events leading to failure are: overheating of the unit, for example in a fire; dropping or crushing of the unit; twisting or bending of the gas tubes. Mechanical damage to the unit is most likely to occur during assembly of the instrument of which the cryocooler forms part.

Risks without controls in place
It is extremely unlikely that the above events will lead to danger. Chase Research Cryogenics Ltd has produced several hundred cryocooler units of various designs, which are in use for a range of applications worldwide. To date there has never been a sudden failure of a cryocooler unit – indicating that with normal use (including inevitable handling mishaps) the units have an excellent safety record. User experience to date shows that accidental mechanical damage to cryocooler units is likely to result in slow leaks, not sudden failures.

Controls in place
The controls that are in place to eliminate (as far as reasonably practicable) the risks arising from mechanical damage to a cryocooler unit are:

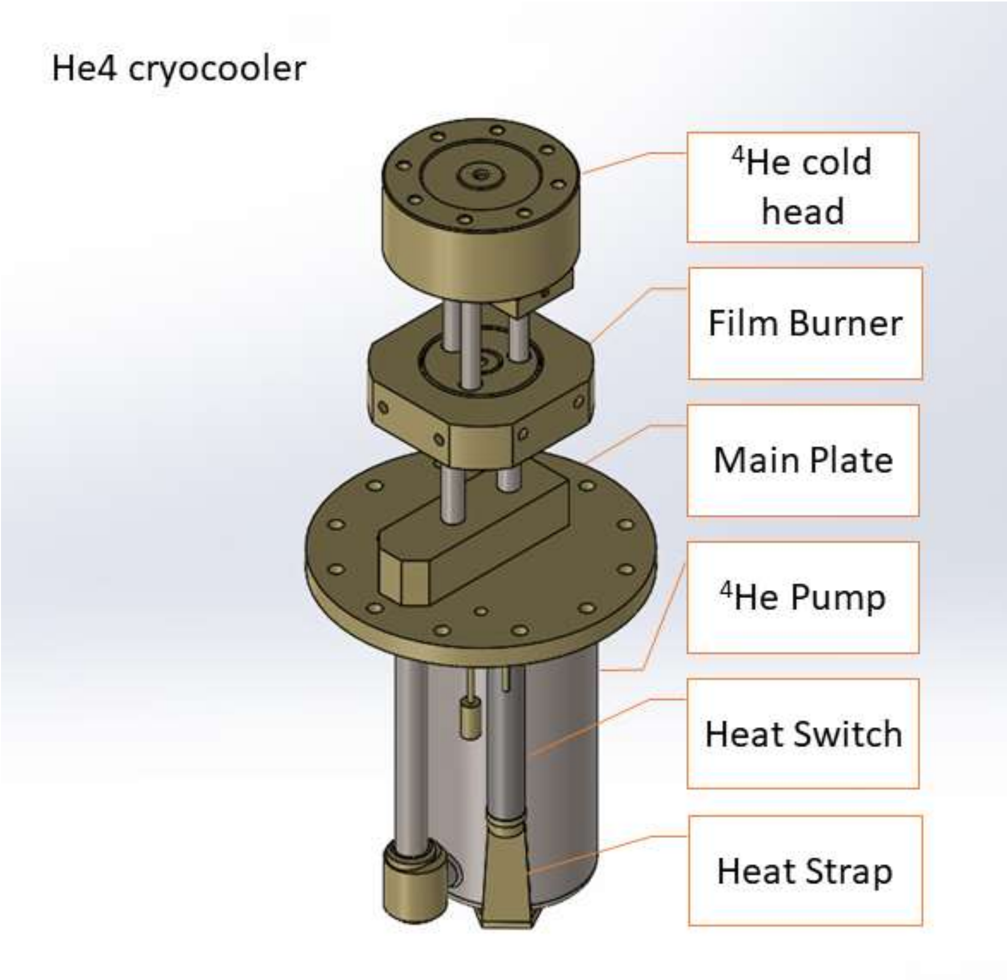
- This written instruction manual, containing warnings about the potential risks arising from damage to the unit and alerting the user to more risky operations;
- Instructions that the unit should not be used if it has been subjected to overheating, dropping, crushing, bending or twisting;
- A warning label on the transit box that the instructions should be read prior to handling the unit.

The applications for which cryocooler units are intended make it impossible to place warning labels on the unit itself. However if the cryocooler is incorporated into another instrument, that instrument should carry a warning label to alert the user that the cryocooler contains no user-serviceable parts and should not be disassembled.

Risks with controls in place
Providing users read and follow this instruction manual the risks are negligible.

3. A BRIEF DESCRIPTION OF THE CRYOCOOLER UNIT

The cryocooler shown in the figure below is a standard model. In use, the cryocooler is inverted, i.e. the head will be at the bottom. The main plate needs to be thermally sunk to the cold head of a precooler 4K or below, see section 4.1 for more information. The ^{4}He cold head and the film burner can both be used to extract heat from the experiment, see section 5 for more information. The pump and heat switch can reach up to 50K during operation, these need to be radiation shielded from the head, for more information see section 5.1. All electrical connections are mounted on the main plate on an MDM connector. Pin-outs are listed at the end of this manual.



The following short names for the various parts of the cryocooler are used throughout this user manual:

Short name used in this manual	Refers to the cryocooler part
4-head	^{4}He cold head
FB	Film burner
4-Pump	^{4}He pump
4-Switch	Heat Switch for the ^{4}He pump

4. INSTALLATION

4.1. Mechanical

Before installing the unit in your cryostat, be sure to remove all the pieces of packing material from around the pump, as mentioned in the unpacking instructions.
There should be no need to touch the heat switch or heat strap during installation or normal operation of the cryocooler. The heat switch can be easily damaged, and if bent or twisted is likely to fail.

This cryocooler is designed to work equally well in either 'wet' cryostat using liquid ^{4}He to cool the mainplate, or in a 'dry' cryostat with the mainplate thermally sunk to a mechanical pre-cooler at 4K, such as a GM or pulse tube cryocooler. The 4K stage of the pre-cooler should be made from gold plated copper to ensure excellent thermal contact between the cryocooler and the pre-cooler. To attach the cryocooler to the 4K stage of the pre-cooler there are twelve 4.1mm diameter (M4 clearance) holes symmetrically distributed upon a 76 mm pitch circle on the main plate. (Note: UNC #6 clearance holes are substituted if requested by the customer). A .step CAD file of your cooler can be provided on request.

Because the cooling down of the heads depends upon gas convection, and on liquid helium collecting in the heads fed by gravity, the cryocooler *must* be kept close to vertical with the heads downwards.

Ensure spring washers are under every bolt head, these will take out differential thermal contraction that might otherwise cause loosening of the bolts, and thus compromise thermal contact.

4.2. Electrical

All electrical connections are on a 21-pin MDM-SSP connector mounted onto the main plate. Pin-outs are listed at the end of this instruction manual.

The table below summarises the temperature sensors installed on the unit.

ITEM	Calibration	Options
4-head RuO_2	Generic lakeshore cryotronics.	Individually calibrated sensors available on request
Film burner diode	Specific calibration supplied in individual data file	No diode supplied
Main plate diode	Generic – supplied by CRC Ltd	No diode supplied
Pump diode	Generic – supplied by CRC Ltd	
Switch diode	Generic – supplied by CRC Ltd	

Voltage / current requirements for driving the heater and thermometers are summarised in the table below

ITEM	NUMBER	IMPEDANCE/ JUNCTION VOLTAGE	VOLTAGE/ CURRENT
4-pump heater	1 off	300Ω approx.	20 to 25 V
Heat switch heater	1 off	10kΩ	4 to 5 V
Diode thermometers	3 or 4 off	0.5 to 1.8V	10μA DC
4-head RuO_2 thermometer	1 off	1kΩ to 3kΩ	1μA max.

Generic (i.e. standard calibration) RuO_2 sensors from Lakeshore Cryotronics are the default option on the head of all CRC cryocoolers. Individually calibrated 'CERNOX' or RuO_2 sensors are only fitted (at additional cost) at the customer's request. The thermometer on the 4-hea is operated as a 4-wire device and should ideally be driven by an AC current no greater than 1μA.

Calibration data for all thermometer sensors are in the Excel data file that accompanies each unit. Generic diode calibration curves for the pump diode and heat switch diode, and calibration curve specific to the film burner diode are supplied as standard. The diode thermometers require excitation with currents of 10μA DC.

The heat switch heater typically requires about 4 to 5 V to keep the switch in the 'ON' state with the absorber pod at greater than ~20K, and it will cool to the off state (T < 10 K) in ten to fifteen minutes.

The pump heater impedance is typically 200Ω or 300Ω. During the cooling cycle it is necessary to warm the 4-pump to 50K to 60K. A heater current of up to 100 to 130mA will heat the 4-pump rapidly; lower heater currents will result in slower heating. Stabilisation of the 4-pump temperature at around 50K will typically require a heater current of around 12 to 15mA. Try to ensure that the lead-in wiring to the heater is not unduly dissipative.

5. ATTACHING YOUR EXPERIMENT TO THE CRYOCOOLER.

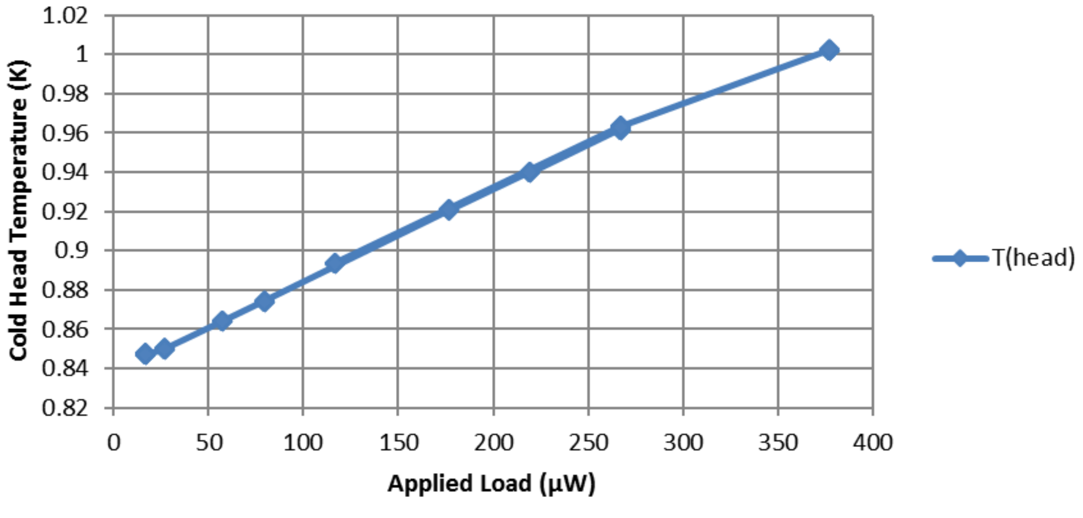
This model of cryocooler provides two points at which heat may be extracted from a user's experiment mounted on a separate cold table. They are the 4-head and the film burner.

The top surface of the 4-head has 8 holes tapped M3 on a 40mm pitch circle and a further axial hole tapped M4. The film burner has 8 M3 tapped holes on the main body, in pairs 20mm apart on each side. (Note: UNC #4 threads are substituted if requested by the customer). A step file can be provided on request.

While fixing experimental equipment to the cold head, extreme care should be taken not to twist or bend the gas pipes. Always support the cold head against the applied torque.

The size of a GL4-type cryocooler determines its run time and temperature at a given heat loading. The cryocooler you have purchased will have been built to your specified customer requirements and tested to verify that it meets its specification. Under no load, and with the main plate at 4.2K, the 4-head will typically run at about 800mK, and the film burner at about 1K. If the main plate can be kept colder than 4.2K then the cryocooler will also run correspondingly colder. When the 4-head is loaded the head temperature increases, as may be seen from the typical data in Figure 1 below. Load data for your specific cryocooler will be supplied in the Excel data file that accompanies your unit. Optimum temperatures and run times should be obtained with the loads on the 4-head and film burner distributed, so that the film burner runs at about 1.5 to 2.0 K.

Figure 1: Typical Load data



5.1. Radiation shielding

The 4-head, and any cold table/experimental equipment/detector assembly you attach, must be properly radiation shielded at around 4K in order to achieve sub-Kelvin operation. Any ancillary support structure (cold table) and experimental wiring looms may be thermally sunk to the film burner to improve the operating temperature. The film burner is designed to buffer the parasitic loads due to wiring and mechanical support structures. No other mechanical attachments to the cryocooler unit are necessary for satisfactory operation. If your cryocooler performance is not meeting the specification this is likely to be due to a radiation load. Check your radiation shielding and consider adding extra multi-layer insulation around your radiation shields, or around the pump.

6. OPERATION: QUICK-START GUIDE

6.1. Summary of the operating steps

The basic operational sequence is as follow.

- Pre-cool to liquid nitrogen temperature.
- While cooling to liquid helium temperature: When the heat switch turns OFF (it is at less than 10K), heat the pump to around 55K and keep it at that temperature until the head cools to ~4K.
- Turn OFF the 4-pump heat and turn ON the 4-switch.

A detailed flow diagram showing all the steps for running the cryocooler is included at the end of this manual. The temperatures suggested are only approximate and may need to be adjusted to achieve the best performance for your specific cryocooler and experiment. If you are using a mechanical pre-cooler with a low cooling power, try the lower end of the suggested temperature range**.**

An operational sequence for a typical GL7 cryocooler is illustrated below.

6.2. Pre-cool

An illustration of a typical pre-cool to liquid nitrogen temperature in a wet dewar is shown in Figure 2. When running the cryocooler from a mechanical pre-cooler (e.g. a PT or GM cryocooler) cooling timescales will be similar unless limited by the cooling rate of the pre-cooler.

Figure 2: Pre-cool to LN_2.

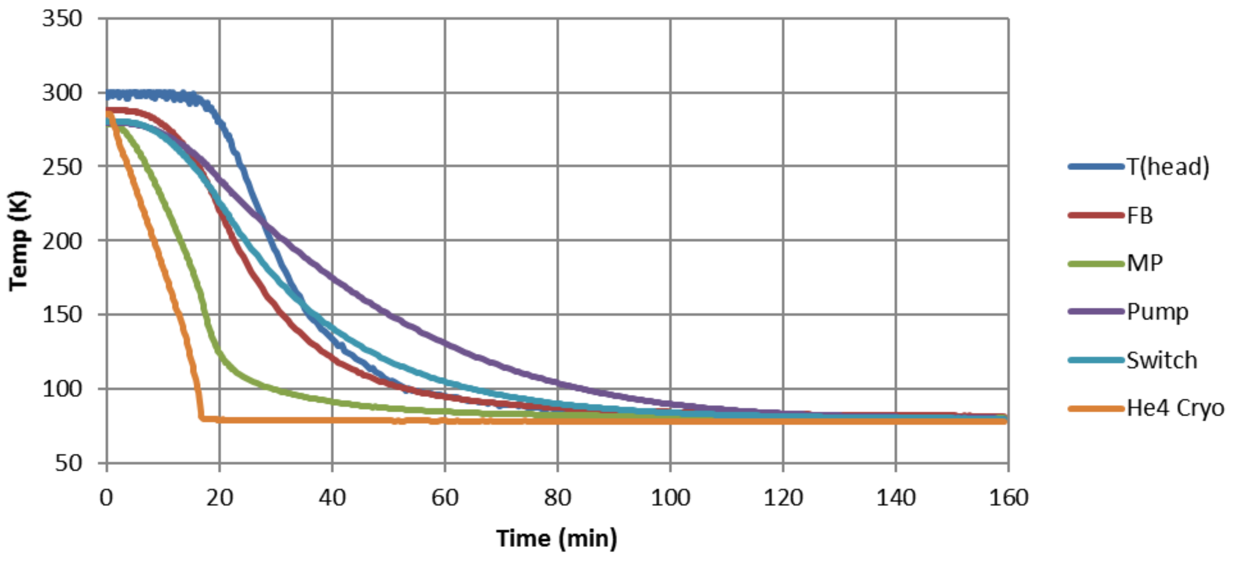
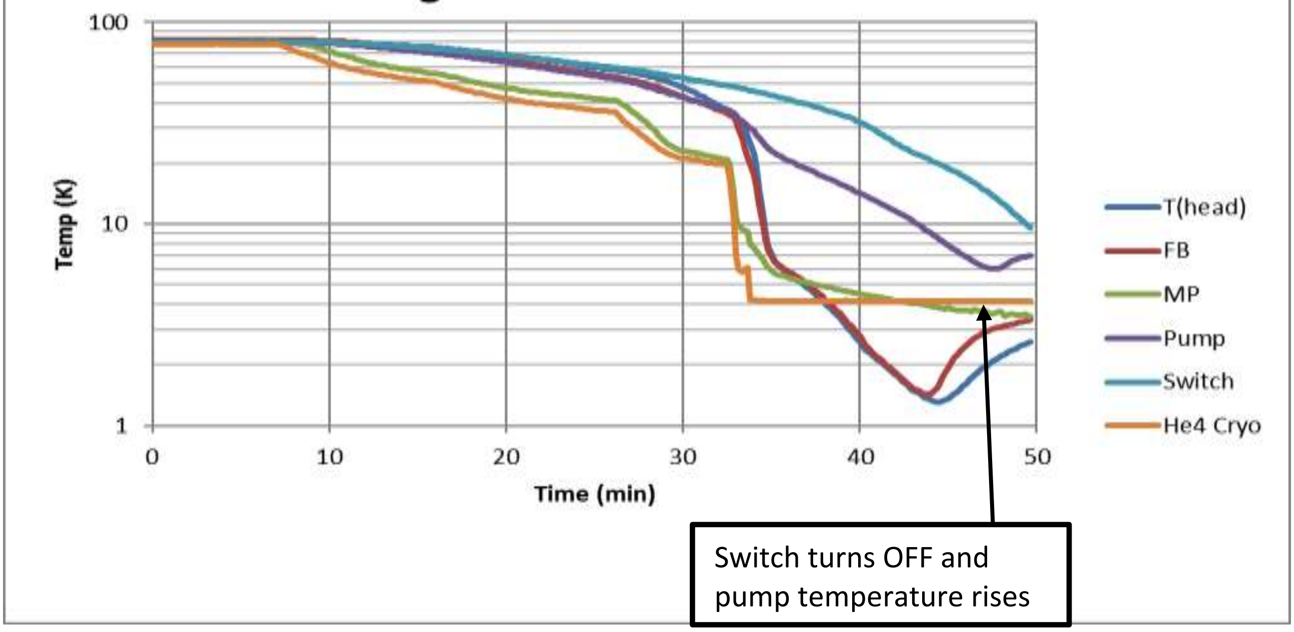


Figure 3 shows the next stage of a typical cooldown in a wet dewar during Helium transfer. Timescales will be similar if using a mechanical pre-cooler. The key event to watch for is the point where the heat switch turns off and the temperature of the pump begins to rise, at around t+47 in the example shown. After this point active monitoring and control is necessary to complete the cooldown.

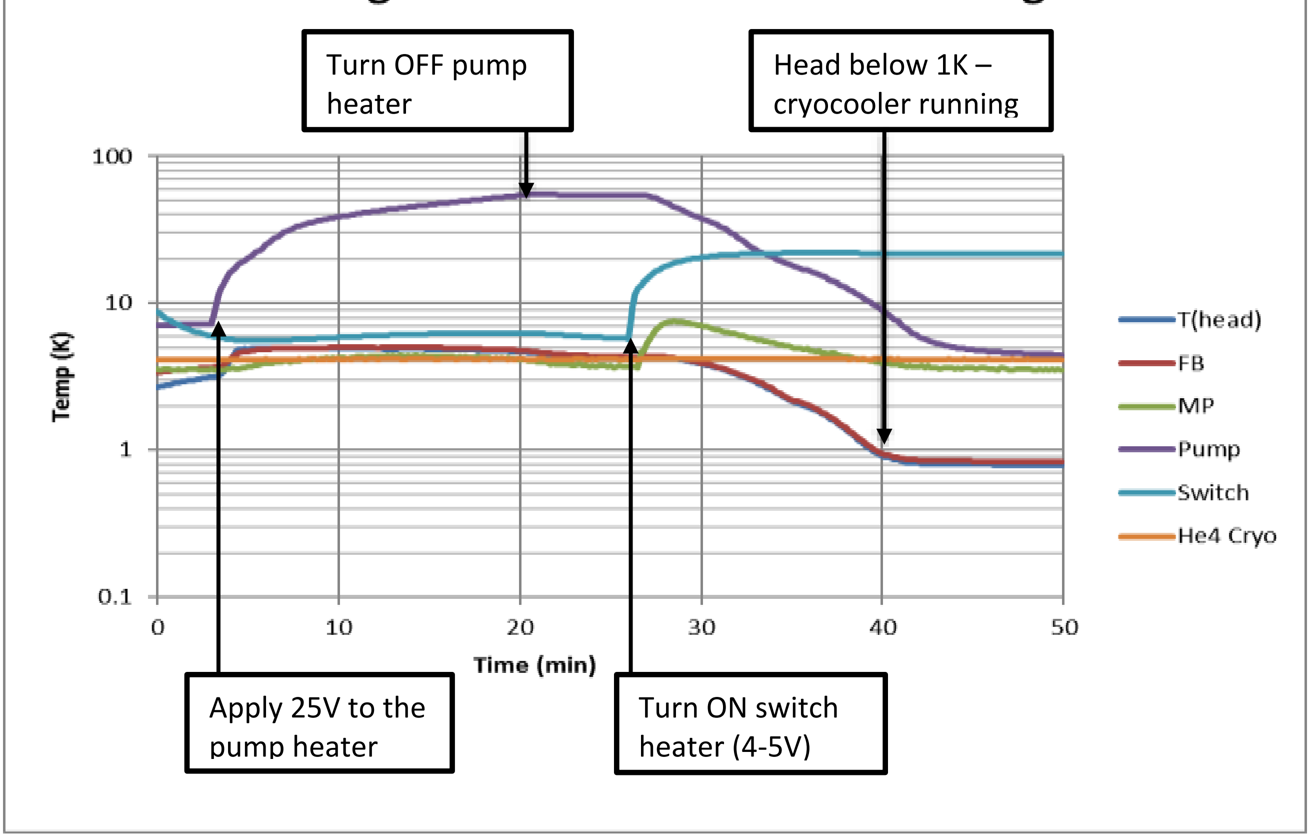
Figure 3: Pre-cool to L4He.



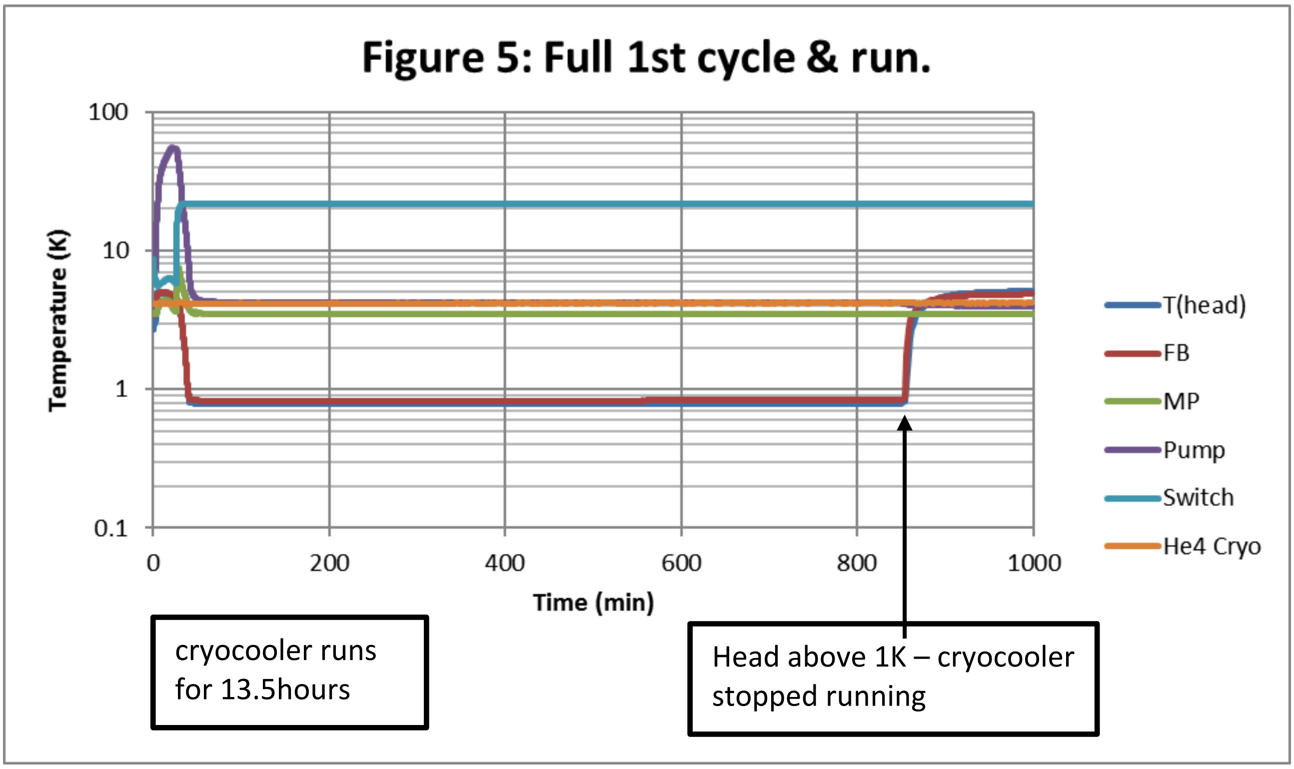
6.3. Complete the cooldown and run

For final cooldown it is necessary to raise the pump temperature to around 50-55K and to stabilise it while the 4-head cools to around 4K – the colder the better. After this, the 4-pump is allowed to cool by turning off the heater power and turning on the heat switch. The 4-head temperature and film burner temperature will then start to fall rapidly. A typical sequence of events is illustrated in Figure 4. The graph begins at t=0 with the heat switch turned off and the 4-pump temperature at around 8K.

Figure 4: Final cooldown to running

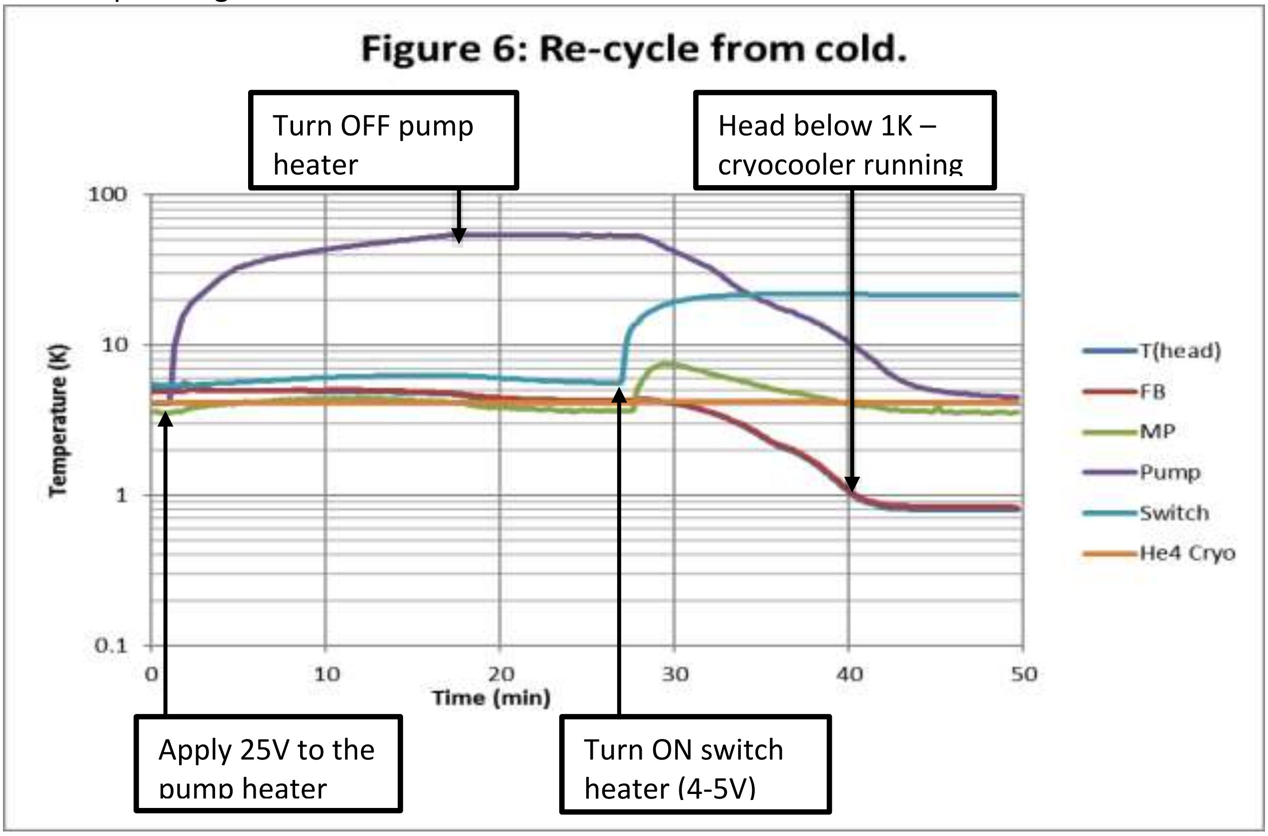


In this example the cryocooler continued to run for a total of around 13.5 hours, see Figure 5. An annotated test log and run data for your specific unit will be given in the Excel file that accompanies your cryocooler.



6.4. Typical re-cycle from cold

The re-cycle from cold is extremely simple to perform and takes less than 1 hour from start to finish. See example in Figure 6.



7. OPTIMISING THE PERFORMANCE OF YOUR CRYOCOOLER

It is easy to get this cryocooler to run, but it takes practice and some experimentation to achieve the best possible performance. Your particular experimental configuration will affect the thermal loadings on, and conductances between, the various parts of your cryocooler, and may consequently alter the optimum mode of operation. You are recommended to experiment with variations on the generic method of operation described above, once some familiarity with the successful operation of the unit has been gained, in order to optimise performance for your own application.

7.1. Pre-cool

Keep the pump above 25K once the switch has turned OFF for the initial cooldown.

It is important to understand that for the initial cool down, the 4-head cools by gas convection, and the pump cools by conduction via the heat switch whilst the heat switch is ON.

The 4-head will cool rapidly while the pump is warmer than ~25K, but once the pump drops below this temperature the head could take up to a few days to reach the final cooldown temperature. This is because when the gas is adsorbed into the pump, the head cannot cool by gas convection. The key to a rapid cooldown is: once the heat switch has turned OFF, reheat the pump above 25K and stabilise them, at this temperature you should then see the cold head cool rapidly to around 4K. In a GL4 cryocooler the head is likely to cool all the way to 4K before pump cools below 20K, so heating the pump during cooldown will not be necessary unless there is a large thermal mass attached to the cooler.

7.2. Running the cryocooler

Experiment with varying the pump temperature during the run to find the best performance for your set up.

Once the 4-head is ~4K, and the switches are off, the cryocooler is ready to start running. The generic method is to heat the pumps to the suggested temperature in the table in section 6.1 and maintain them there whilst ensuring the 4-head cools to below the critical liquefaction point of ^{4}He (5.2K). The colder the 4-head gets while the pumps are hot, the higher the liquefaction efficiency, and hence the longer the cryocooler will run before it must be recycled. You should try variations of pump temperatures to find a procedure that provides the best performance for your set up. When operating from a low-powered mechanical pre-cooler (e.g. 100mW @ 4K PT unit) you will probably achieve more efficient ^{4}He condensation by starting at the lower end of the suggested range of temperatures. This is because imposing smaller load on the mechanical pre-cooler from the hot pumps will enable a faster and more efficient recycle and run.

7.3. Operating the heat switch

Turning the switch on slowly will put less load into the precooler.

Once the ^{4}He is liquified (when the 4-head and film burner temperatures have stopped falling) the 4-pump is allowed to cool by turning OFF the pump heater and turning ON the heat switch. The hot 4-pump will impose a large heat load onto the 4K plate, this can cause the temperature is rise temporarily. However, the rate of cooling can be varied depending on the voltage applied to the switch. The switch will begin to turn ON at 14-17K and be fully on above ~20K. If the switch is turned on slowly by applying a lower voltage and gradually increasing it, the heat from the pump is dissipated more slowly and so there is less temperature rise in the 4K plate. In addition to this, if there is a small pause between turning off the pump power and turning on the switch power, in this time the pump will cool slightly by the parasitic load down the pump tube. At this stage the cold head temperatures and film burner temperatures will fall rapidly.

7.4. Parasitic loads

Use the Film burner to buffer any parasitic loads.

In operation, the parasitic loading may be dissipated on the film burner in order to optimise the 4-head temperature or the run time. The longest run times will be obtained when the loads on the 4-head are kept low.

8. STANDARD PIN-OUT ASSIGNMENTS

The table below shows the standard wiring pin-outs to 21-pin micro-D SSP. Please note that standard pin-outs changed in 2017 for the switch heater. In older models the switch heater pin-outs were pins 10 and 20.

Function	Red box for twisted pair.	Designation	MDM 21-SSP.	Drive current or voltage
4-HEAD RuO_2 V+ 4-HEAD RuO_2 V- 4-HEAD RuO_2 I+ 4-HEAD RuO_2 I-			1 12 2 13	100nA AC Or low voltage Driver e.g. V<0.5mV
NC			3	
DIODE FILM BURNER I+ DIODE FILM BURNER I-			4 14	10μA
DIODE MAINPLATE I+ DIODE MAINPLATE I-			5 15	10μA
DIODE 4-PUMP I+ DIODE 4-PUMP I-			6 16	10μA
DIODE 4-SWITCH I+ DIODE 4-SWITCH I-			7 17	10μA
			8 18	
HEATER 4-SWITCH I+ HEATER 4-SWITCH I-			9 19	4 to 5 Volts
			10 20	
HEATER 4-PUMP I+ HEATER 4-PUMP I-			11 21	50 to 100 mA 24 to 30 V 300Ω

Diode thermometer

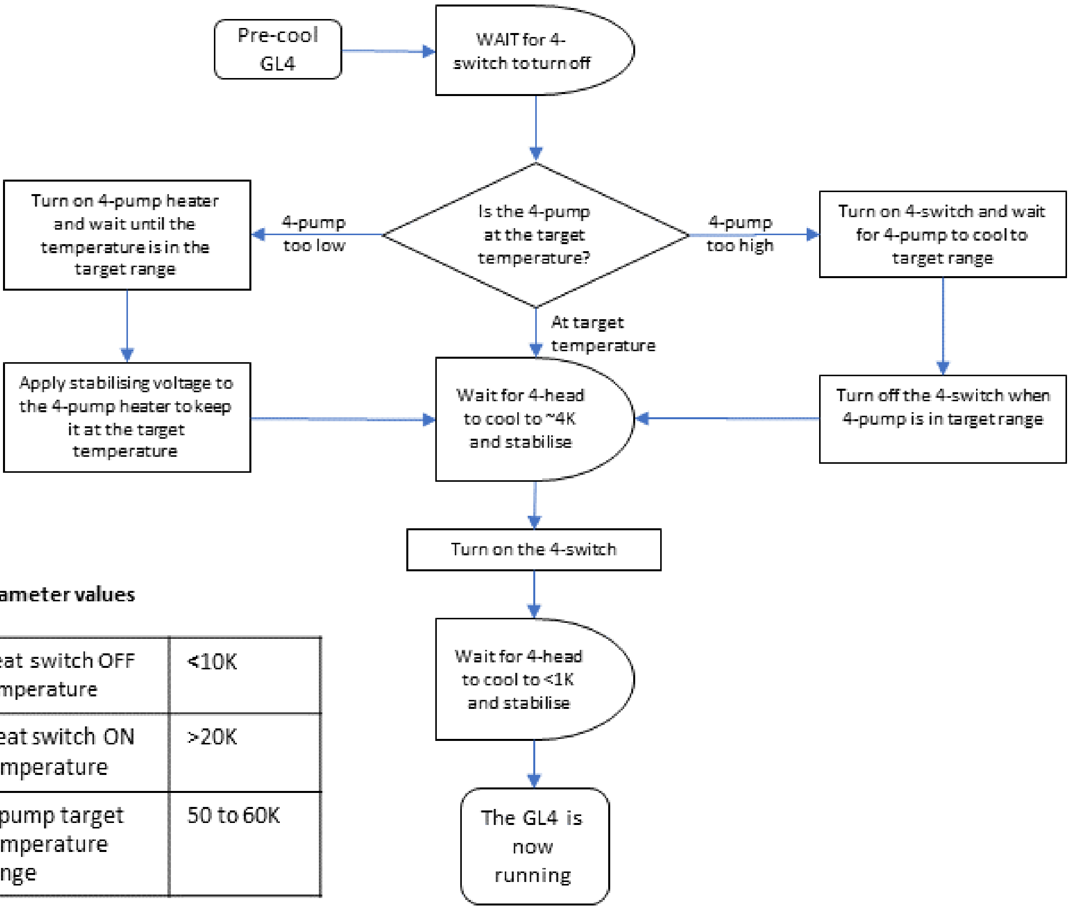
Ruthenium Oxide thermometer

Heater wires

Twisted pair

9. FLOW CHART OF GL4 OPERATING PROCEDURE

Note that some operations occur in parallel



Parameter values

Heat switch OFF temperature	<10K
Heat switch ON temperature	>20K
4-pump target temperature range	50 to 60K