Chase
Research
Cryogenics

World leaders in
sub-Kelvin cryogenics

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

TYPE GL4 (Helium 4)

GENERIC INSTALLATION AND OPERATING INSTRUCTIONS

Photo shows a standard 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.

Both this manual and the Excel data file are important parts of the technical documentation for this product. You are advised to make a note below of the location of the Excel file specific to your cryocooler unit. CRC can, on request, provide a copy of the Excel file for your unit – just let us know the serial number engraved around the mainplate.

This revision of the manual was created in September 2021.

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.

Always allow the unit to warm to room temperature before allowing air into your cryostat. Opening the air valve of a cold cryostat is likely to damage the unit.

After unpacking the cryocooler according to the instructions supplied, it 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, nor 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. UK 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:

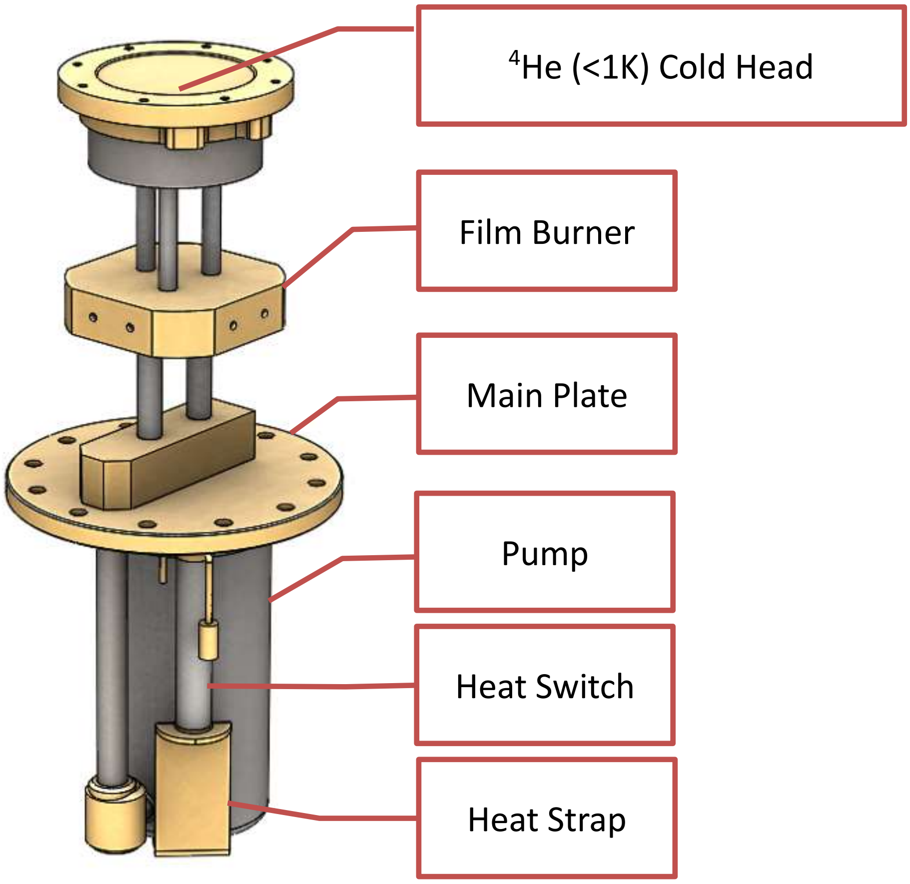
- This written instruction manual, containing warnings about the potential risks arising from damage to the unit and alerting the user to more risky operations;
- Instructions that the unit should not be used if it has been subjected to overheating, dropping, crushing, bending or twisting;
- A warning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

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 the current standard model. The ^4He head of older models may look slightly different but the operation is the same. 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 ^4He 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	^4He cold head
FB	Film burner
4-Pump	^4He pump
4-Switch	Heat Switch for the ^4He 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 a '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 or below, such as a GM or pulse tube cryocooler. The thermal link to 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 around the perimeter of the main plate. (Note: UNC #6 clearance holes are substituted if preferred by the customer). A CAD file of your cryocooler will be provided on request to enable the design of the interfacing. Several interfacing options are possible, depending on the space available in your cryostat, see our website for the most common options and contact CRC for more advice. We can provide cryocoolers with additional mounting holes, or custom hole patterns, where this will make interfacing and radiation shielding easier.

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 or Scientific Instruments Inc.	Individually calibrated sensors can be fitted 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	

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

Calibration tables for all thermometer sensors are sent in the Excel data file that accompanies each unit. Generic diode calibration curves for the pump diode and heat switch diode, and a 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 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 300Ω. During the cooling cycle it is necessary to warm the 4-pump to between 45 and 50k. 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.

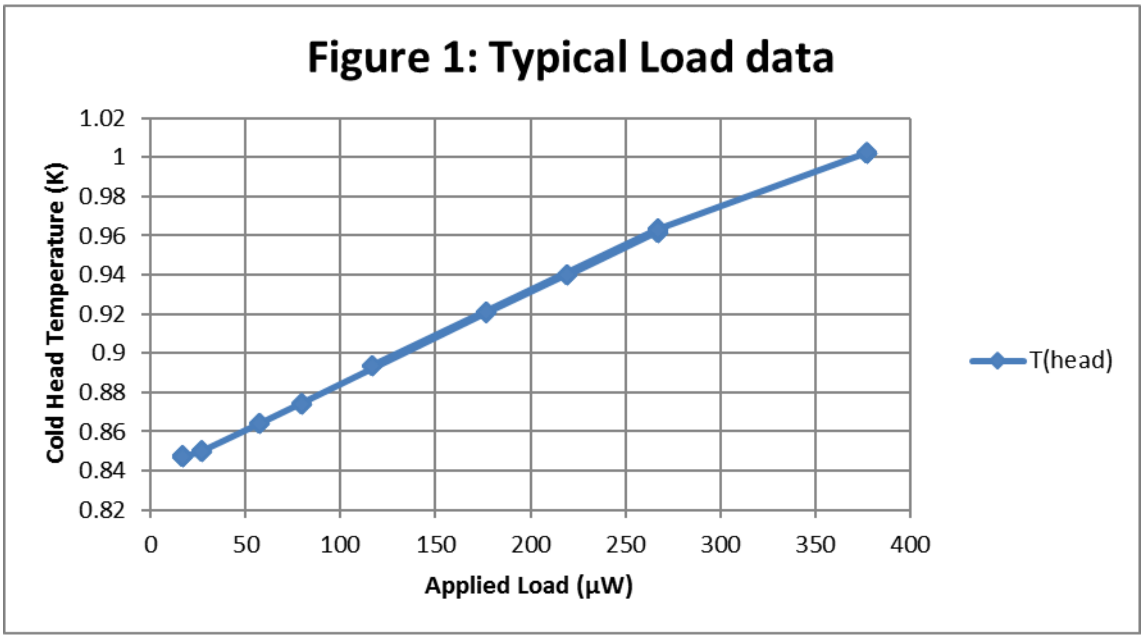
This model of cryocooler provides two points at which heat may be extracted from a user's experiment mounted on a separate cold table; these are the 4-head and the film burner. Attachments to the 4-head and film burner can be made using the tapped holes provided.

The top surface of the 4-head has 8 holes tapped M3 on a pitch circle. The film burner has four pairs of M3 tapped holes on the sides of the main body. In both cases UNC #4 threads can be substituted if preferred by the customer.

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.

GL4 cryocoolers are made in different sizes. 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 requirements and tested to verify that it meets its specification. Details of the specification and of the test results are in the Excel file accompanying your unit.

Under no load, and with the main plate at ~4K, the 4-head will typically run at about 825mK, and the film burner at about 1K. If the main plate can be kept colder than 4K (for example by a GM/PT cold head), then the cryocooler will also run slightly colder and longer. When the 4-head is loaded the head temperature increases, as seen in 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 distributed between the 4-head and film burner, and with the film burner temperature running at approximately 1.5 to 2 K.



5.1. Radiation shielding

The 4-head, and any cold table/experimental equipment/detector assembly you attach to it, must be properly radiation shielded at <4K to achieve a sub-Kelvin operation. The film burner is designed to buffer the parasitic loads due to wiring and mechanical support structures, and heat sinking these items to it will reduce the load on the 4-head. No other mechanical attachments to the cryocooler unit are necessary for satisfactory operation. If, in your system, your GL4 cryocooler performance is not meeting the stated specification, this is most likely to be due to a radiation load. Check your radiation shielding and consider adding extra multi-layered insulation around your radiation shields, or around the 4-pump.

6. OPERATION: QUICK-START GUIDE

6.1. Summary of the operating steps

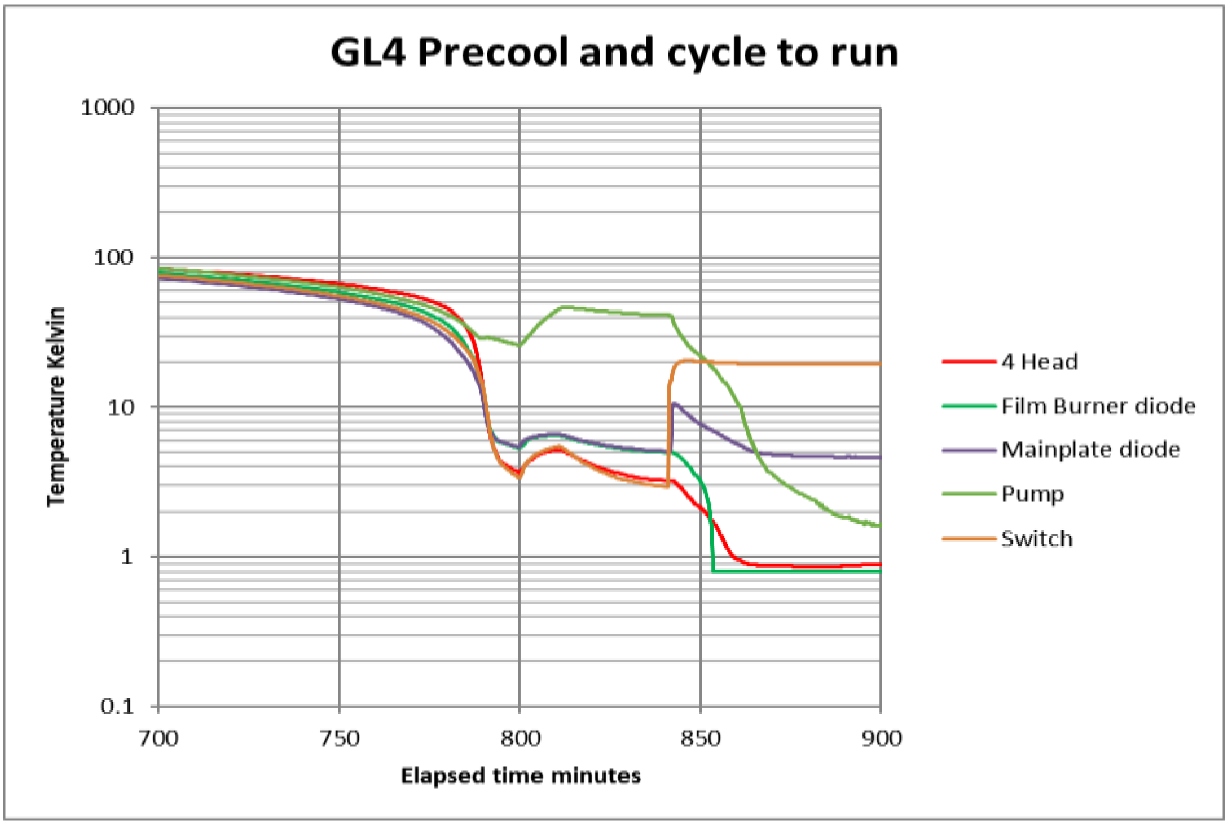
The basic operational sequence is as follows.

- Pre-cool from room temperature to ~4K.
- During pre-cooling, when the 4-switch turns OFF (it is at less than 10K), heat the 4-pump to 45-55K and keep it in that temperature range while the 4-head cools to below 4K and its temperature stabilises.
- Turn OFF the 4-pump heat and turn ON the 4-switch.

A detailed flow diagram showing all the steps for running the cryocooler can be seen 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 (e.g. 100mW) use the lower end of the suggested 4-pump temperature range. If you are using a more powerful mechanical precooler, or precooling with liquid helium, you will get the best performance at the top end of the suggested temperature range. An operational sequence for a typical GL4 cryocooler is illustrated below.

6.2. Pre-cool and cycle to run

An illustration of a typical pre-cool and first cycle with a low-power GM precooler is shown below. Cooling times will be shorter with a higher-power GM.

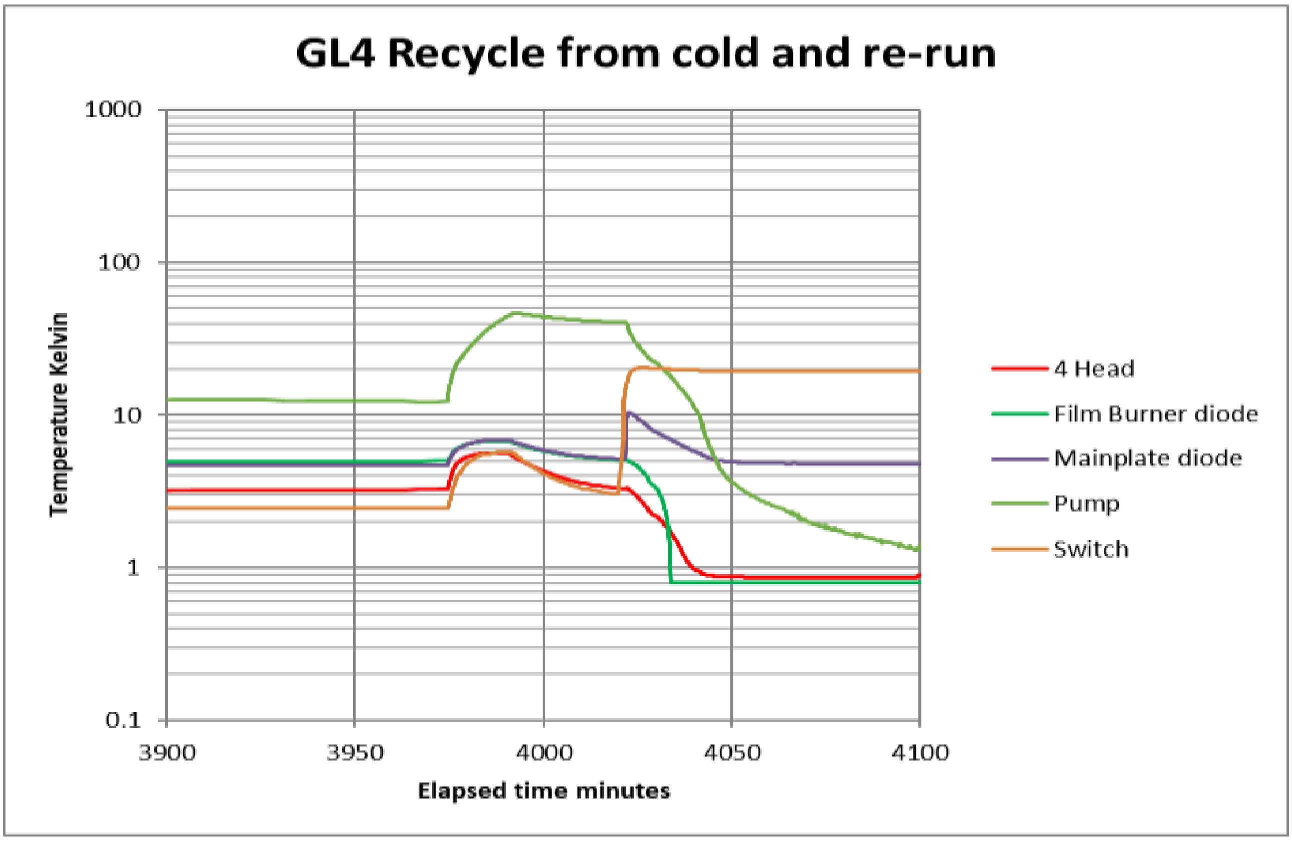


Here you can see that after ~800 minutes the 4-head temperature is less than 4K, the 4-switch is off (<10K) and the pump is at more than 25K. To get the GL4 running the pump is warmed to ~ 45K by applying a voltage of 20V. The pump heater is turned down or off while the head temperature drops to less than 3K (lower is better). As the 4-head temperature stabilises, the 4-switch is turned on with a voltage of 5V and the GL4 starts to run (4-head drops to <1K).

Note in this figure that the film burner diode readings bottom out during the run because the generic diode calibration has been used. Diode readings below ~20K are only indicative and are used primarily for 'housekeeping'. In most cases we are able to provide a specific calibration for the film burner diode fitted to your cryocooler, which will improve the accuracy of the FB diode readings below 4K.

6.3. Recycle from cold and run

The run time of a GL4 cryocooler will depend on the size of the unit (i.e. how much gas it contains), on parasitic loads, and on the loads applied by your cryostat and experiment. When the unit expires, it can be recycled from cold and run again. A typical sequence with a low-power GM precooler is illustrated below.



At the beginning of this sequence the 4-head has expired and the 4-switch has been turned off. To recycle the GL4 the 4-pump is warmed to ~ 45K and kept warm until the 4-head re-cools and stabilises (around t=4025). The 4-switch is turned on and the GL4 once again begins to run. The entire recycling sequence takes less than 100 minutes. A faster recycle (warming the pump rapidly with a higher voltage) can be carried out if a higher-power GM is used, as it has more capacity to quickly remove the heat input to cycle the 4-pump.

7. OPTIMISING THE PERFORMANCE OF YOUR CRYOCOOLER

It is easy to get your cryocooler to run, but takes practice and experimentation to achieve the very best possible performance. Your experimental configuration will affect the thermal loadings on, and conductances between, the various parts of your cryocooler. Try experimenting with slight variations of the generic method of operation described in this manual to optimise the performance for your own application.

7.1. Pre cool

Keep the 4-pump above 25K once the switch has turned OFF during the initial cooldown.

It is important to understand that for the initial cool down, the cold head cools by gas convection, and the pump cools by conduction via the heat switch while the heat switch is ON. The cold head will cool rapidly while the pump is warmer than ~25K, but once the pump drops below this temperature the head could take a very long while to reach its 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 it at this temperature. You should then see the cold head cool rapidly to around 4K.

7.2. Running the cryocooler

Experiment with varying the 4-pump temperature during the run to find the best performance for your set up.

Once the 4-head is ~4K, and the switch is off, the cryocooler is ready to start running. The generic method is to heat the 4-pump to the suggested temperature in the flow diagram and maintain it there while the 4-head cools below the critical liquefaction point of ^{4}He (5.2K). But the colder the 4-head gets while the 4-pump is 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 GM unit), you will achieve more efficient ^{4}He condensation by starting at the lower end of the suggested range of temperatures. This is because imposing a smaller load on the mechanical pre-cooler from the hot pump will enable a faster and more efficient recycle and run.

7.3. Operating the heat switch

Turning the 4-switch on slowly will put less load into the pre-cooler.

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. During this time the hot 4-pump will impose a large heat load onto the 4K plate which will cause the temperature to rise temporarily. However, the rate of cooling the 4-pump can be varied depending on the voltage applied to the 4-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 at first and gradually increasing it, the heat from the pump is dissipated more slowly and so there is less temperature rise at the 4K plate. In addition, 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 point the 4-head temperature and film burner temperature will fall rapidly.

7.4. Applied loads

Use the 4-Head and Film burner to buffer any applied loads.

In operation, the applied loading from lead-in wiring may be dissipated on the film burner to optimise the 4-head temperature or run time. The longest run times will be obtained when the loads on the 4-head are minimised.

8. STANDARD PIN-OUT ASSIGNMENTS

The table below shows the standard wiring pin-outs to 21-pin micro-D SSP.

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	5 Volts
			10 20	
HEATER 4-PUMP I+ HEATER 4-PUMP I-			11 21	50 to 100 mA 20 to 30 V 300Ω

Diode thermometer

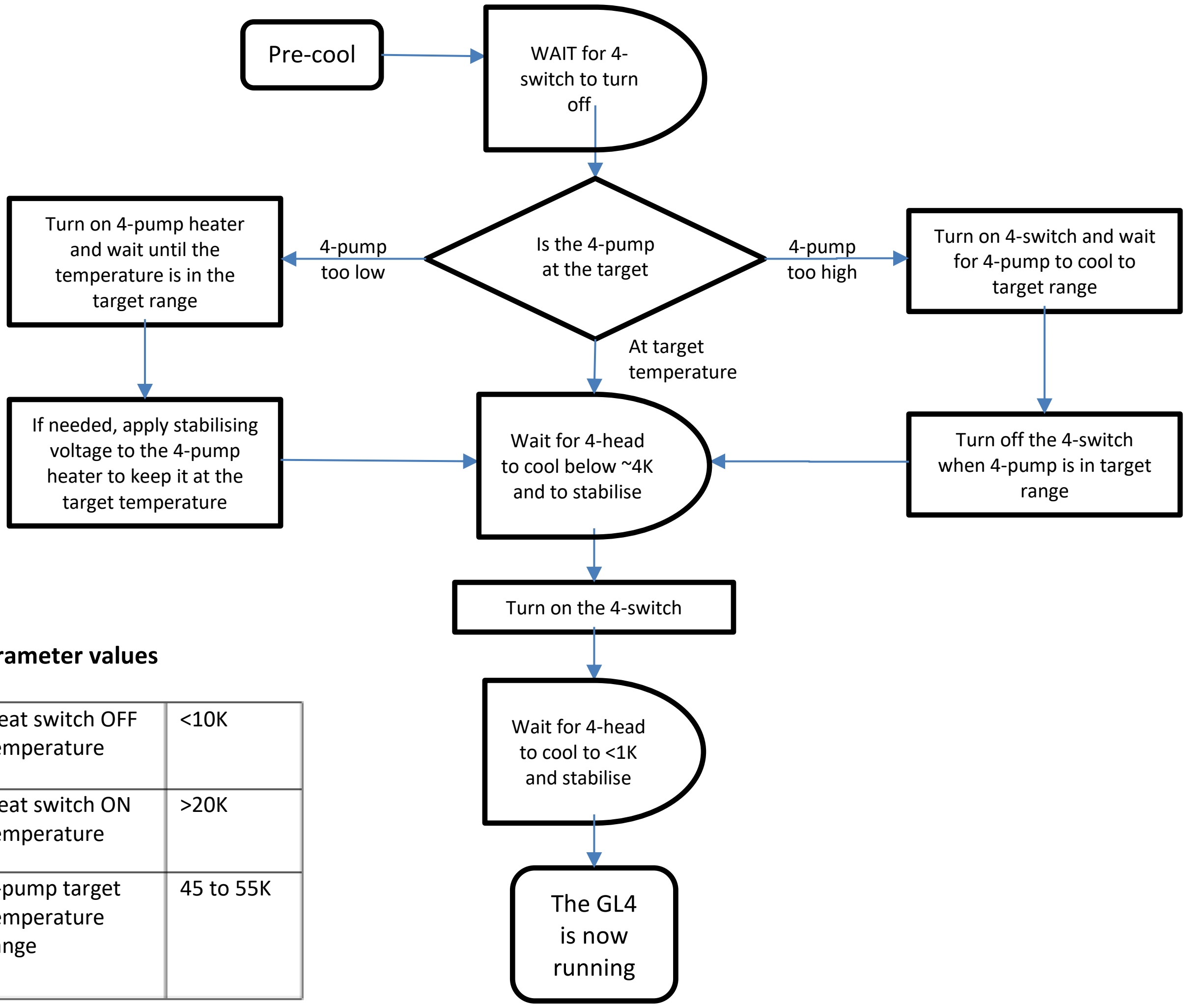
Ruthenium Oxide thermometer

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	45 to 55K