CHASE RESEARCH CRYOGENICS LTD.
WORLD LEADERS IN SUB-KELVIN CRYOGENICS

CONTINUOUS ^{4}He CRYOCOOLER

TYPE CC4

GENERIC INSTALLATION AND OPERATING INSTRUCTIONS

Photo shows a typical CRC CC4 cryocooler

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THIS GENERIC OPERATING MANUAL describes how to install and operate a CRC 1KCC 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.

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 means of the cold heads.

Do not tamper with the copper capillary fill tubes.

Avoid the use of acid fluxes when soldering in the vicinity of the cooler. Chloride based fluxes will corrode stainless steel and could damage your cooler.

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 three screws through the aluminium plate into the cold heads should NOT be in place. When picking the cryocooler up, it should be firmly grasped by the cryopump radiation shield or the main plate/angle bracket.

2. SAFETY OF CHASE RESEARCH CRYOGENICS PRODUCTS

2.1. Pressure Equipment Directive 97/23/EC (Pressure Equipment Regulations 1999)

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 3 Paragraph 3 of the Pressure Equipment Directive, which states: “Pressure equipment and/or assemblies below or equal to the limits in sections 1.1, 1.2 and 1.3 and section 2 respectively must be designed and manufactured in accordance with the sound engineering practice of a Member State in order to ensure safe use. Pressure equipment and/or assemblies must be accompanied by adequate instructions for use and must bear markings to permit identification of the manufacturer or of his authorized representative established within the Community. Such equipment and/or assemblies must not bear the CE marking referred to in Article 15.”

2.2. Pressure Systems Safety Regulations 2000

This cryocooler unit does not contain a pressure x volume product exceeding 250 bar-litres hence PSSR regulations 5(4), 8-10 and 14 do not apply. This means that the system does not require a written scheme of examination. The cryocooler is not ‘mobile’ in the sense intended in the PSSR hence *the owner* has duties under these 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 more than one 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.

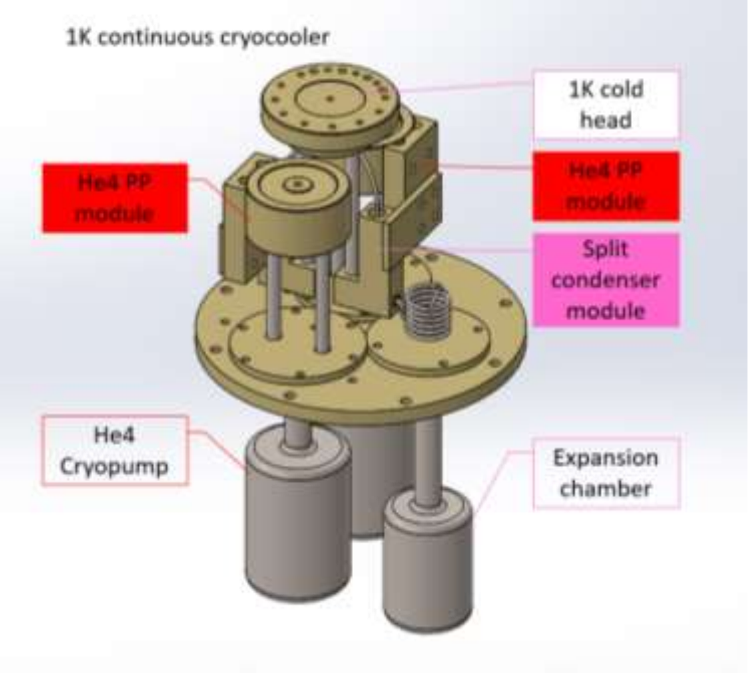
The applications for which cryocooler units are intended make it impossible to place warning labels on the unit itself. However if the cryocooler is incorporated into another instrument, that instrument should carry a warning label to alert the user that the cryocooler contains no user-serviceable parts 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

This cryocooler unit has a single 1K cold head and two ^{4}He modules on one side of the circular main plate, as can be clearly seen in the illustration below. The 1K cold head is connected to the two ^{4}He modules and the main plate via a split condenser. In operation the unit will be inverted with respect to this picture, with the cold head at the bottom. Continuous cooling of the 1K cold head is achieved by alternately cycling each ^{4}He module at intervals, such that the 1K cold head is always being cooled by one or the other module.



This model of cryocooler provides just one point at which heat may be extracted from a user's experiment mounted on a separate cold table, which is the 1K cold head. There are holes tapped in this surface for thermal connections between your experiment and the cryocooler.

The cold head and the ^{4}He modules are provided with RuO_2 thermometer sensors to monitor the temperature. The sensors are inserted into sockets machined directly into the heads. Wiring for the thermometer sensors is carried from isolated standoffs. All electrical connections are brought out to a connector mounted onto the main plate. Pin-outs are listed at the end of this manual.

Each ^{4}He module has a cryopump and gas-gap heat switch on the other side of the main plate. The cryopumps have heater elements that control the cooling cycle. They are provided with standard active gas-gap heat switches activated by 10 kΩ heater resistors, and they also each carry a diode thermometer. A heat strap is fitted between each heat switch and cryopump. The split condenser unit also has an expansion chamber that sits alongside the cryopumps; this chamber has no heat switch, and only a simple wire heat sink.

4. INSTALLATION

4.1. Mechanical

Before installing the unit in your cryostat, be sure to remove all of the pieces of foam board packing from around the pump, as mentioned in the unpacking instructions.

There should be no need to touch the heat switches or heat straps during installation or normal operation of the cryocooler. The heat switches can be easily damaged, and if bent or twisted are likely to fail.

This unit is designed to work equally well in either 'wet' cryostat using liquid ^{4}He, or in a 'dry' cryostat, i.e. from a mechanical cooler head such as a pulse tube.

Mounting holes are provided on the main plate for attaching the cryocooler to your cryostat cold plate. There are twelve 4.1mm diameter (M4 clearance) holes symmetrically distributed upon a 115 mm pitch circle around the periphery of the circular main plate. (Note: UNC holes and threads can be supplied at customer request). Good thermal contact between the cryocooler main plate and the 4K stage of your pre-cooling apparatus is essential for proper operation of the unit.

Always use spring washers, or suitable low expansion washers (e.g. Invar or Tungsten), under every bolt head. These will take out differential thermal contraction that might otherwise cause loosening of the bolts, and thus compromise thermal contact. Because the cooling down of the heads depends upon gas convection, the cryocooler *must* be kept close to vertical during the cooldown process.

4.2. Electrical

All electrical connections are brought out to a connector mounted onto the main plate. This will normally be a 37-pin connector whose pin-outs are listed at the end of this instruction manual though other wiring arrangements can be supplied on request. Voltage / current requirements for driving the heaters and thermometers are summarised in the table below.

ITEM	NUMBER	IMPEDANCE/ JUNCTION VOLTAGE	VOLTAGE/ CURRENT
4-pump heaters	2 off	200Ω approx.	70 to 100 mA
Heat switch heaters	2 off	10kΩ	4 to 5V
Diode thermometers	4 off	0.5 to 1.8V	10μA DC
^{4}He-module and 1K cold head RuO$_2$ thermometers	3 off	1kΩ to 3kΩ	1μA max.

Generic (i.e. standard calibration) RuO$_2$ sensors from Lakeshore Cryotronics are the default option on all CRC cryocoolers. Individually calibrated 'CERNOX' or RuO$_2$ sensors are only fitted (at additional cost) at the customer's express requirement. Generic diode calibration curves for the cryopump and heat switch diodes are supplied as standard by CRC Ltd in the Excel data file that accompanies each cryocooler.

The temperature sensors on the ^{4}He modules and the 1K cold head are operated as 4-wire devices and should ideally be driven by an AC current no greater than 1µA. The diode thermometers require excitation with currents of 10µA DC.

As supplied, the heat switch heaters require about 3 to 4 V to keep the switch in the 'ON' state with the absorber pod at around 20 to 25 K, and they will cool to the off state ($T < 8$ or 10 K) in ten to fifteen minutes.

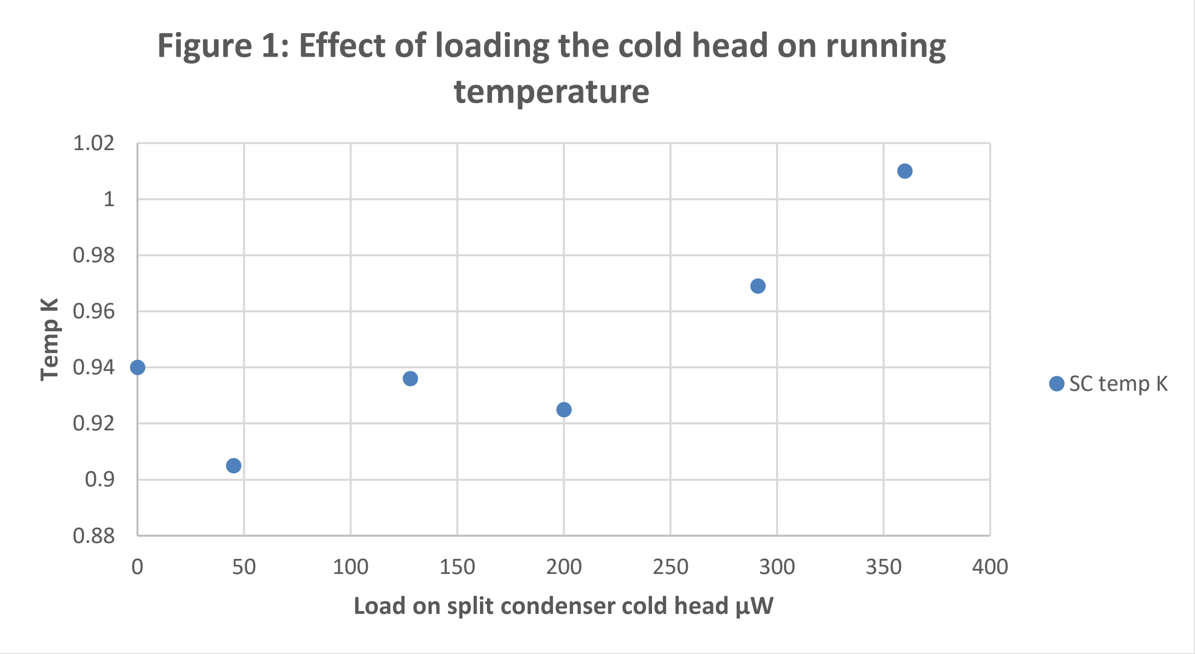
The ^{4}He cryopump heater impedance is about 200Ω. During initial cooldown, and continuous operation, it is necessary to warm each ^{4}He cryopump to around 50K. A heater current of up to 100 to 130mA or so will heat the pump rapidly; lower heater currents will result in slower heating and a smaller perturbation to the main plate temperature. Stabilisation of the 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 just one at which heat may be extracted from a user's experiment mounted on a separate cold table, which is the 1K cold head. The top surface of the cold head has 8 holes tapped M3 on a 40mm P.C.D. and a further axial hole tapped M4. (Note: UNC threads are substituted if requested by the customer).

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

Under no load, and with the main plate at 4.2K, the cold head will run at an average temperature of about 900mK. When the cold head is loaded the temperature increases, as illustrated in Figure 1 below. Load data for your specific cryocooler are supplied in the Excel data file that accompanies your unit.



5.1. Radiation shielding

The cold head, and any cold table/experimental equipment/detector assembly you attach, must be properly radiation shielded at around 4K to achieve satisfactory operation. The cold table should be connected to the 1K cold head of the cryocooler with a copper heat strap. No other mechanical attachments to the cryocooler unit are necessary for satisfactory operation.

6. OPERATION: QUICK-START GUIDE

6.1. Cooldown and commence continuous operation

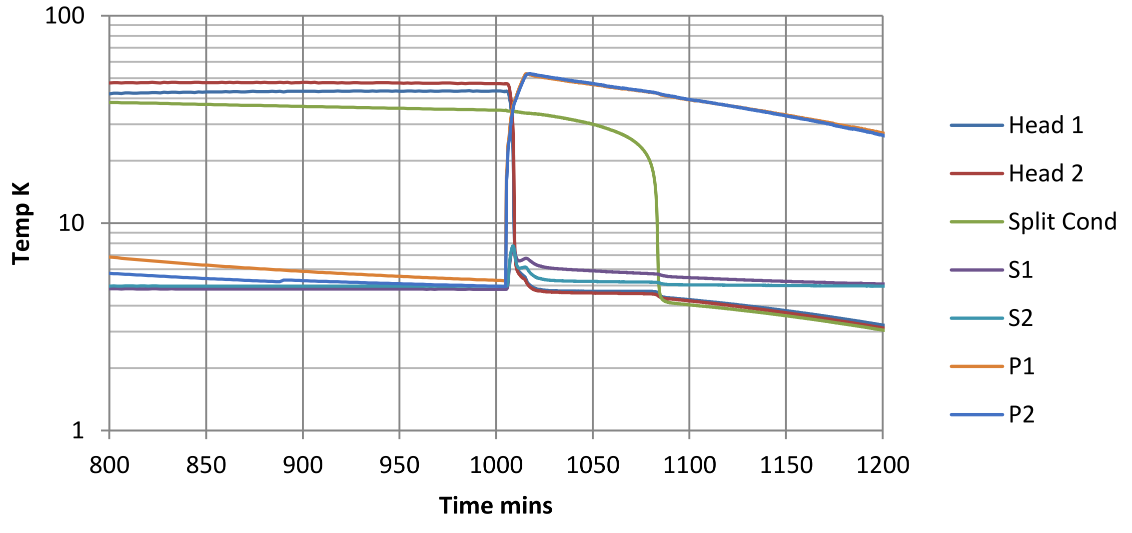
Figure 2 shows a cooldown from liquid nitrogen to liquid helium temperature and then to 1K in a wet dewar, after helium transfer. In the example shown the unit had been left to stabilise overnight – though this is not a necessary step. The procedure can begin as soon as both heat switches cool sufficiently to turn OFF, i.e. the switches are below around 10-15K. At this point it is necessary to warm both cryopumps to around 50K so that both module heads and the split condenser cold head continue to cool down towards the operating temperature.

The legend entries in all the following figures are:
Head 1: ^{4}He module 1
Head 2: ^{4}He module 2
Split Cond: the 1K cold head of the split condenser
S1: heat switch on module 1
S2: heat switch on module 2
P1: cryopump on module 1
P1: cryopump on module 1

The sequence of events shown in Figure 2 is after the overnight stabilisation period.

t+1005	15V on both pumps
t+1015	pump heaters off
t+1033	helium top-up
t+1216	Everything is cold except pumps

Figure 2 Cooldown from LN2 to L^{4}He and below



6.2. Commence alternate cycling

With the split condenser 1K cold head below 4K it is possible to start cycling the modules. The sequence of events is illustrated in Fig 3., which begins at t=0 with both cryopumps hot and both heat switches turned off.

t+1	SW1 on, 4V (this allows pump 1 to cool)
t+18	SW1 off, SW2 on (this allows pump 2 to cool)
t+40	Split condenser has now cooled to around 1K. Alternate cycling of the modules can begin.
t+40	10V (530 mW) on pump 1 only.
t+53	Reduce pump 1 heater power to 4V (85mW) to stabilise it close to 40K.

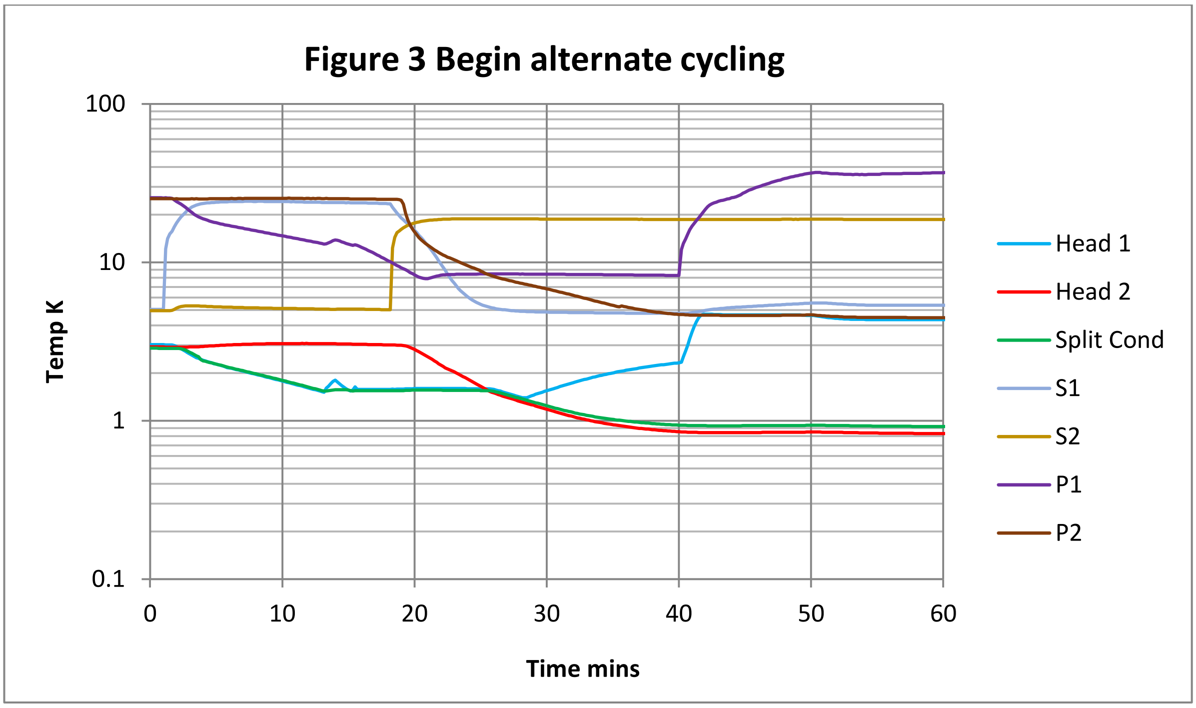


Figure 3 Begin alternate cycling

The sequence of events continues in Figure 4 is as follows:

t+137	SW1 on pump 1 off
t+138	SW2 off
t+247	pump 2 to 8V (347mW)
t+270	pump 2 to 3V (49mW)
t+282	pump 2 off, SW2 on

This sequence, with cycling at suitable intervals, can be repeated for as long as required for the user's application.

In the example shown, having cycled first module 1 and then module 2 the remainder of the run was utilised to verify the expiry time for both modules. For the unit tested module 1 ran for a total of approx 4 hours, and module 2 also ran for a total of approx 4 hours before expiry. This therefore sets the *maximum* possible interval between alternate cycles when running this unit under no load. In practice, sufficient time – e.g. around 30 minutes - must be allowed to cycle the 'other module' before the first one has expired, so for this unit a maximum time of 3.5 hours between cycles would be a good starting point. In practice expiry time will be affected by other factors such as loading, so you are recommended to experiment with your own system in order to optimise its performance in your setup.

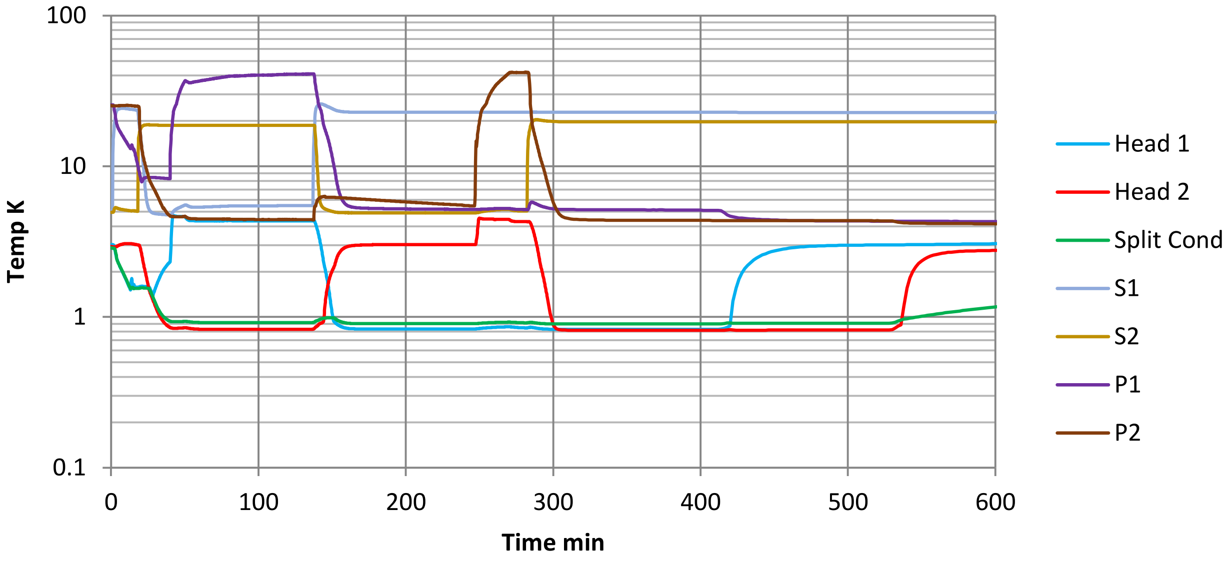


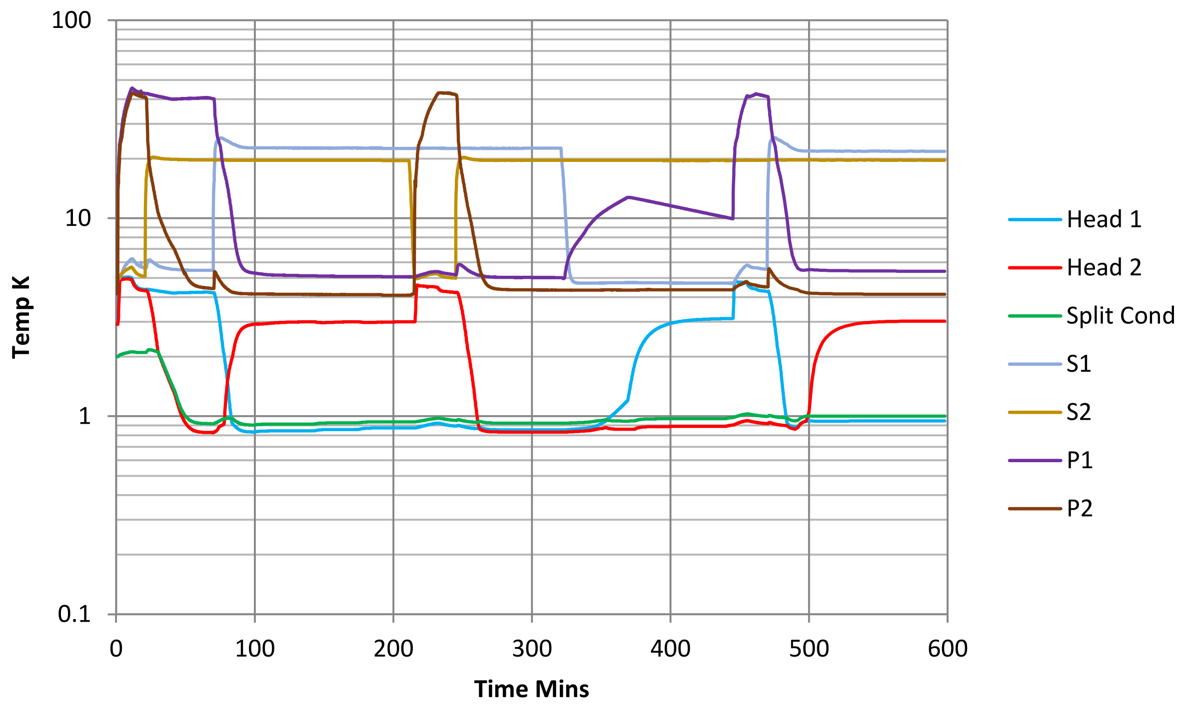
Figure 4 Alternate cycle and run to expiry

6.3. Standard continuous operation once cold, including under load

In Fig 5 we illustrate continuous operation with an interval of approximately 3 hours between cycling each module alternately. Three cycles are shown, with various loadings applied to the split condenser 1K cold head throughout. The sequence of events is:

t+1	12V (864 mW) on pump 1
t+11	pump heater power off
t+21	SW2 on
t+40	pump 1 to 3V (48mW)
t+66	pump 1 off
t+70	SW1 on
t+100	0.7V (45µW) on split condensor (SC)
t+143	1V (90µW) on SC
t+175	1.2V (128µW) on SC
t+211	SW2 off
t+215	pump 2 to 10V (542mW)
t+232	pump 2 to 3V (49mW)
t+239	pump 2 off, SW2 on
t+245	SW2 on
t+260	1.5V (200µW) on SC
t+321	SW1 off
t+374	1.8V (291µW) on SC
t+440	2V (360µW) on SC
t+445	pump 1 to 12V
t+456	pump 1 to 3V
t+456	pump 1 to 6V
t+462	pump 2 off
t+470	SW2 on

Figure 5 Continuous operation from cold, under load



Left

The unit was left running overnight under 360µW load and expired at t~700.

6.4. Automating the sequence of operations

Once the cooler is cold and ready for alternate cycling the sequence and timing of operations is as follows:

t=0 10V on pump 1
t+10 pump heater power to 3V
t+20 pump heater power off
t+30 SW 1 on by applying 4V
t+50 turn off SW2
after 2.5-3 hours repeat the cycle from t=0 but for pump 2, SW2.

SW1 can be turned off any time after Head 2 is cold, but it must be off before the sequence is next repeated for pump 1, SW1. We suggest above that 20 minutes is sufficient time for a module’s head to cool after its heat switch is turned on.

Note that in Figure 5 there was no set time used to turn off the heat switch for the ‘resting’ module and in some cases the switch was turned off immediately before starting the cycle. Some experimentation would be worthwhile to identify whether this timing makes any difference to the operation of the cooler.

7. OPTIMISING THE PERFORMANCE OF YOUR CRYOCOOLER

It will take practice and some experimentation to achieve the best possible performance of this cryocooler. 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

The cold head will cool very slowly after the cryopumps cool below 20 K and the gas is adsorbed into them. The key to a rapid cooldown is to keep the ^{4}He cryopumps *warmer* than about 20 K until the head is cold. The optimum strategy and timings will naturally depend upon the thermal loads and masses connected to the cooler unit.

7.2. Running the cooler

This cryocooler is designed to run from a mechanical cooler and for the heater and heat switch voltages to be applied in a predetermined sequence using a programmable interface. We have established its mode of operation using manual control.

It would be useful to try variations on the cryopump temperatures used to trigger switching events in order find the regime that gives the best performance for your particular experimental set-up. You may not need to heat the cryopumps as high as 50K if you can keep the main plate significantly below 4K while the operating pump is hot. In fact, if the main plate is kept below about 3.5K, the ^{4}He cryopumps may not need to get hotter than about 40K. This is because, with a lower main plate temperature the ^{4}He condensation will be more efficient, and also less ^{4}He will be used in cooling the cold head to the working temperature.

7.3. Operating the heat switches

Heat switches can be turned on more or less abruptly, depending upon the voltage applied to the switch heater. The heat switches will start to turn on when only about 1 to 1.5V is applied, and will be fully on when about 4V is applied. The switches begin to turn on at around 14 to 17K, and are fully on at around 20 to 25K. They should be fully off when their temperature falls below 10K.

8. STANDARD PIN-OUT ASSIGNMENTS

The table below shows wiring pin-outs to 37-pin micro-D SSP. Note that pins 16,34 or 17,35 are available to wire in a PID, should you wish to improve the temperature stability of the 1K cold head via a feedback loop.

FUNCTION	TYPE	PIN #	SUPPLY
Module 1 THERMOMETER V+	🟩	1	AC bridge or low-current driver 100nA typical
Module 1 THERMOMETER V-		20	
Module 1 THERMOMETER I+		2	
Module 1 THERMOMETER I-		21	
Module 2 THERMOMETER V+	🟩	3	AC bridge or low-current driver 100nA typical
Module 2 THERMOMETER V-		22	
Module 2 THERMOMETER I+		4	
Module 2 THERMOMETER I-		23	
n/c	⬜	5	
Split condenser HEAD RuO2 V+	🟩	6	AC bridge or low-current driver 100nA typical
Split condenser HEAD RuO2 V-		24	
Split condenser HEAD RuO2 I+		7	
Split condenser HEAD RuO2 I-		25	
DIODE pump 1 I+	🟦	8	10 µA Constant current, Read Junction Voltage.
DIODE pump 1 I1		26	
DIODE pump 2 I+	🟦	9	10 µA Constant current, Read Junction Voltage.
DIODE pump 2 I1		27	
DIODEswitch 1 I+	🟦	10	10 µA Constant current, Read Junction Voltage.
DIODE switch 1 I-		28	
DIODE switch 2 I+	🟦	11	10 µA Constant current, Read Junction Voltage.
DIODE switch 2 I-		29	
n/c	⬜	12	
n/c		30	
n/c	⬜	13	
n/c		31	
HEATER SWITCH 1 I+	🟪	14	10kΩ heater element 0-5V supply (approx)
HEATER SWITCH 1 I-		32	
HEATER SWITCH 2 I+	🟪	15	10kΩ heater element 0-5V supply (approx)
HEATER SWITCH 2 I-		33	
n/c	⬜	16	
n/c		34	
n/c	⬜	17	
n/c		35	
HEATER PUMP 1 I+	🟥	18	200Ω heater element 0-30V supply (approx)
HEATER PUMP 1 I-		36	
HEATER PUMP 2 I+	🟥	19	200Ω heater element 0-30V supply (approx)
HEATER PUMP 2 I-		37	

Resistance thermometer	🟩
Diode thermometer	🟦
Low power heater (a few mW)	🟪
High power heater (up to about 2W)	🟥