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

TWO-STAGE SUB-KELVIN ^{3}He COOLER

TYPE “HELIUM 7”

GENERIC INSTALLATION AND OPERATING INSTRUCTIONS

Photo shows a typical CRC ‘Helium 7’ cooler

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Registered in England & Wales, No. 4643351 **VAT registration No. GB 763 8558 84**

Contents

THIS GENERIC OPERATING MANUAL describes how to install and operate a CRC ‘Helium 7’ 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 cooler according to the instructions supplied, the cooler should be immediately transferred into the host cryostat. The shipping brace doubles as a stand for the cooler, 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 cooler up, it should be firmly grasped by the cryopump radiation shield or the main plate/angle bracket.

1. SAFETY OF CHASE RESEARCH CRYOGENICS PRODUCTS

1.1. 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.”

1.2. 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.

1.3. Safe Operation

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

1.4. 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 (also referred to as a fridge) has two cold heads on one side of the circular main plate, as can be clearly seen in the illustration on the title page. The ^{3}He ultra-cold head is the taller one, and the ^{4}He buffer head is lower (i.e. closer to the main plate). Between the ^{4}He buffer head and the main plate there is a film burning stage (^{4}He film burner), to which one of the ^{3}He support brackets is bolted. An additional ^{3}He buffer plate connects the ^{3}He gas pipes to the ^{4}He buffer head. In operation the unit will be inverted with respect to this picture, with the cold heads lowermost.

This model of cryocooler provides three points at which heat may be extracted from an experiment mounted on a separate cold table. They are the ^{3}He ultra-cold head, the ^{4}He buffer head, and the ^{4}He film burner (the copper platform that sits between the ^{4}He buffer head and the main plate). There are holes tapped on each of these surfaces for thermal connections between your experiment and the cryocooler.

Each of the two cold heads is provided with a calibrated RuO_2 or Cernox thermometer sensor to monitor the temperature. These sensors are inserted into sockets machined directly into the heads. Wiring for the thermometer sensors is carried from two sets of two isolated standoffs, one set on each head.

The two cryopumps and gas-gap heat switches are on the other side of the main plate. Each cryopump has a heater element that controls the cooling cycle. Both cryopumps are provided with standard 2.5” active gas-gap heat switches that are activated by 10 kΩ heater resistors, and each heat switch also carries a diode thermometer. Heat straps are fitted between the heat switches and the cryopumps.

All electrical connections are brought out to a 25-pin MDM-SSP connector mounted onto the main plate. Pin-outs are listed at the end of this manual.

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 pumps, 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 fridge. The heat switches can be easily damaged, and if bent or twisted are likely to fail.

This unit is designed to work 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. In addition to these, there is also a row of 4 x M4 clearance holes at ½” (12.7mm) centres, close to one edge of the main plate.

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.

4.2. Electrical

All electrical connections are brought out to a 25-pin MDM-SSP connector mounted onto the main plate. Pin-outs are listed at the end of this instruction manual. Voltage / current requirements for driving the heater and thermometers are summarised in the table below.

ITEM	NUMBER	IMPEDANCE/ JUNCTION VOLTAGE	VOLTAGE/ CURRENT
3-pump heater	1 off	400Ω approx.	0 to 20V
4-pump heater	1 off	200Ω approx.	0 to 24V
Heat switch heaters	2 off	10kΩ	0 to 5V
Diode thermometers	5 off	0.5 to 1.8V	10µA DC
^{4}He-head RuO_2 thermometer	1 off	1kΩ to 3kΩ	1µA max.
^{3}He-head RuO_2 thermometer	1 off	1kΩ to 7kΩ	100nA 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. A calibration curve specific to the film burner diode is also supplied.

Wiring for the temperature sensors on the cold heads is carried to insulated stand-offs mounted on each cold head, and from there directly to the 25-pin connector.

The thermometer on the ^{3}He ultra-cold head is operated as a 4-wire device and should be excited with an AC current no greater than 10nA, corresponding to a voltage of around 2mV at base temperature.

The thermometer on the ^{4}He buffer head is operated as a 2-wire device and should ideally be driven by an AC current no greater than 1µA. A reasonable temperature estimate can be gained by driving this sensor with 10µA DC, though this is likely to cause some self-heating and also be vulnerable to thermo-electric DC offsets, particularly at higher temperatures (see Figure 1).

The five diode thermometers require excitation with currents of 10µA DC.

As supplied, the heat switches require about 4V to keep them fully on at around 20 to 25 K, and cool to the OFF state (T < 12 or 15 K) in five to ten minutes.

The cryopump heater impedances are about 200Ω for the ^{4}He cryopump and about 400Ω for the ^{3}He cryopump. To begin the cooling cycle, once the main plate and cold heads are at around 4.2K, it is necessary to warm the ^{4}He cryopump to around 50 to 60K and the ^{3}He cryopump to 45 to 50K. A heater current of up to 100 to 130mA or so for the ^{4}He cryopump, and around 50 to 60mA for the ^{3}He cryopump, will heat the pumps rapidly. Lower heater currents will result in slower heating. Stabilisation of the pump temperatures at around 50K will typically require heater currents of around 12 to 15mA. Try to ensure that the lead-in wiring to these heaters is not unduly dissipative.

5. ATTACHING YOUR EXPERIMENT TO THE CRYOCOOLER.

This model of cryocooler provides three points at which heat may be extracted from an experiment mounted on a separate cold table. They are the ^{3}He ultra-cold head, the ^{4}He buffer head, and the ^{4}He film burner (the copper platform that sits between the heads and the main plate). In fact, to achieve optimum performance, only a very small load should be applied directly to the ^{3}He ultra-cold head. The main source of cooling power is the ^{4}He buffer head, which can sustain a thermal load of at least 250μW at a temperature of less than 1K. The ^{4}He film burner may also be used to sink some load at around 2K.

The top surface of the ^{4}He buffer head has 8 holes tapped M3 on a 40mm P.C.D. and a further axial hole tapped M4. The ^{3}He ultra-cold head has 9 tapped holes, again M3, on a 40mm P.C.D. The film burner has 6 M3 tapped holes on the main body, in pairs on each of the three free sides.

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

Under no load, the ^{3}He ultra-cold head will run at about 260mK, the ^{4}He buffer head at about 865mK, and the film burner at about 1 to 1.6K. When loads are applied, the heads and film burner naturally run warmer. Run time is limited by the buffer head, which (for this model of cooler) will last about 24 hours under the specified loads of 20μW on the ^{3}He ultra-cold head and 100μW on the ^{4}He buffer stage. Load data for your specific cooler are included in the accompanying Excel test data file.

5.1. Radiation shielding

The cold heads, 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 must be thermally sunk to the ^{4}He buffer head at some point between the ^{3}He ultra-cold head and the 4K plate, if a satisfactory operating temperature is to be reached. Temperatures below around 300mK are only achievable if the total thermal load on the ultra-cold head is kept to a minimum (below about 20 or 25μW). The ^{4}He buffer head and film burner are designed to buffer the parasitic loads due to wiring and mechanical support structures. An additional contact to the film burner may also be desirable, though not mandatory. No other mechanical attachments to the fridge unit are necessary, in order to achieve satisfactory operation.

6. OPERATION.

6.1. Pre-cool to 4K.

Because the cooling down of the heads depends upon gas convection, the fridge should be kept close to vertical during the cooldown process.

It is most important to understand that the cold heads cool by gas convection in the gas tubes, whereas the cryopumps cool by conduction through the heat switches, while the switches are in the ON state. The heat switches will turn OFF once they cool below around 12 to 15K.

In a 'wet' cryostat, the bare unit will cool to around 80 K in 3 to 4 hours, once LN_2 is introduced into the cryostat. During L^4He transfer, the cold heads cool rapidly while the cryopumps are warmer than about 25 or 30K, but they will cool very slowly after the cryopumps have cooled to below 25K, and the gas is adsorbed into them. If left like this, the cold heads will take two or three days to cool. The key to a rapid cooldown is to reheat both of the cryopumps to warmer than 25K (as described below) and to keep them at that temperature until the cold heads have cooled.

Once the cryopumps cool to below around 25K you must wait until the corresponding heat switches have cooled sufficiently and turned OFF (i.e. to less than about 12K) before applying heater power to the cryopumps. This will warm them up to more than 25K and allow the cold heads to resume cooling by gas convection. It will be necessary to apply heat to both cryopumps at the rate of about 50mW each, in order to keep them warm while the heads cool.

When filling your cryostat, if L^4He is transferred at a normal rate until the main bath is full, the cryopump heat switches may not turn off until after the cryopumps are also cold. An alternate strategy is to do an initial partial transfer at a slow pace, stopping the transfer when the cryopumps reach about 20 K, and restarting an hour or two later. The optimum strategy and timings will naturally depend upon the thermal loads and masses connected to the cooler unit.

When running the cooler from a mechanical pre-cooler (e.g. a PT or GM cooler) the same considerations apply. Cooling timescales will be similar unless limited by the cooling rate of the pre-cooler.

Once the cold heads have cooled to around 4 to 5K and both cryopump heat switches have turned OFF, the fridge is ready to run. The cryopumps should be warmed to around 50K to commence the cycle.

The following example figures are for a cooler designed to run for around 24 hours. Your own cooler may have a different run time and you should refer to your excel test file for the data specific to your instrument.

Figure 1 shows an example of a cooldown from room temperature to LN_2, and Figure 2 a cooldown from LN_2 to L^4He. In the example shown only the ^3He cryopump cooled down below 25K before the corresponding heat switch had turned off, but both cryopumps were re-heated to around 40 or 50K while the heads cooled down, so that the cycle could be commenced immediately.

In Figure 1 the RuO_2 sensor on the 4-head is excited with 10µA DC, and the effects of thermo-electric DC offsets are clear, particularly at higher temperatures. These effects are greatly mitigated at lower temperatures, and essentially vanish once the system has cooled below around 40K.

Figure 1: Pre-cool to LN_2.

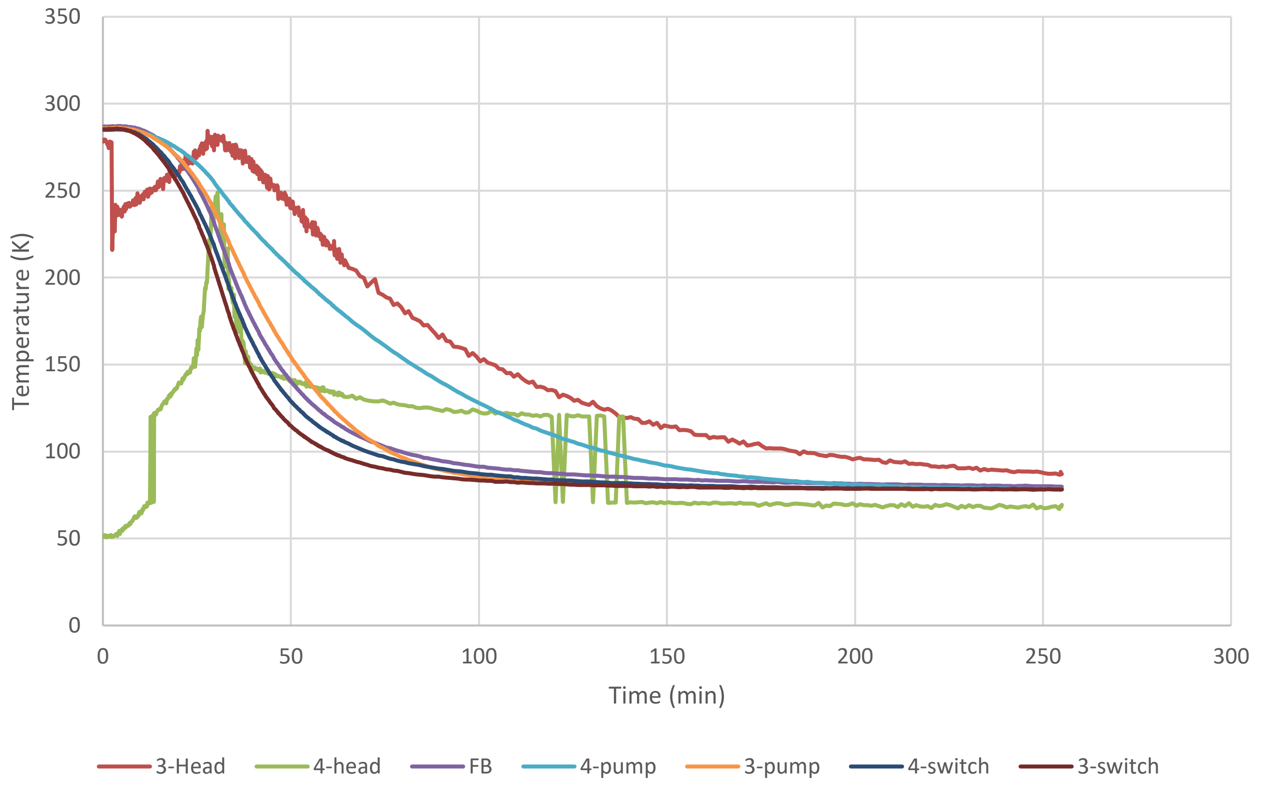
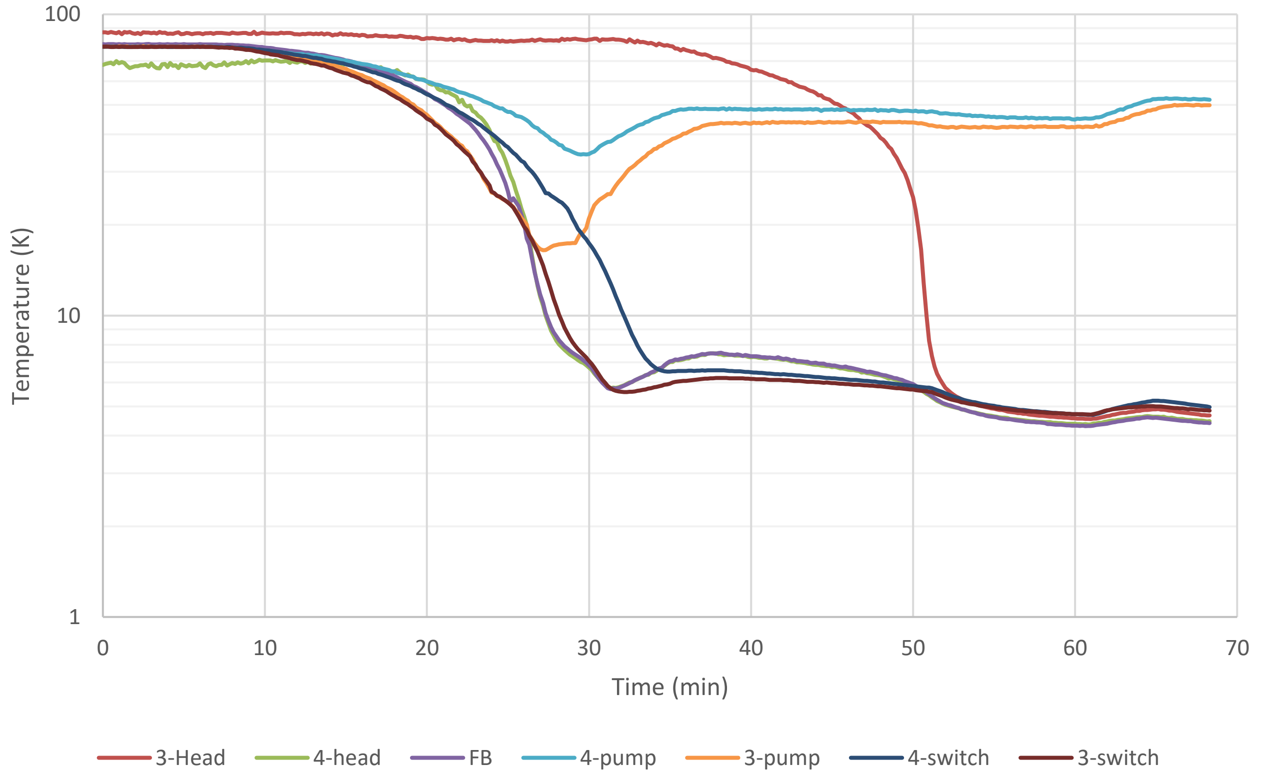


Figure 2: Pre-cool to L^4He,



6.2. Running the cooler

It is easy to get this cooler 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 the cooler, and may consequently alter the optimum mode of operation. The generic method of operation is described below and full test data for your specific cooler are given in the Excel file that accompanies this operating manual. You are recommended to experiment with variations on the method of operation, once some familiarity with the successful operation of the unit has been gained, in order to optimise performance for your application.

The generic method for this type of cooler is first to heat both pumps up to between 50 and 60 K, and to maintain them at this temperature while ensuring that the ^{4}He liquefaction point (in this model, the main plate) cools to below the critical point of ^{4}He (5.2K). In order to get the unit to operate satisfactorily, it is crucial that high liquefaction efficiency is achieved with the ^{4}He stage. The colder the liquefaction point gets while the pumps are warm (particularly the ^{4}He pump), the higher will be the liquefaction efficiency, and hence the longer the fridge will run before needing to be recycled. You should aim for a ^{4}He liquefaction temperature of below 4.6K. You should try variations on the cryopump temperatures to find a regime giving the best performance for your particular experimental set-up. Stabilising power for the ^{3}He cryopump should be around 40 to 50mW at 40 or 50K.

When operating from a low-powered mechanical cooler (e.g. 100mW @ 4K PT unit) you will probably achieve more efficient ^{4}He condensation by starting with the cryopumps at around 40 to 45K, rather than a higher temperature. This is because there will then be a smaller load imposed on the mechanical cooler due to the hot pumps. You will need to experiment in order to optimise performance for your set-up.

Once the ^{4}He charge is liquefied, the ^{4}He cryopump is allowed to cool by turning off the heater power and turning on the heat switch. This can be done more or less abruptly, depending upon the voltage applied to the switch heater. As the heat switch turns ON, the hot 4-pump imposes a large heat load onto the main plate, and this causes the main plate temperature to rise abruptly. When operating from the cold plate of a ‘wet’ cryostat this temperature rise is typically around 4 or 5K, to about 9K or so. When operating from a low capacity mechanical cooler the main plate temperature rise may briefly be greater than this, and there is the danger that if the main plate temperature should rise above about 12 or 15K the 3-pump heat switch might turn on prematurely. If this occurs then the heat switch can be turned ON slowly, by applying a lower activation voltage, and increasing it gradually, so that heat is not dumped too rapidly from the hot cryopump. If you are not in a hurry to complete the cycle you can even leave the 4-pump heat switch OFF for a while as the cryopump cools by heat leakage. It is most important to keep the 3-pump hot ($T > 35K$ or so) until the head temperatures have dropped below about 2K. The ^{3}He does not liquefy at the main plate, but at the film burner. The temperature of the main plate after ^{4}He liquefaction is not of direct relevance to the liquefaction efficiency of the ^{3}He charge, although the lower you can get the head temperature before cooling the ^{3}He pump, the better. The precise timings and temperatures can be varied to optimise the run time for your particular application, of course.

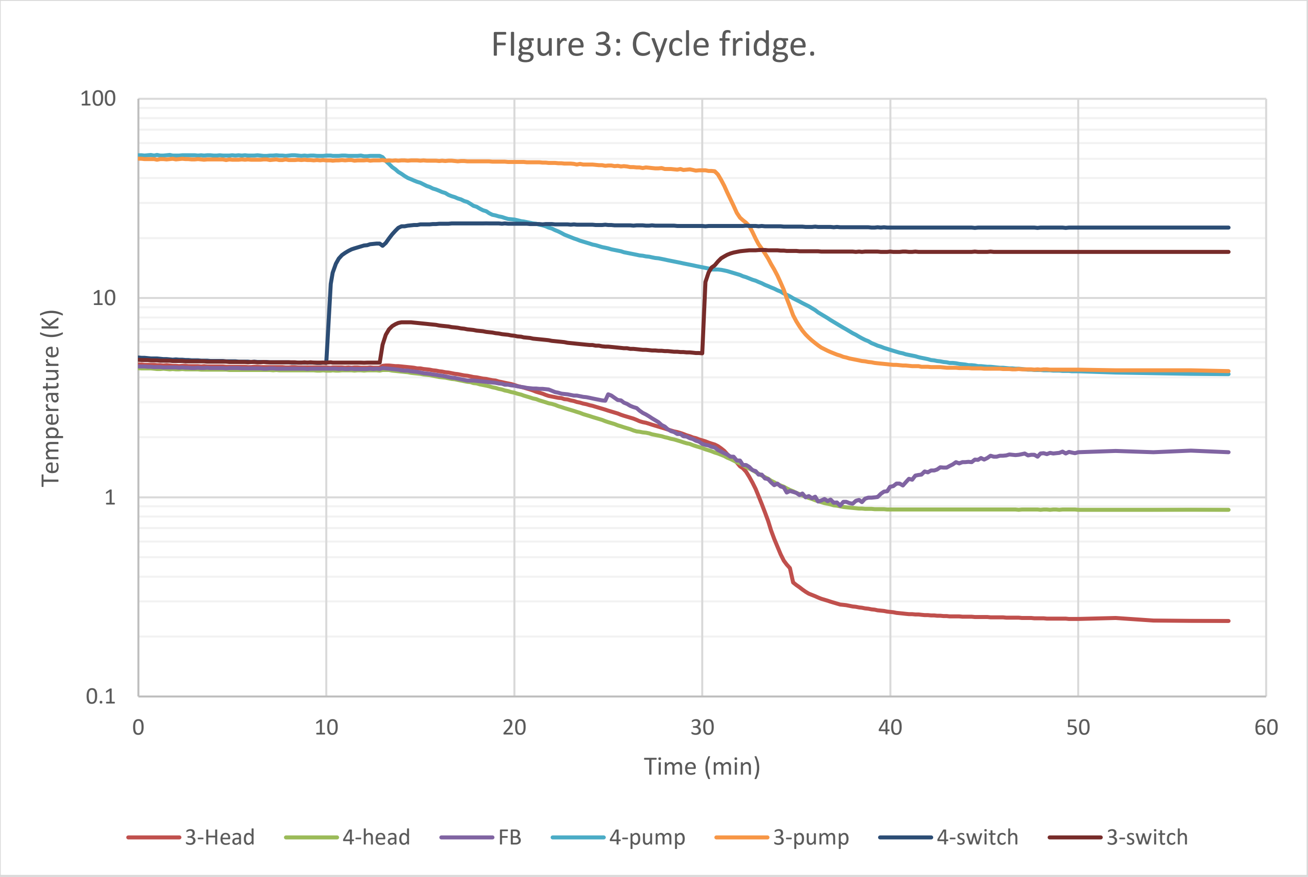
Once the ^{4}He has been liquefied, and the ^{4}He cryopump is cooling, the cold head temperatures and film burner temperature will start to fall rapidly. The ^{4}He cryopump cooling curve will flatten below 25K as the charcoal begins to pump on the ^{4}He vapour, and the head temperature will continue to drop. You can turn off the ^{3}He cryopump heater power once the ^{4}He cryopump switch is ON, and achieve satisfactory liquefaction efficiency by waiting to turn the ^{3}He cryopump heat switch ON until the head temperature has dropped to below 2K or so.

Once the ^{3}He cryopump has begun to cool, the ^{3}He cold head will also cool rapidly. Final stabilisation at the operating temperature will take some time, though how long will depend upon the thermal loads that are applied to the heads by your experimental arrangement. In general, lower loads result in lower running temperatures and these require longer to achieve stabilisation. The 3-head in particular can take some while to stabilise, particularly with applied loads of less than 1µW or so. This is because the liquid ^{3}He has a high specific heat capacity compared to the rate at which gas evaporation at very low vapour pressure can extract latent heat. The lower the final temperature, the lower will be the corresponding saturated vapour pressure, and thus the rate at which gas evaporates.

Finally, when the fridge is running, the heat switches for both cryopumps should be kept ON, or the cryopumps will warm up a bit and this will result in higher head temperatures.

6.3. Typical first cycle after cool-down to 4K.

The cycle shown in Figure 3 commences with the L^{4}He transfer complete, immediately after cool-down as shown in Figure 2, with the fridge main plate and cold heads at around 5K, and the cryopumps hot at around 50 to 60K. At the start of the cycle the ^{4}He cryopump heater power was about 48mW (3V, 16mA), and the ^{3}He cryopump heater power was about 40mW (4V, 10mA). Beginning at t = 0, all timings are in minutes.



t = 5. Turn ^{4}He cryopump heater OFF.

t = 10. Turn ^{4}He cryopump heat switch ON, 4V.

t = 14. Increase ^{4}He cryopump heat switch voltage to 4.5V.

t = 20. Turn ^{3}He cryopump heater current OFF.

t = 30. Turn ^{3}He cryopump heat switch ON, 4.5V.

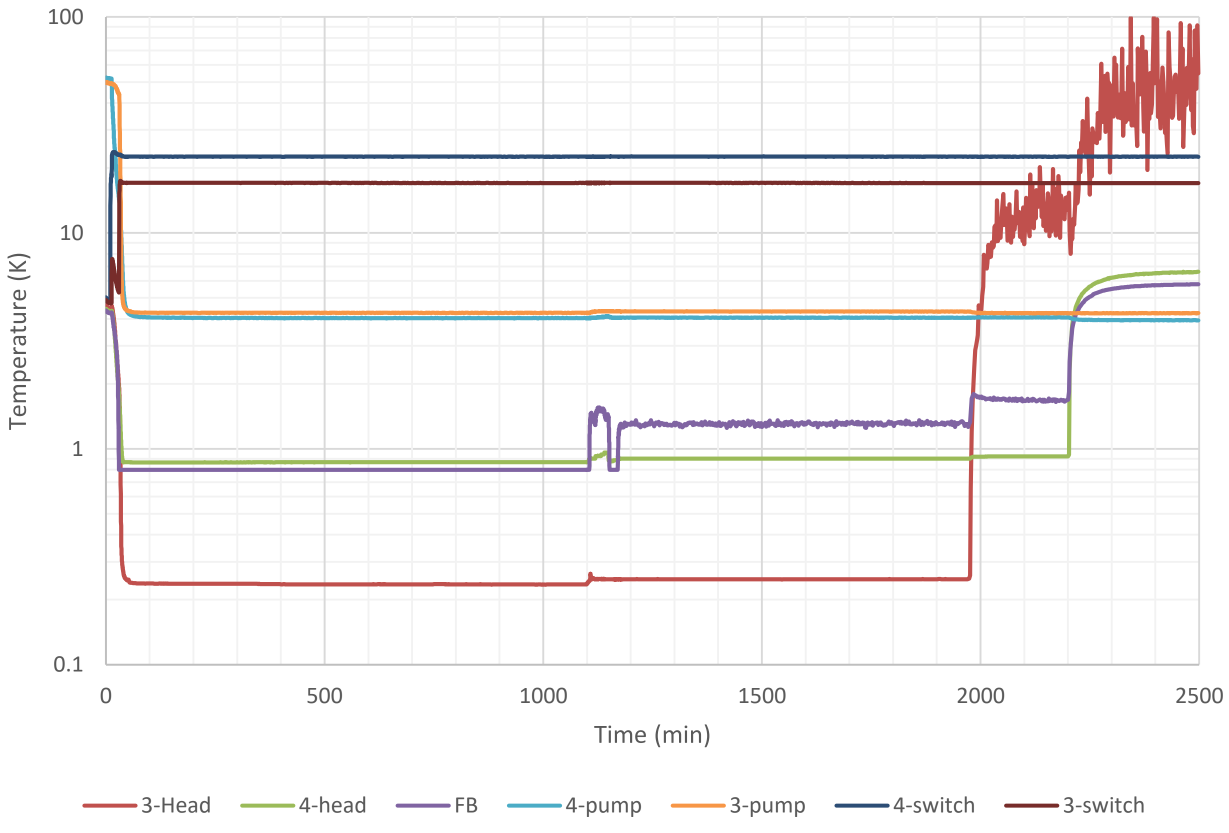
t = 45. Fridge is cooling nicely.

Figure 4 shows an example of a full cycle and run of the cooler, with no applied heat load for the first 18 hours, and under load thereafter. In this example the cooler continued to run for around 18 hours under load. Under no applied load, the base temperatures were around 260mK for the ^{3}He head, 865mK for 4He buffer head, and 1.5 or 1.6K for the film burner.

In operation, the parasitic loading may be distributed between the ^{4}He buffer head and the film burner in order to optimise the ^{3}He head temperature or the run time. Run times of around 22 to 24 hours should be possible provided that the loads on the ^{4}He buffer head and the ^{3}He head are kept below about 150µW and 20µW respectively.

An annotated test log and run data for your specific cooler are given in the Excel file that accompanies this manual. The operation of your cooler is shown with no applied load, and with a range of applied thermal loads.

Figure 4: Full Cycle & run.



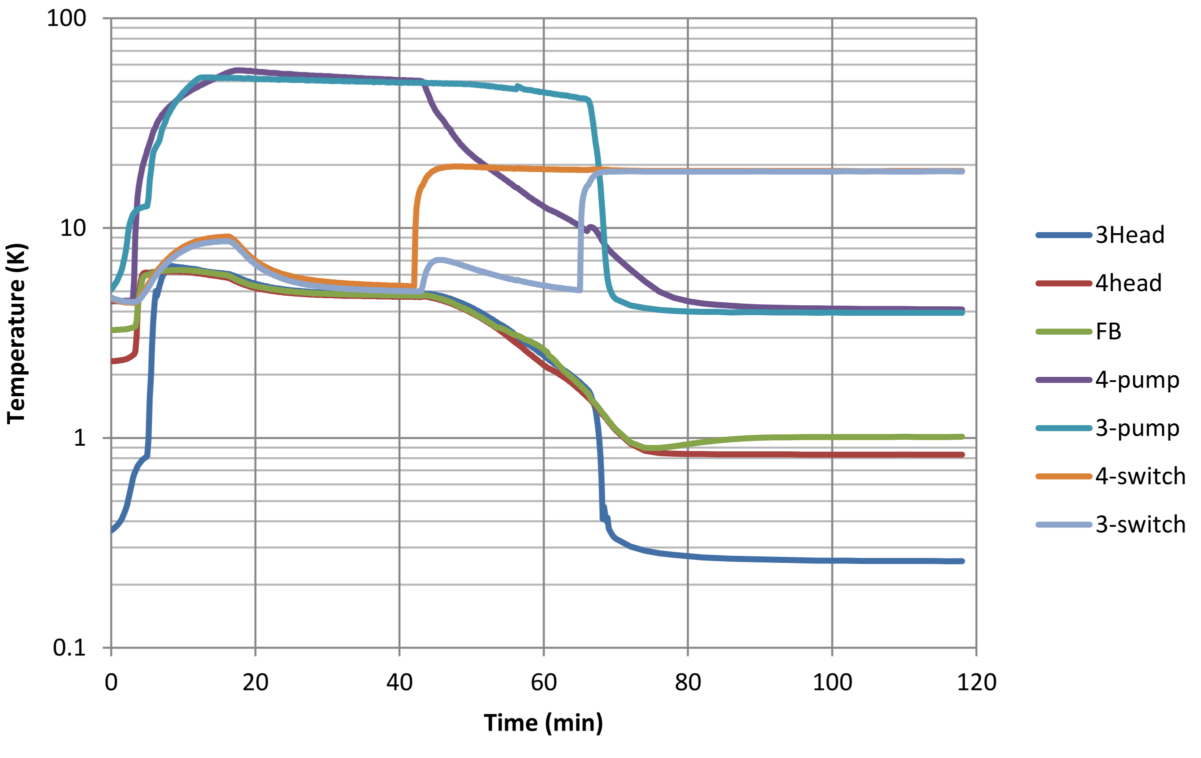
6.4. Typical re-cycle from cold

This example commences with all parts of the fridge at around 4.5 to 6K. In particular, the ^{4}He buffer head, the film burner and the ^{3}He cold head were all at around 4.5K.

Beginning at t = 0, all timings in minutes. At the start of this sequence all heater power was OFF. See Figure 5.

t = 3. Turn ON the ^{4}He cryopump heater, apply 25V (128mA, 3.2W).
t = 5. Turn ON the ^{3}He cryopump heater, apply 15V (48.9mA, 733.5mW).
t = 12. Reduce ^{3}He cryopump heater voltage to 4V (13.2mA, 52.8mW).
t = 16. Reduce ^{4}He cryopump heater voltage to 3V (15.6mA, 46.8mW).
t = 20. Turn ^{4}He cryopump heater current OFF
t = 42. Turn ^{4}He cryopump switch ON, 4V.
t = 50. Turn ^{3}He cryopump heater current OFF.
t = 65. Turn ^{3}He cryopump heat switch ON, 4V.
t = 80. Fridge is cooling nicely.

Figure 5: Re-cycle from cold.

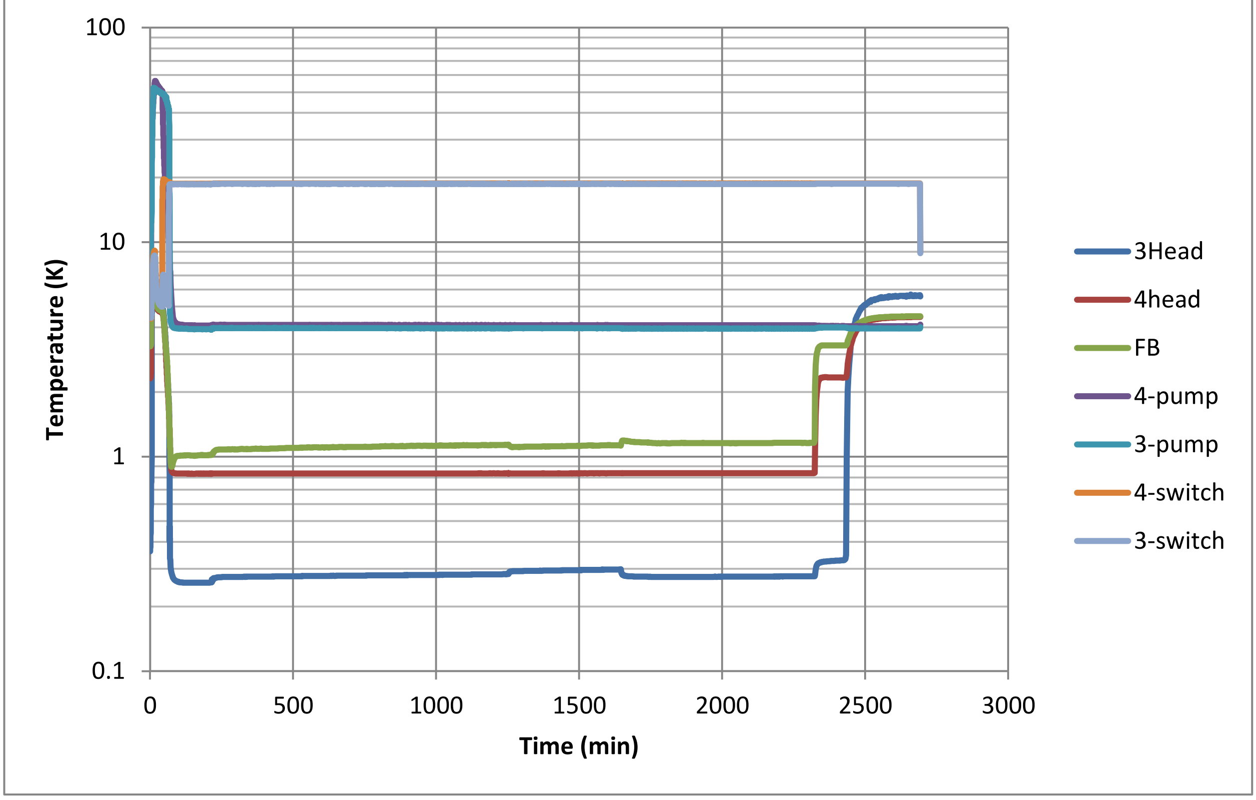


In this example the cycle is completed in less than 80 minutes, which includes heating the cryopumps from 4K to 50K. The ^{4}He buffer head stabilises very rapidly again, due to the superfluid state of the contents. The film burner takes longer to stabilise under no-load conditions, as does the ^{3}He cold head.

After the cycle is complete, the fridge is left to run under no applied loads until around t = 210, when the base temperature of the ^{3}He cold head reaches about 260mK. After this, a range of loads are applied until the host cryostat main bath ^{4}He runs out and the run is terminated, see Figure 6.

Data for you own cooler are presented in the annotated Excel test log that accompanies this instruction manual.

Figure 6: Full re-cycle and run.



In both of the example test cycles shown one can observe that the film burner temperature closely follows the ^{4}He cold head temperature as they cool down from 4K to around 0.9K after the 4-pump is allowed to cool. After a short while at around 0.9K the film burner temperature then starts to rise again. This signals the end of the first phase of ^{4}He pre-cooling. When operating the unit from a low powered pre-cooler, you are recommended to wait until this signal occurs before turning ON the ^{3}He cryopump heat switch. The run time of the ^{4}He cold head will not be greatly affected, but you may be able to achieve efficient condensation of the ^{3}He at a temperature below 2K without the need to raise the temperature of either cryopump as high as 50K. If the cryopump temperatures can be kept lower while still achieving efficient condensation, then the system will recycle more rapidly and also will place less strain on the pre-cooler stage. This in turn is likely to produce a more efficient and satisfactory cycle and run.

7. STANDARD PIN-OUT ASSIGNMENTS.

1	Cernox or RuO_2	^{3}He HEAD	V+
14	Cernox or RuO_2	^{3}He HEAD	V-
2	Cernox or RuO_2	^{3}He HEAD	I+
15	Cernox or RuO_2	^{3}He HEAD	I-
3	NC	NC	
4	RuO_2	BUFFER HEAD	I+
16	RuO_2	BUFFER HEAD	I-
5	DIODE	FILM BURNER	I+
17	DIODE	FILM BURNER	I-
6	DIODE	^{4}He PUMP	I+
18	DIODE	^{4}He PUMP	I-
7	DIODE	^{3}He PUMP	I+
19	DIODE	^{3}He PUMP	I-
8	DIODE	^{4}He PUMP SWITCH	I+
20	DIODE	^{4}He PUMP SWITCH	I-
9	DIODE	^{3}He PUMP SWITCH	I+
21	DIODE	^{3}He PUMP SWITCH	I-
10	HEATER	^{4}He PUMP SWITCH	I+
22	HEATER	^{4}He PUMP SWITCH	I-
11	HEATER	^{3}He PUMP SWITCH	I+
23	HEATER	^{3}He PUMP SWITCH	I-
12	HEATER	^{4}He PUMP	I+
24	HEATER	^{4}He PUMP	I-
13	HEATER	^{3}He PUMP	I+
25	HEATER	^{3}He PUMP	I

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