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SUPERCONDUCTING ROCK MAGNETOMETER CRYOGENIC SYSTEM MANUAL

February 2006

CONTENTS

1. INTRODUCTION :

1.1 Pulse Tube Cryocooler:

The 4 K SRM uses a Cryomech pulse tube cryocooler to achieve the required 4 Kelvin operating temperatures without the use of any liquid helium. The differences between the pulse tube cooled system and the liquid helium cooled magnetometers have very significant impact on the system ease of use, convenience, safety and long term reliability.

It is important to understand that the basic superconducting instrument remains the same. A superconducting shield, SQUIDS and pickup coils are identical and are cooled to below the superconducting transition and maintained at this temperature by intimate thermal contact with the low temperature stage of the pulse tube cryocooler. The thermal insulation and high vacuum requirements remain the same. Also, the superconducting shield dimensions are the same, giving the same attenuation of external magnetic field changes.

The system is cooled from room temperature by simply turning on the pulse tube cryocooler and leaving it operating for about 24 hours.When the system is cold the magnetic field at the measurement region will be equal to its room temperature value. A typical cooling curve is given in figure 1-1.

The field can be changed and reduced to near zero using helmholtz type field control coils that are wrapped onto the vacuum jacket. These coils are the same as those used with the liquid helium cooled SRM. The field control is described in section 3 of this manual.

If the cryocooler is turned off for any reason the 4 K stage will start to warm within a few minutes. This warming time versus temperature is given in figure 2-1. The superconducting components will warm to above their transtion temperature in about 30 minutes. Warming will continue as long as the cryocooler is off. When the cryocooler is turned back on the cooling will start and return to 4 K in from a few minutes to 24 hours depending on how warm the system reached.

Whenever the superconducting shield is warmed above its transition temperature of 7.2 K the trapped magnetic field will be lost. When the system is cooled back down this field must be retrapped. If the laboratory magnetic field environment has not changed significantly, then it will usually be sufficient to simply turn the nulling supplies on when the system is warm and keep them on until the system is back to the 4 K temperature.

Another significant difference between the pulse tube cryocooled system and the liquid helium cooled system with GM cryocooler is the long term reliability. The pulse tube cold head has no moving parts , only a properly phased flow of helium gas into and out of the cold head. The compressor , motor and valve that controls this gas flow are all at room temperature and are easily replaced without warming the system.

1.2 Calibration data for SRM:

CALIBRATION CONSTANTS FOR SQUIDS

:

X axis = 10^{-5} emu/ flux quanta
I bias

Y axis = 10^{-5} emu/ flux quanta
I bias

Z axis = 10^{-5} emu/ flux quanta
I bias

Field Control Coils:

Sense region trim coils:

These coils are helmholtz pairs of 15 turns each coil of 0.016 inch insulated copper wire wrapped directly on the 21 inch OD dewar vacuum jacket.

The Axial trim coil : 1 milliamp = 60 gamma

The SQUID direction trim coil : 1 milliamp = 70 gamma

The Fill port direction trim coil : 1 milliamp = 70 gamma

Cryocooler tube gradient coil 1 milliamp = 25 gamma

This coil is a 50 turn coil wound on the cryocooler mounting tube. Its purpose is to cancel the vertical field produced by the cold head and by the opening in the ferromagnetic shield There is an independent coil power supply and potentiometer for the control of this current.

Temperature sensors:

The equilibrium diode voltages at temperatures shown are:

diode location	BNC	box	295K	77K	50 K	4.0 K
4K cryo	T1	1	0.4	1.0	1.07	1.65
shield	T2	1 or 2	0.4	1.0	1.07	1.65
50 K cryo	T1	3	0.4	1.0	1.07	N/A

1.3. Suggested data recording for magnetometer:

DAILY:

1 Measure and record standard sample. Dipole moment to be about 1 X E-5 emu on each axis.

2 Wipe sample handler bars with clean cloth and use light spray of dry silicone or teflon lubricant for discrete sample handlers..

WEEKLY:

1 SQUID signals with scope. Record peak to peak AC voltage, and value of I BIAS potentiometer.

2 Temperatures T1 and T2 using box # 1 and T1 using box # 2. Cryocooler compressor pressure. This should be about 270/280 for the high pressure and 90/100 for the low pressure, and should fluctuate by about 10 psig each cycle.

EVERY TWO YEARS:

1 Change the cryocooler adsorber. This takes about 30 minutes and is done with the magnetometer cold. New adsorbers are available directly from Cryomech new adsorbers cost about US$1,200. Please refer to the Cryomech manual for addresses.

2. SYSTEM EVACUATION AND COOL DOWN:

The system is pumped out and cooled to operating temperatures for all performance testing prior to delivery. The system is then warmed to room temperature for shipment

Figures 2-1, and 2-2 will assist in understanding the construction and connections of the magnetometer. The Cryomech, Inc. manual describes the installation of the cryocooler compressor, gas line connection and operation.

2.1 CHECKING VACUUM:

a) Remove the brass threaded plug from the vacuum valve on the SRM top plate (on the end of the SRM where the SQUID amplifiers are located), see 1-3. Using teflon thread seal, screw the brass to KF 25 flange fitting into the vacuum valve until it is tight. Do not over tighten. The brass fitting supplied with the SRM is for KF 25 O ring sealed flanges.

b) Connect the fitting a vacuum pump that will reach a vacuum of at least 5 microns (5 millitorr) and install a vacuum gauge in the pumping line close to the SRM valve.

c) Pump the vacuum line and gauge down to 5 microns then open the vacuum valve on the SRM and record the pressure. If convenient close the pumping line between the gauge and the vacuum pump and record the initial pressure in the SRM. If the SRM has not been pumped since delivery and it has been allowed to warm to room temperature, then the initial pressure should be between 100 and 1000 microns.

d) Close the SRM vacuum valve as soon as the pressure is determined. Proceed to the next section if additional pumping is required.

2.2 PUMPING ON THE SRM VACUUM:

a) If the initial pressure at room temperature is above 100 microns then it is desirable to pump on the vacuum space to remove the outgassing contaminants that have accumulated since the previous cool down.

b) A trap MUST be inserted between the vacuum pump and the SRM to prevent pump oil vapor from back streaming into the superinsulation space of the SRM. We strongly recommend a liquid nitrogen cooled trap although a good antiback streaming gauze type trap is adequate if it is clean. If a turbo molecular pump is used the trap is not needed.

c) With the pump, trap and gauge installed, pump out the line to the SRM valve before opening the valve. Now open the valve to the SRM and pump until the vacuum reaches at least 30 microns and preferably 10 microns. This will take anywhere from 1 to 3 days depending on the time since the previous pump down. When the pump down is completed close the SRM valve and remove the vacuum pump. Replace the brass vacuum valve plug.

2.3 LEAK TESTING:

If a vacuum leak is suspected it will be necessary to connect a helium mass spectrometer detector to the SRM vacuum valve. Pump down the connecting line in the manner described in 1-1-a through c and then open the vacuum valve and measure the background level of helium in the SRM vacuum space. External leaks can be located by normal leak detection techniques of applying small amounts of helium gas on any suspected regions and monitoring the internal helium background. The leak detector response can be very slow because of the large volume of the vacuum region in the SRM and the many layers of thermal insulation, so patience and care will be required in the leak testing process. It is advisable to contact the factory before leak testing the system and we will provide specific instructions depending on the nature of the suspected leak.

2.4 COOL DOWN

When the magnetometer is installed the compressor, gas lines and remote motor are connected to the crycooler cold head as described in the Cryomech manual. The following steps are recommended to cool the magnetometer to operating

temperature:
1. Measure the 3 diode temperatures (for the 4 K cryocooler, superconducting shield and 50 K cryocooler) These voltages should be approximately 0.54 at room temperature. See Figure 1 for the diode voltage versus temperature calibration.
2. Record the static compressor pressure. Keep a record of the time, compressor pressure and diode temperatures. The initial compressor pressure before turning on will be 195 psig on the high and low pressure gauges.
3. Turn on the compressor and cold head. See Figure 2 for a typical cool down.
4. After 60 minutes of cool down record the compressor pressures and the 3 diode temperatures. The high pressure should be 280/290 and the low pressure 75/85. The diodes should be approximately box #1, T1 = 0.9 V = 135 K for the 4 K cryocooler stage., box # 1, T2 = 0.65 V = 245 K, and box #2, T1 = .7 V = 220 K = 50 K cryocooler stage.
5. Inspect the access tube and it should be at room temperature with no condensation.
6. Feel the cold head near its base and it should be very warm, at approximately 130 F.
7. At this time if the pressure and temperature are approximately as noted above, the system can be left with t he compressor and cold head running and it will take approximately 24 hours for the superconducting shield to reach 4 K. No further operator attention is required.
8. It is useful to adjust the magnetic field at the measurement center using the 4 current controls as described in section 3.3. The field and field gradient can be set to near zero and the power supplies left on until the cooling is complete and the field is trapped. The final field should be checked to be certain that the current or ambient field has not changed during the cool down.
9. When the system is cold for at least a few hours turn on the SQUID electronics and confirm that the SQUID signal are correct.
10. The system is now ready for measurement.

2.5: COLD HEAD SHUT DOWN

If the cold head or compressor is turned off for any reason the system will start to warm up. Figure 3 shows a typical warming curve. If the superconducting shield warms to above 1.5 volts

(7.2 K) the trapped field will be lost and the nulling coil power supplies should be turned back on to the null the field before cooling back down.

3. INSTRUMENTATION:

The SRM dewar system is fitted with 3 diode thermometers, 3 resistive heaters and a 4 axis set of field nulling coils. The diodes and heaters are connected through a 15 pin connector on the SQUID end top plate. The cable to the control electronics is fitted with a 9 pin connector and two adapter interconnect boxes are supplied to fit between the 15 pin and 9 pin connectors. The box number and function is given in the table below:

Box#	function	9 pin#	15 pin #	switch
1	shield heater	5,4	5,4	shield htr.
1	SQUID heater	5,6	5,6	heater #1
1	Strip line heater	5,3	5,3	heater #2
1	Supercomducting shield	1,7	1,7	T1
1	4 K cryo diode	1,8	1,8	T2
2	50K cryo diode	1,7	1,11	T1

3.1 THERMOMETERS:

There is a silicon diode thermometer mounted on the superconducting shield that is thermally linked to the cryocooler and one on the 4 K cryocooler stage. One other diode is mounted on the 50 K cryocooler stage. Power to the diodes is supplied from the SQUID control/monitor electronics through its interconnect cable. Diode power is applied whenever the electronics is turned on and the cable is connected. The diode voltage is measured with an external DVM connected to either of two BNC outputs on the rear panel of the control electronics. The diode voltage at critical temperatures is given in the table above. Figure 3-3 gives an approximate diode voltage versus temperature for the Lakesshore diodes. standard diodes. The voltage change with temperature is approximately 2.7 millivolts per Kelvin from room temperature to about 55K, and is about 0.040 volts per Kelvin from 55 K temperature to 10 K. The diodes are Lakeshore silicon type DT-

471 and the calibration curve is given in figure 4 When the control/monitor cable is connected directly to the SRM top plate electrical feed-thru 15 pin connector, using adapter number 1 the two BNC's monitor the superconducting shield temperature and the 4K cryocooler temperature. The 50 K cryocooler diode is read by connecting the control/monitor cable to the 15 pin connector on the SRM using adapter number 2 (see table above for pin connections).

3.2 HEATERS:

There are three heaters built into the system:

1. The superconducting shield heater on pins 4-5 of the electrical feedthru connector is a 500 ohm resistor attached to the superconducting shield. It is used to heat the shield above its transition temperature to change the trapped magnetic field.

2. The SQUID heater (#1) on pins 5 and 6 is a 500 ohm heater attached to the SQUID mounting block. It is used to heat the SQUIDS above their transition temperature to remove any trapped magnetic flux.

3. The strip line heater (#2) on pins 3 and 5 is a 500 ohm heater attached to the superconducting strip lines between the pickup coils and the SQUIDS. It is used to remove large circulating currents from the pickup coil structure without heating the SQUIDS or shield.

3.3 FIELD NULLING COILS:

There are four coils mounted outside the dewar vacuum jacket to help establish a low field environment in the SRM measurement region. The calibration constants for these coils are given below and in the front of this manual. To use the coils to change the field it is first necessary to heat the superconducting shield to above its critical temperature as described in the following section. The coils are referred to as axial (to change the field in the sample access direction) and transverse - two orthogonal sets of saddle coils for changing the field in the directions transverse to the dewar axis, and gradient to control the vertical field gradient that is produced by the col dhead and the opening in the ferromagnetic shield.

The axial coil is a helmholtz pair of coils wrapped on the dewar vacuum jacket. Each transverse coil is a pair of saddle shaped helmholtz coils 1/2 meter long and 1/2 meter circumferential length. The vertical field gradient coil is a 50 turn solenoid wound one the cryocooler mounting tube. The approximate field constants for these coils with 15 turns in each coil are given below:

transverse	= 70	gamma per milliamp.
transverse	= 70	gamma per milliamp.
axial	= 60	gamma per milliamp.
gradient	= 20	gamma per milliamp

To null the SRM field it is advisable to use four independent current supplies for the coils (a simple 4 axis line powered supply is provided with the system) and a three axis flux gate in the access of the SRM. The APSI models 520 and 520A fluxgates are often used for this application. Heat the superconducting shield as described in the following section and adjust the coil currents to achieve the desired field. It requires about 45 seconds to heat the shield to its non-superconducting state and it can be maintained at this higher temperature (about 10 kelvin) by turning the heater on for about 10 seconds then off at 4 minute intervals and monitoring the diode voltage. When the superconducting shield is heated then first cancel the vertical gradient using the gradient coil. Measure the vertical field at the measurement center and then at +/- 2 cm about the center. Adjust the gradient coil to eliminate the gradient. Next, use the 3 helmholtz coils to reduce the field at the measurement center to below 5 gamma in all three directions. Check the field gradient by measuring the fields at +/- 2 cm about the measurement center and redjust the currents as needed. When the desired internal field is achieved keep the coil currents constant and let the superconducting shield cool to trap the field. Wait until the superconducting shield temperature reaches 5 kelvin or less before turning off the coil currents. This temperature is measured with diode T-1 using box 1. Please check the actual equilibrium values for the specific SRM. It will require about 20 minutes for the shield to cool after it has been heated to 10 kelvin and another hour before the system lowest noise performance is achieved. Record the setting of each of the 4 potentiometers

3.4 SWITCHING THE SUPERCONDUCTING SHIELD:

The superconducting shield is a crucial part of the SRM. Because of the unique properties of superconducting materials this shield provides very high attenuation of external magnetic field changes and permits the trapping of a specific field environment. Superconducting materials exhibit zero D.C. resistance so any change in magnetic field will produce an induced current that flows undiminished so long as the field change is applied. This means that the net magnetic flux linking a superconducting ring will remain constant. For a cylindrical shell structure of the type used on the SRM it can be shown that axial magnetic fields are attenuated by a factor of $31^{(l/r)}$, where l is the distance in from the open end of the shield measured on axis and r is the shield radius. Transverse fields are attenuated by a factor of $36^{(l/2r)}$. For the shield dimensions used in the 7.6 cm (3.0 in) 760 SRM and the 4.1 cm (1.65 inch) 755 this provides an attenuation of axial fields at the measurement center of 10^{11} and of transverse fields of 10^{6}.

The only operational procedure used with the superconducting shield in the SRM is its thermal switching. To trap a given magnetic field environment it is necessary to produce the desired field with coils, magnetic shields, etc. then turn on the shield heater for about one minute, then turn it off. The field at the SRM access can be measured with a fluxgate magnetometer during this process to determine the value to be trapped. As described in the previous section the field is usually adjusted with the built in nulling coils when the shield is normal. Maintain the desired field as constant as possible for the next 20 minutes. It is best to monitor the superconducting shield temperature (Diode T1, box 1) and wait until it cools to about 5 K at 1.6 volts, before removing the external field source. At this time the shield will be well below its superconducting transition temperature and the field will be trapped by the superconductor. It will take an additional hour or more for the SQUIDS to reach their lowest noise performance.

4. CRYOCOOLER MAINTENANCE AND PROBLEMS :

4.1. COLD HEAD MAINTANENCE:

The cold head of the pulse tube cryocooler is permanently mounted to the magnetometer vacuum jacket. This cold head has no mechanical moving parts and it should last almost indefinitely. All mechanical parts are in the remote motor and valve assembly. This is serviced by exchanging for a rebuilt or new motor valve assemble available from Cryomech. The exchange is done by turning orr the cryocooler disconnecting the three aeroquip quick connect fittings and replacing the assembly. The process takes less than 30 minutes. The SQUIDS and superconducting shield will warm slightly during this process and it will take a few hours to reach equilibrium temperature after the cryocooler is restarted. The trapped magnetic field must be checked and if it has changed a field trapping procedure will; be required.

4.2 Compressor maintenance.

The gas adsorber of the compressor must be changed every two years. For air cooled compressors the air filter must be changed every two months. Please see the Cryomech manual for specific details of this maintenance.

5. TELEPHONE, E-MAIL AND FAX NUMBERS

William Goree office: 831-883-0196
e-mail: goree@2gsuper.com
FAX: 831-883-0197

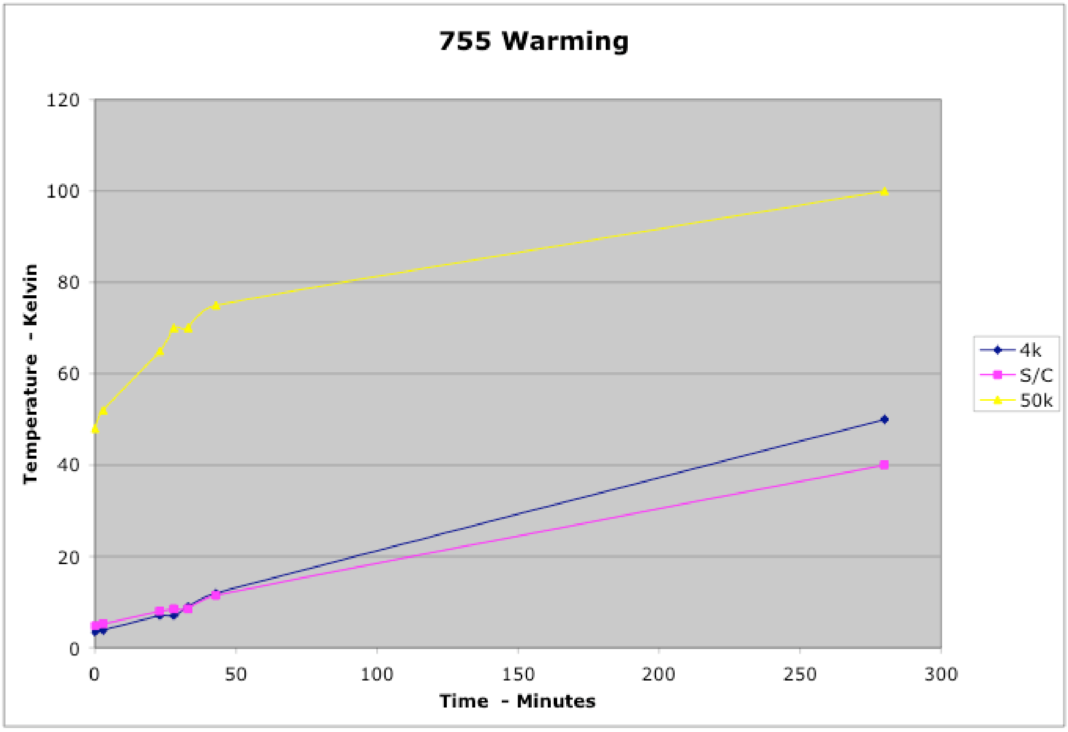
Standard Curve 10

Standard Curve 10: Measurement Current = 10 µA ±0.05%

T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)
1.40	1.69812	–13.1	16.0	1.28527	–18.6	95.0	0.98564	–2.02
1.60	1.69521	–15.9	16.5	1.27607	–18.2	100.0	0.97550	–2.04
1.80	1.69177	–18.4	17.0	1.26702	–18.0	110.0	0.95487	–2.08
2.00	1.68786	–20.7	17.5	1.25810	–17.7	120.0	0.93383	–2.12
2.20	1.68352	–22.7	18.0	1.24928	–17.6	130.0	0.91243	–2.16
2.40	1.67880	–24.4	18.5	1.24053	–17.4	140.0	0.89072	–2.19
2.60	1.67376	–25.9	19.0	1.23184	–17.4	150.0	0.86873	–2.21
2.80	1.66845	–27.1	19.5	1.22314	–17.4	160.0	0.84650	–2.24
3.00	1.66292	–28.1	20.0	1.21440	–17.6	170.0	0.82404	–2.26
3.20	1.65721	–29.0	21.0	1.19645	–18.5	180.0	0.80138	–2.28
3.40	1.65134	–29.8	22.0	1.17705	–20.6	190.0	0.77855	–2.29
3.60	1.64529	–30.7	23.0	1.15558	–21.7	200.0	0.75554	–2.31
3.80	1.63905	–31.6	24.0	1.13598	–15.9	210.0	0.73238	–2.32
4.00	1.63263	–32.7	25.0	1.12463	–7.72	220.0	0.70908	–2.34
4.20	1.62602	–33.6	26.0	1.11896	–4.34	230.0	0.68564	–2.35
4.40	1.61920	–34.6	27.0	1.11517	–3.34	240.0	0.66208	–2.36
4.60	1.61220	–35.4	28.0	1.11212	–2.82	250.0	0.63841	–2.37
4.80	1.60506	–36.0	29.0	1.10945	–2.53	260.0	0.61465	–2.38
5.00	1.59782	–36.5	30.0	1.10702	–2.34	270.0	0.59080	–2.39
5.50	1.57928	–37.6	32.0	1.10263	–2.08	280.0	0.56690	–2.39
6.00	1.56027	–38.4	34.0	1.09864	–1.92	290.0	0.54294	–2.40
6.50	1.54097	–38.7	36.0	1.09490	–1.83	300.0	0.51892	–2.40
7.00	1.52166	–38.4	38.0	1.09131	–1.77	310.0	0.49484	–2.41
7.50	1.50272	–37.3	40.0	1.08781	–1.74	320.0	0.47069	–2.42
8.00	1.48443	–35.8	42.0	1.08436	–1.72	330.0	0.44647	–2.42
8.50	1.46700	–34.0	44.0	1.08093	–1.72	340.0	0.42221	–2.43
9.00	1.45048	–32.1	46.0	1.07748	–1.73	350.0	0.39783	–2.44
9.50	1.43488	–30.3	48.0	1.07402	–1.74	360.0	0.37337	–2.45
10.0	1.42013	–28.7	50.0	1.07053	–1.75	370.0	0.34881	–2.46
10.5	1.40615	–27.2	52.0	1.06700	–1.77	380.0	0.32416	–2.47
11.0	1.39287	–25.9	54.0	1.06346	–1.78	390.0	0.29941	–2.48
11.5	1.38021	–24.8	56.0	1.05988	–1.79	400.0	0.27456	–2.49
12.0	1.36809	–23.7	58.0	1.05629	–1.80	410.0	0.24963	–2.50
12.5	1.35647	–22.8	60.0	1.05267	–1.81	420.0	0.22463	–2.50
13.0	1.34530	–21.9	65.0	1.04353	–1.84	430.0	0.19961	–2.50
13.5	1.33453	–21.2	70.0	1.03425	–1.87	440.0	0.17464	–2.49
14.0	1.32412	–20.5	75.0	1.02482	–1.91	450.0	0.14985	–2.46
14.5	1.31403	–19.9	80.0	1.01525	–1.93	460.0	0.12547	–2.41
15.0	1.30422	–19.4	85.0	1.00552	–1.96	470.0	0.10191	–2.30
15.5	1.29464	–18.9	90.0	0.99565	–1.99	475.0	0.09062	–2.22

Lighter numbers indicate truncated portion of Standard Curve 10 corresponding to the reduced temperature range of DT-471 diode sensors. The 1.4 – 325 K portion of Curve 10 is applicable to the DT-450 miniature silicon diode sensor.

Lake Shore Cryotronics, 575 McCorkle Blvd. Westerville, OH 43082-8888. Visit Our Website: www.lakeshore.com
(614) 891-2243 – Phone, (614) 891-1392 – Fax. E-Mail: sales@lakeshore.com, service@lakeshore.com


755 Warming
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Time - Minutes
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60
80
100
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300
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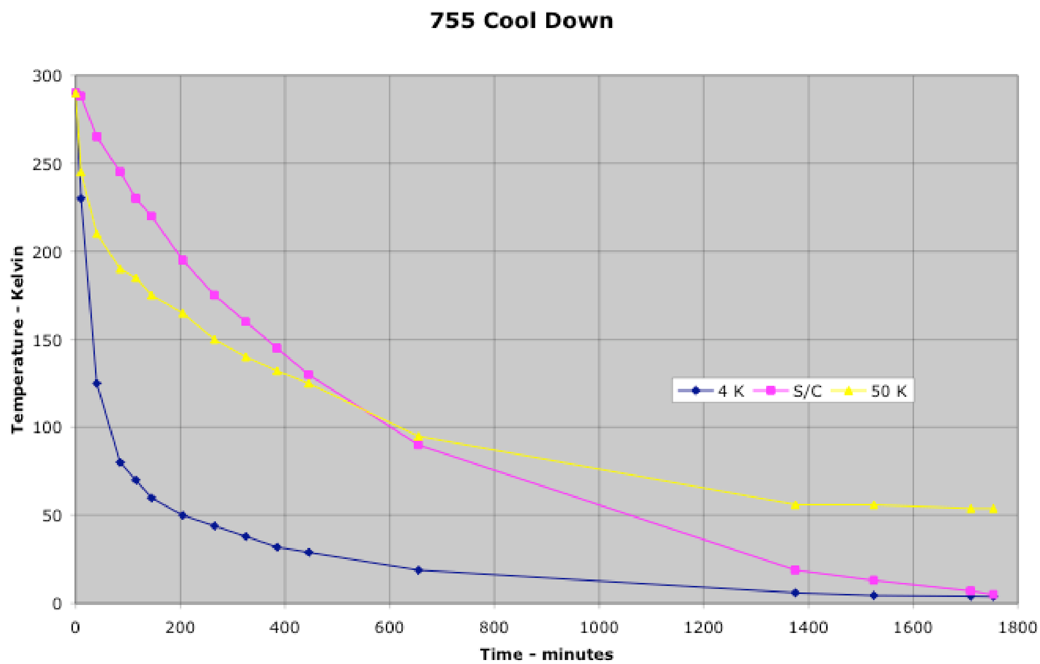
S/C
50k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Temperature - Kelvin
Time - minutes
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