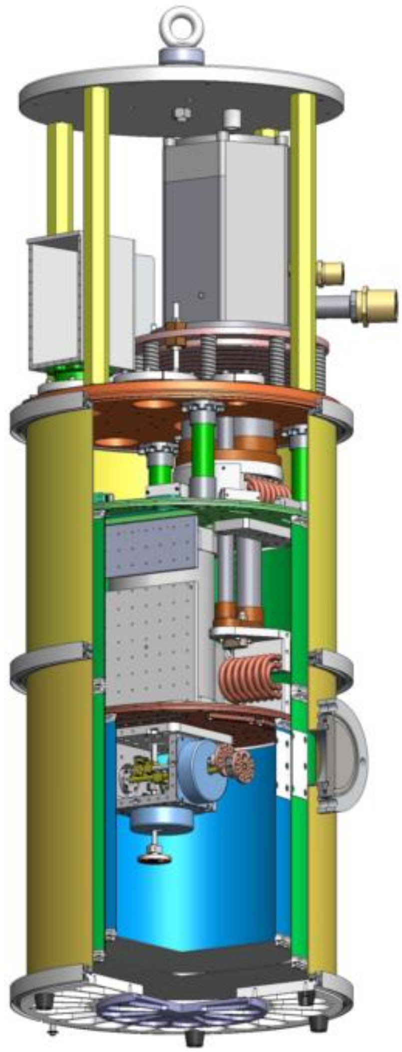
ADR Cryostat Installation and Operation Manual



Pulse-Tube Driven ADR Cryostats:

- **Model 102 Denali**
- **Model 103 Rainier**
- **Model 103 RCC**
- **Model 104 Olympus**
- **Model 106 Shasta**
- **Model 107 K2, with He3 Cooler**
- **CE**

CE

Declaration of Conformity

Product Name: **ADR Cryostat**
Model Numbers: **Model 103**

We, High Precision Devices, Inc., 1668 Valtec Lane, Boulder Colorado, 80301 declare that the above-referenced product is in conformity with the following standards:

EMC Directive:	EN 61326-1: 2013 EN 55011: 2009 + A1: 2010, Class A, Group 1 CISPR 11, Ed. 5.1, 2010-05, Class A, Group 1
Testing Laboratory:	NTS-Longmont
EC Certificate and Report No.:	TRB60609-PR047697
Low voltage Directive:	2014/35/EU EN 61010-1: 2010 (3rd Edition)
Testing Laboratory:	NSS Laboratories, Inc.

1/18/2017
(Signature) (Date)

Wm Hollander President
(Printed name) (Title)

1668 Valtec Lane, Suite C □ Boulder, Colorado 80301 □ Phone (303) 447-2558 □ Fax (303) 447-2548

Table of Contents

Table of Figures

Table of Tables

1. Introduction

1.1. General Description

High Precision Devices, Inc. (HPD) has designed a line of cryogen-free pulse-tube driven cryostats using adiabatic demagnetization refrigerators (ADR) to reach cryogenic temperatures for laboratory experimentation. The cryostat stage temperatures are approximately 60 K, 3 K, 500 mK, and 50 mK, depending on the cryostat model and configuration. This manual will describe HPD's line of ADR cryostats and their proper installation and operation. Some details contained in this document may not be applicable to legacy systems.

All models of the ADR cryostats include a Cryomech pulse-tube refrigerator (PTR) which provides cooling for the 60 K and 3 K stages. The PTR consists of a compressor package, remote motor, cold head, bellows, and helium flex lines. The PTR is a closed-loop system that provides reliable cooling without the use of any liquid cryogens.

The ADR (shown in Figure 6) in HPD cryostats generates the coldest stage temperatures (500 mK and 50 mK). The ADR contains a superconducting 4 T magnet, a Gadolinium Gallium Garnet (GGG) paramagnetic salt pill, a Ferric Ammonium Alum (FAA) paramagnetic salt pill, a Hiperco 50 magnetic shield, and a Kevlar suspension system. The ADR generates cooling through adiabatic demagnetization of the paramagnetic salt pills. The Kevlar suspension isolates the salt pills from warmer stage temperatures while supporting modest experimental payloads of 1 kg or less.

The cryostat frame (shown in Figure 1) consists of 3 stage plates (room temperature, 60 K, and 3 K) connected by thermally isolating supports. Each plate includes a series of pass-throughs for experimental and thermometer wiring. Radiation shields are connected to the 60 K and 3 K plates to block blackbody radiation from reaching the low temperature experimental volume. The PTR is attached to the cryostat frame with bellows and copper jumper cables to reduce vibrations and allow for differential thermal contraction. A vacuum jacket attaches to the 300 K plate and encloses the cryostat.

1.2. Standard Cryostat Features

- Fast cool down from room temperature
- Low base temperatures (< 50 mK)
- Long hold times (> 150 hours, no load)
- Cryomech pulse-tube refrigerator
- Vibration isolation
- Multiple feed-through ports
- Quick release vacuum jackets (Models 103, 106)
- Captive screws on thermal shields for quick assembly/disassembly (Models 104, 106)
- Electronically controlled mechanical ADR heat switch (except Model 102)
- Kevlar ADR suspension

1.3. Glossary

1.3.1. Definitions

Back EMF	**The voltage opposing any change of current in the inductive circuit of the superconducting magnet.**
Cold Head	The portion of the pulse-tube refrigerator built into the cryostat that generates the 60 K and 3 K stages.
High T_c Leads	The high temperature superconducting leads made from Yttrium Barium Copper Oxide (YBCO) that serve as the portion of the ADR magnet power circuit between the 60 K stage and the 3 K stage. The leads pass high current with reduced heat conduction relative to other materials.
Jumper Cables	A flexible braided copper wire connection between the 60 K stage of the cold head and the 60 K stage plate and between the 3 K stage of the cold head and the 3 K stage plate.
Puck	Subassembly of the ADR suspension system, about the size of a hockey puck, containing three stages thermally isolated from each other by Kevlar thread. Four pucks are used per ADR suspension.
Quench	The sudden catastrophic collapse of the magnetic field of the superconducting magnet. In the ADR, magnet quenches most commonly occur when too much current is sent through the magnet, the magnet is warmed above its superconducting temperature, or the driving voltage across the magnet is changed too rapidly.

Table 1: Definitions

1.3.2. Acronyms and Abbreviations

ADR	**Adiabatic Demagnetization Refrigerator**
BOB	Break Out Box
EMF	Electromotive Force
FAA	Ferric Ammonium Alum
GGG	Gadolinium Gallium Garnet
HPD	High Precision Devices, Inc.
PTR	Pulse-Tube Refrigerator
RuO_2	Ruthenium Oxide Thermometer
UPS	Uninterruptable Power Supply
YBCO	Yttrium Barium Copper Oxide

Table 2: Abbreviations

1.4. Safety Symbol Definitions

Color coded separate sections containing information about safety warnings, safety cautions, and special information are spread throughout the manual. A summary list of all the separate sections can be found in the appendix. The color codes and section descriptions are:

	Electrostatic Sensitive Device: To prevent equipment damage use proper grounding techniques. Electromagnetic Environment. The Cryostat system is intended for use in a controlled electromagnetic environment. Higher levels of RF interference may degrade performance of sensitive measurement circuitry.
NOTICE	**NOTICE:** Used to address practices not related to personal injury. Risk of damage to equipment. Additional information to aid the operator.
CAUTION	**CAUTION:** This warning is used without the safety alert exclamation point, and addresses practices not related to personal injury.
! CAUTION	**CAUTION:** Used with the safety alert symbol, indicates a hazardous situation which, if not avoided, **could result in minor or moderate injury**. Care must be taken to prevent potentially significant damage to equipment and ensure safety of operator. Consult manual.
! WARNING	**WARNING:** Used to indicate a hazardous situation which, if not avoided **could result in death or serious injury**.

1.4.1. Equipment Safety

	**Control Rack** For operating parameters refer to Table 5: Operating Parameters. Rack input power is 230VAC, 50/60 Hz, 7amps. All equipment in rack must be connected as indicated in supplied Wiring Schematics and in accordance with Manual. Rack must be powered with supplied power cord or with one rated per local codes and jurisdictions. Operator must wear properly grounded wrist strap when rack is open. Do not install on an uneven surface.
	**Cryostat** Cryostat weight is greater than 150 lbs. Operator must lift Cryostat with a crane.
	**Model 100 Atlas Service Stand** Operator must adjust the load to the lowest position when traveling. Do not install on an uneven surface. No incline more than 10% grade.
	**Liquid Nitrogen Outlet (RCC Cryostats Only)** Extreme cold. Operator must wear approved personal protective equipment (PPE). • Safety Goggles (unvented)-required at all times. • Face Shield-required when pouring or filling. • Insulated Gloves- gloves should be loose fitting enough so they can be quickly removed if liquid should pour in them. You can also purchase elastic cuff insulated gloves- gloves are required. • A lab coat with long sleeves is required to minimize skin contact. Also, pants should be worn on the outside of shoes or boots to prevent shoes from filling in the event of spillage. • When handling large quantities of LN2, an apron should be used as well. The release of nitrogen can also displace oxygen in a room and cause asphyxiation. If dewars and insulated flasks containing liquid nitrogen are left uncovered for extended periods of time, liquid oxygen can build up to levels which may cause violent reactions with organic materials (i.e. severe clothing fire could result). HPD recommends Research Labs use Oxygen Monitors in Cryostat areas.

The helium compressor module needs to be installed according to manufacturer specifications.

If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

1.5. Contact Information

High Precision Devices, Inc.
1668 Valtec Lane, Suite C
Boulder, CO 80301-4655

Phone: 303-447-2558
Fax: 303-447-2548

Website: www.hpd-online.com
Email: info@hpd-online.com

Engineers and scientists are available at HPD during normal business hours (9 a.m. to 6 p.m. Mountain Time USA, GMT -7) to assist customers in the event there is a problem or question with a cryostat.

2. System Components

2.1. Cryostat Chassis Assembly

The main purpose of the cryostat chassis, shown in Figure 1, is to support the two stage pulse-tube cryocooler and ADR, to reduce the thermal load on the ADR, and to provide a structure to mount and heat sink wiring and other components. The cryostat frame has three stage plates: 300 K, 60 K, and 3 K. The 60 K and 3 K stages are cooled by the 1st stage and 2nd stage of the pulse-tube, respectively. Low thermal conductivity G10 supports connect the stage plates. High thermal conductivity radiation shields attach to, and hang from, the 60 K and 3 K stages creating a series of volumes to reduce the heat load on the ADR stages. A vacuum jacket hangs from the 300 K plate creating the vacuum envelope.

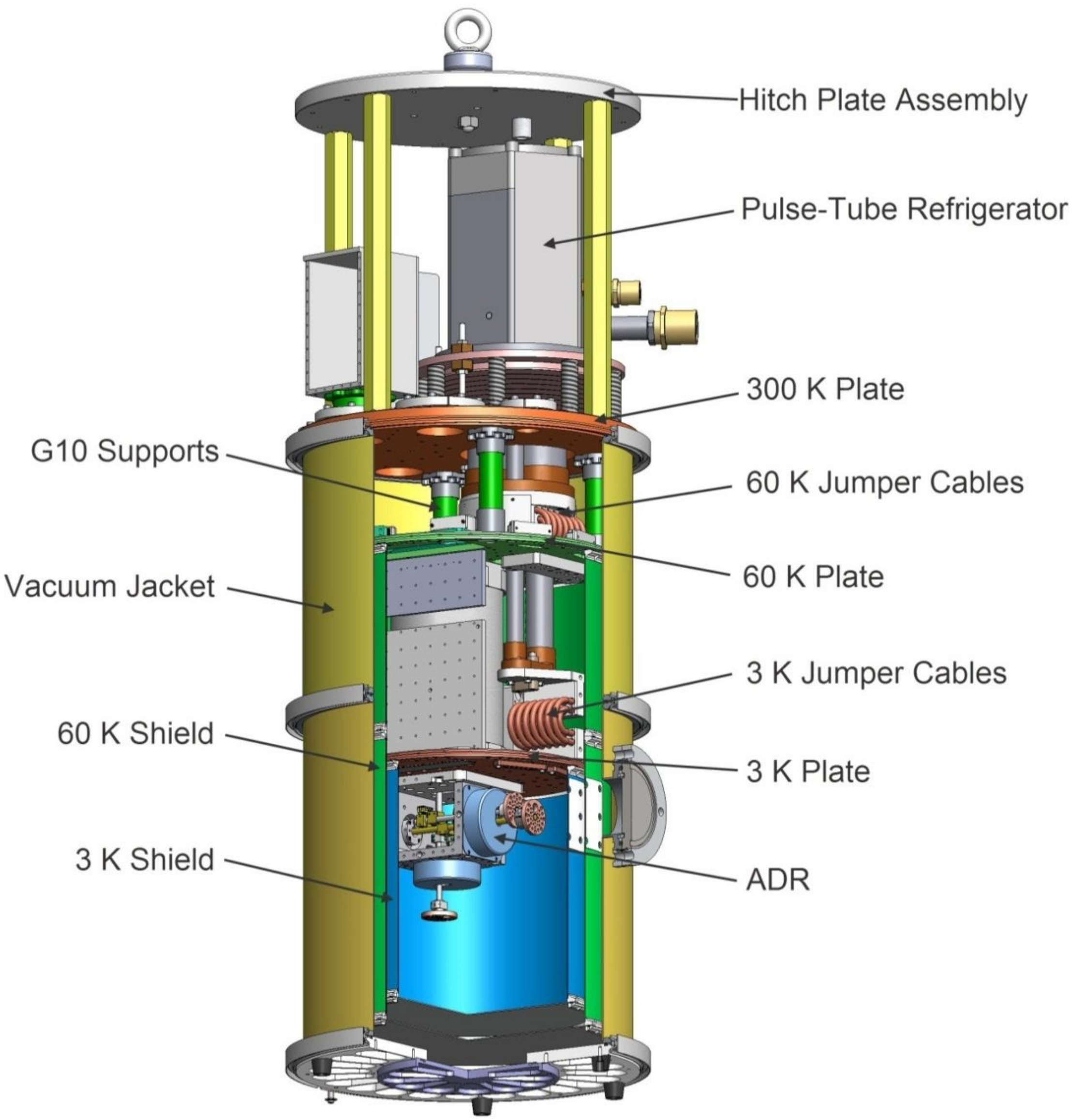


Figure 1: Cut-away view of the Model 103 Rainier

The 300 K plate, shown in Figure 2, contains a series of ports to hermetically pass wires and components into the vacuum space. The pulse-tube cold head enters the cryostat through a bellows that is sealed to the 300 K plate. The 300 K plate also contains a series of standard NW type vacuum ports. Depending on the cryostat model the NW ports are used for some or all of the following:

- To pass thermometry and magnet wiring into the vacuum space
- To attach the heat switch control box
- To attach the vacuum valve (On Model 102 Cryostats the vacuum valve is located on the vacuum jacket.)
- To pass liquid nitrogen lines into the vacuum space (only on the RapidCool Cryostat)

The remaining NW type vacuum ports are reserved for customer use. Openings into the vacuum space at the vacuum jacket joints, ports, and bellows are sealed with standard O-rings and are also sealed against RF radiation using Spira rings. The top plate also includes a grounding stud to ground the top plate. Grounding is discussed further in section 4.4. The 300 K plate also has a 1 bar over-pressure safety relief valve to prevent dangerous pressurization of the vacuum space.

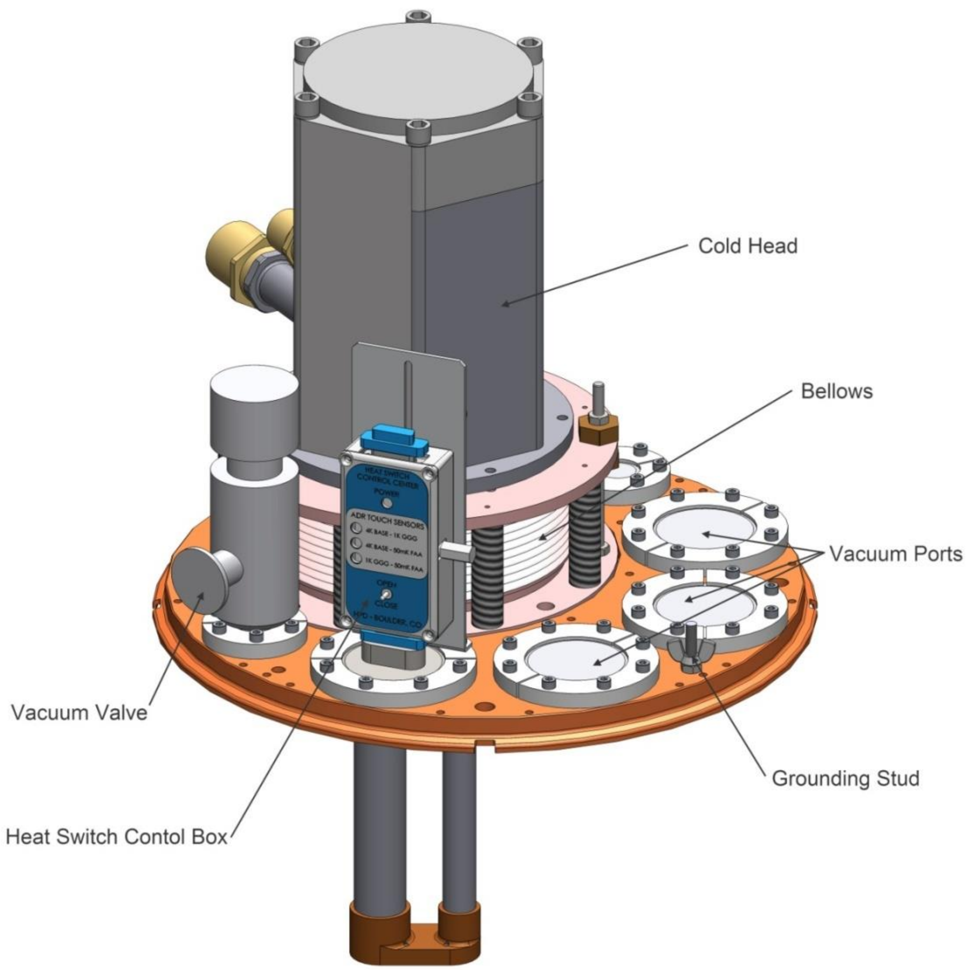


Figure 2: Model 103 Rainier 300 K plate assembly

The 60 K plate, shown in Figure 3, attaches to the 1st stage of the pulse-tube cold head via a set of jumper cables to create the first thermal stage. The 60 K plate has ports for passing and heat sinking wires and also attaches to and cools the 60 K shield. A 60 K electronics plate with a grid of #4-40 holes is provided for customer mounting. The 60 K plate has a silicon diode thermometer.

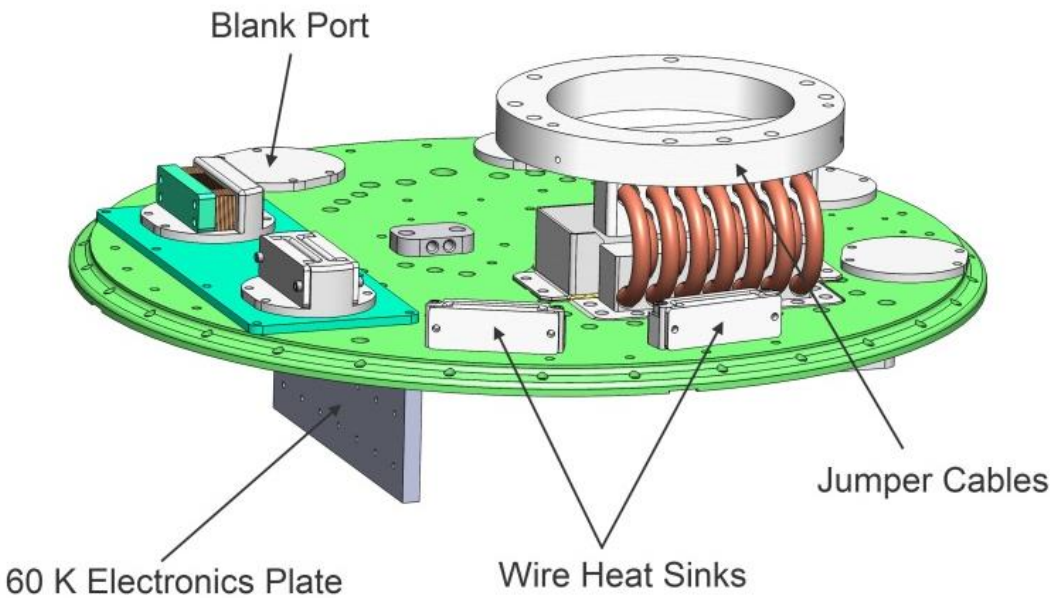


Figure 3: Model 103 Rainier 60 K plate assembly

The 3 K plate, shown in Figure 4, attaches to the 2nd stage of the pulse-tube cold head via a set of jumper cables to create the second thermal stage. The 3 K plate has ports for passing and heat sinking wires and also attaches to and cools the 3 K shield. The ADR and the heat switch for the ADR mount to the 3 K plate. The heat switch shaft shield, located over the hole where the heat switch shaft penetrates the 3 K plate, prevents radiation from heating the heat switch vise drive shaft and blocks light from entering the 3 K envelope around the shaft. A pair of High T_c (high temperature superconducting) leads carries high current between the 60 K and 3 K stages to power the superconducting magnet in the ADR while minimizing the heat load. A serpentine box allows gas to flow out of the 3 K space during vacuum pump-down while preventing light radiation from entering the 3 K space. A 3 K electronics plate with a grid of #4-40 holes is provided for customer mounting. The 3 K connector plate can be modified by the customer to accommodate feedthroughs into the 3 K space. In systems with an ADR that includes a 20 A magnet, the protection diodes for the magnet are mounted on the 3 K plate. The 3 K plate also has a silicon diode thermometer.

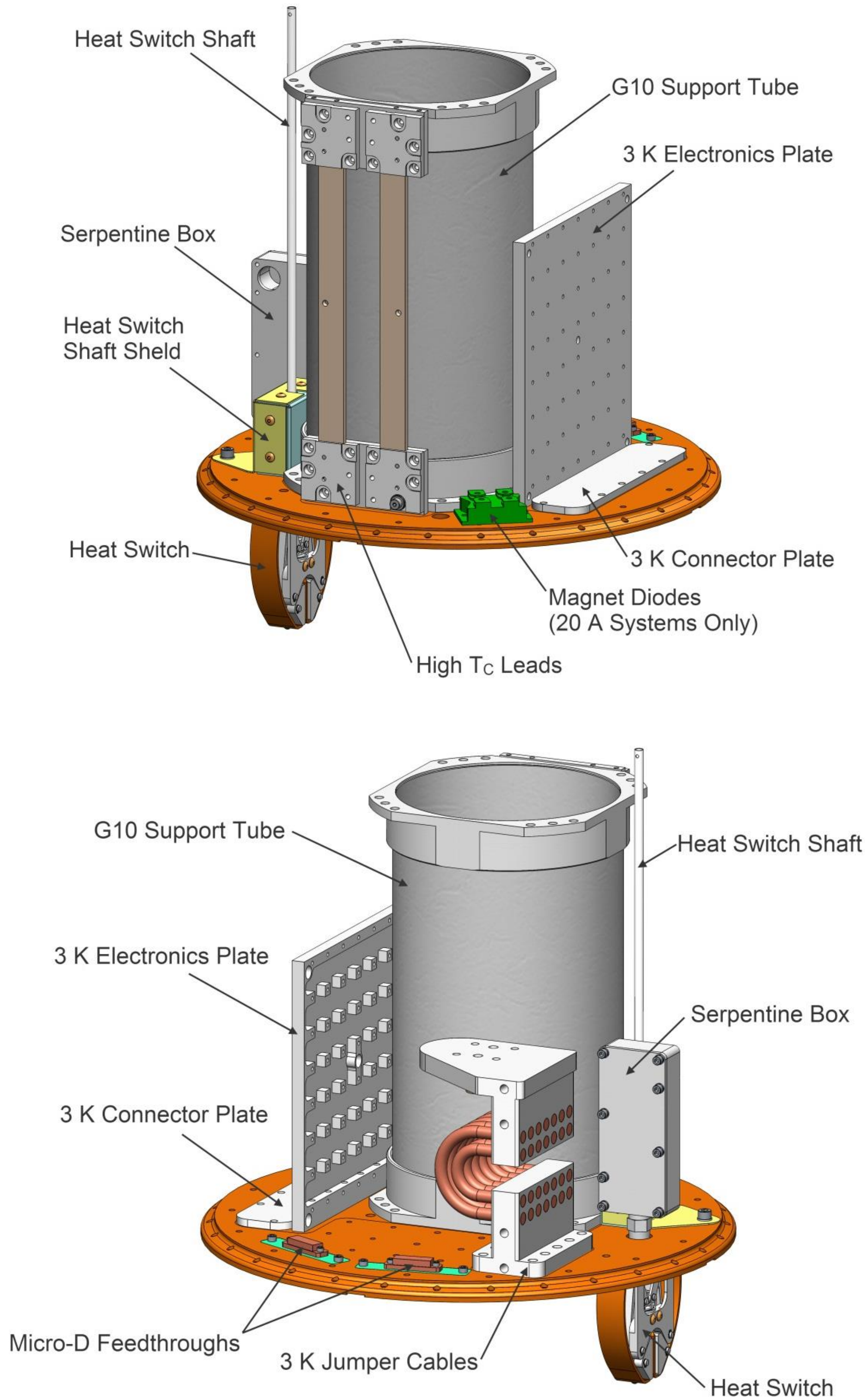


Figure 4: Model 103 Rainier 3 K plate assembly

2.2. Cryomech Pulse-Tube Refrigerator

The 60 K and 3 K stages are cooled by a Cryomech pulse-tube refrigerator (PTR) shown in Figure 5. The PTR is a closed-loop system, meaning that the helium in the system is recycled and is not consumed during normal operation. The PTR consists of a compressor package, high-pressure stainless steel helium flex lines, a remote motor, and a cold head. The system requires an electrical connection and a chilled cooling water connection to operate. For the PT407, Air-cooled compressors are available if cooling water is not available. Please refer to the installation and operating manual from Cryomech for more information on the proper installation and operation of the PTR.

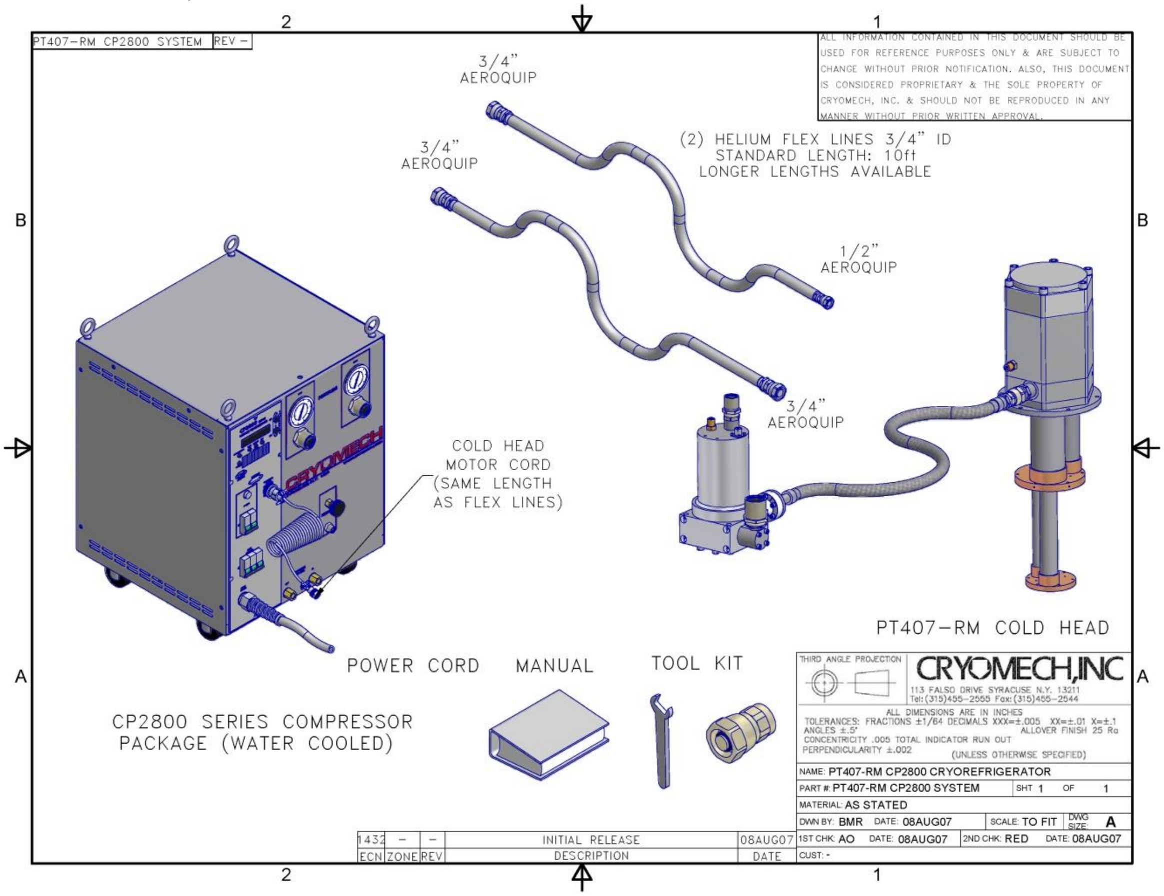


Figure 5: Typical Cryomech Pulse-Tube Refrigerator System

2.3. Adiabatic Demagnetization Refrigerator (ADR)

The ADR, shown in Figure 6, generates the coldest two stages of the cryostat through adiabatic demagnetization of paramagnetic salt pills. The ADR contains two paramagnetic salt pills: a Gadolinium Gallium Garnet (GGG) pill, generating a 500 mK stage and a Ferric Ammonium Alum (FAA) pill, generating a 50 mK stage. The pills are located in the bore of a cylindrical 4 T superconducting magnet that generates the magnetic field necessary for the operation of the ADR. The magnet lies within a Hiperco 50 magnetic shield which prevents the majority of the magnetic field from escaping to the rest of the cryostat (200 µT typically seen at the bottom of the 50 mK rod). A gold-plated copper thermal shield reduces the radiative load on the Hiperco 50 shield and magnet.

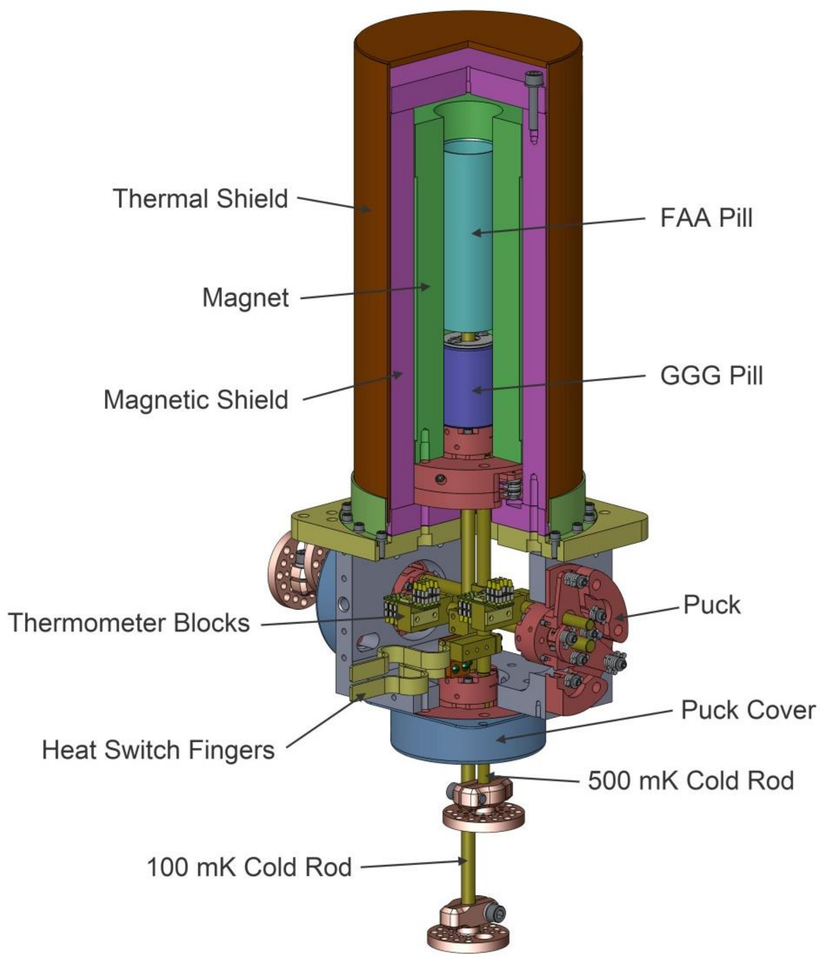


Figure 6: Cut-away view of an ADR

CAUTION	The temperature of the FAA salt pill must NEVER exceed 104° F (40° C, 313 K). Permanent damage will result.

The salt pills are semi-rigidly held in place and thermally isolated from other stages with a Kevlar thread suspension system. The suspension system consists of four individually strung pucks: a top puck (hidden from view inside the magnetic shield and above the ADR base plate), a bottom puck, and two side pucks. Each puck, as shown in Figure 7, has three stages isolated from each other with Kevlar thread that winds around capstans: the 3 K outer ring, the 500 mK trefoil piece, and the 50 mK central stud. The four pucks are linked with vertical and horizontal rods to form the suspension system. The two side pucks include travel stops that limit the vertical displacement of the trefoil towards the magnet when the GGG pill is pulled upwards toward the center of the magnet when at field. Both the 500 mK and 50 mK temperature stages include a Ruthenium Oxide (RuO_2) thermometer.

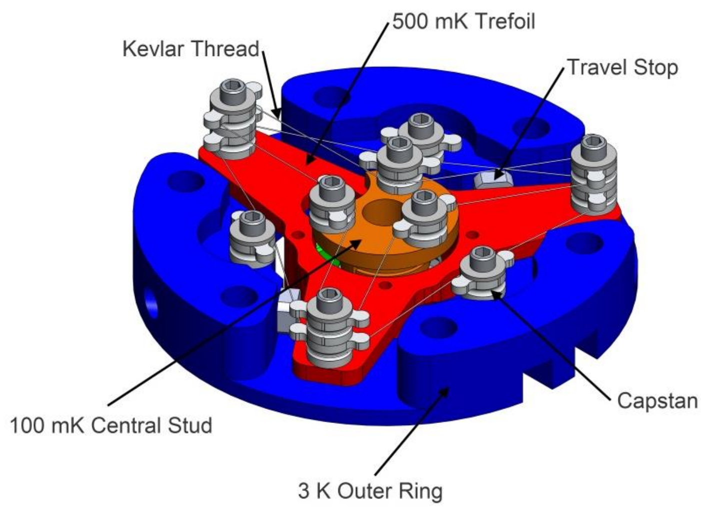
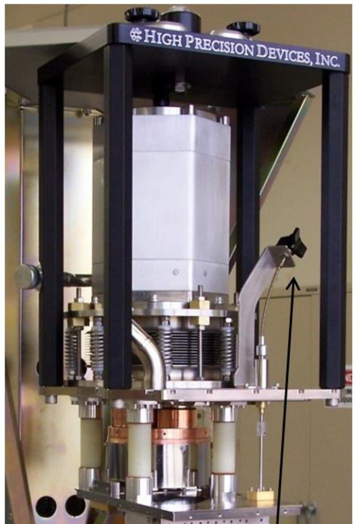


Figure 7: Puck of ADR suspension

2.4. Heat Switch & Heat Switch Motor

The ADR cryostats use a heat switch to thermally short the 3 K plate to both stages of the ADR (FAA and GGG), when closed, and to thermally disconnect the 3 K stage and both stages of the ADR from each other, when open. When the heat switch is open, the ADR stages are thermally isolated by the Kevlar suspension system of the ADR. The Model 102 Denali cryostat uses a manually operated heat switch, while the other cryostats use an internal electric motor to operate the heat switch. The manual heat switch is closed by turning the knob clockwise until the closing resistance increases and is opened by turning the knob counterclockwise until the switch hits a stop. The electronic heat switch is opened and closed using the physical switch on the heat switch control box as shown in Figure 8. The electronic heat switch can also be opened and closed by sending signals to pins in the DA15 connector on the top of the heat switch control box. More details about controlling the electronic heat switch remotely are provided in the wiring schematics supplied with the cryostat.



Manual Heat Switch

Electronic Heat Switch

Figure 8: Manual and Electronic Heat Switch Controls

2.5. Cryostat Control System

High Precision Devices CryoBoss Control Systems for ADR cryostats include the following items mounted in a 19" electronics rack: (See Figure 9.)

- Computer
- HPD DS100 Breakout Box for management of wiring connections
- HPD CryoBoss Interface Box contains a DAQ input/output which performs these functions:
  - Reads magnet voltage Back EMF
  - Reads magnet current
  - Reads power supply voltage
  - Auxiliary differential voltage channel
  - Sends open/close signals to heat switch control box
  - Reads touch lights from heat switch control box
  - Reads opening/closing status from heat switch control box
  - Operates Magnet Cycle/Regulate switch
- Magnet Power Supply
- Resistance Bridge options for reading 50 mK FAA Stage, 1 K GGG Stage and other RuOx temperatures.
- Diode Reader
- PID Controller
- Power for control system is provided through a USB-connected uninterruptable power supply with zero latency switching (e.g. APC UPS SURTA2200RMXL2U, with Battery Pack SURTA48RMXLBP2U). The zero-latency switching ensures that the power supply circuit breaker does not trip during the transition to battery power.

- The specific components and connectivity of each control system is detailed in the Wiring Schematics documents provided with each system.

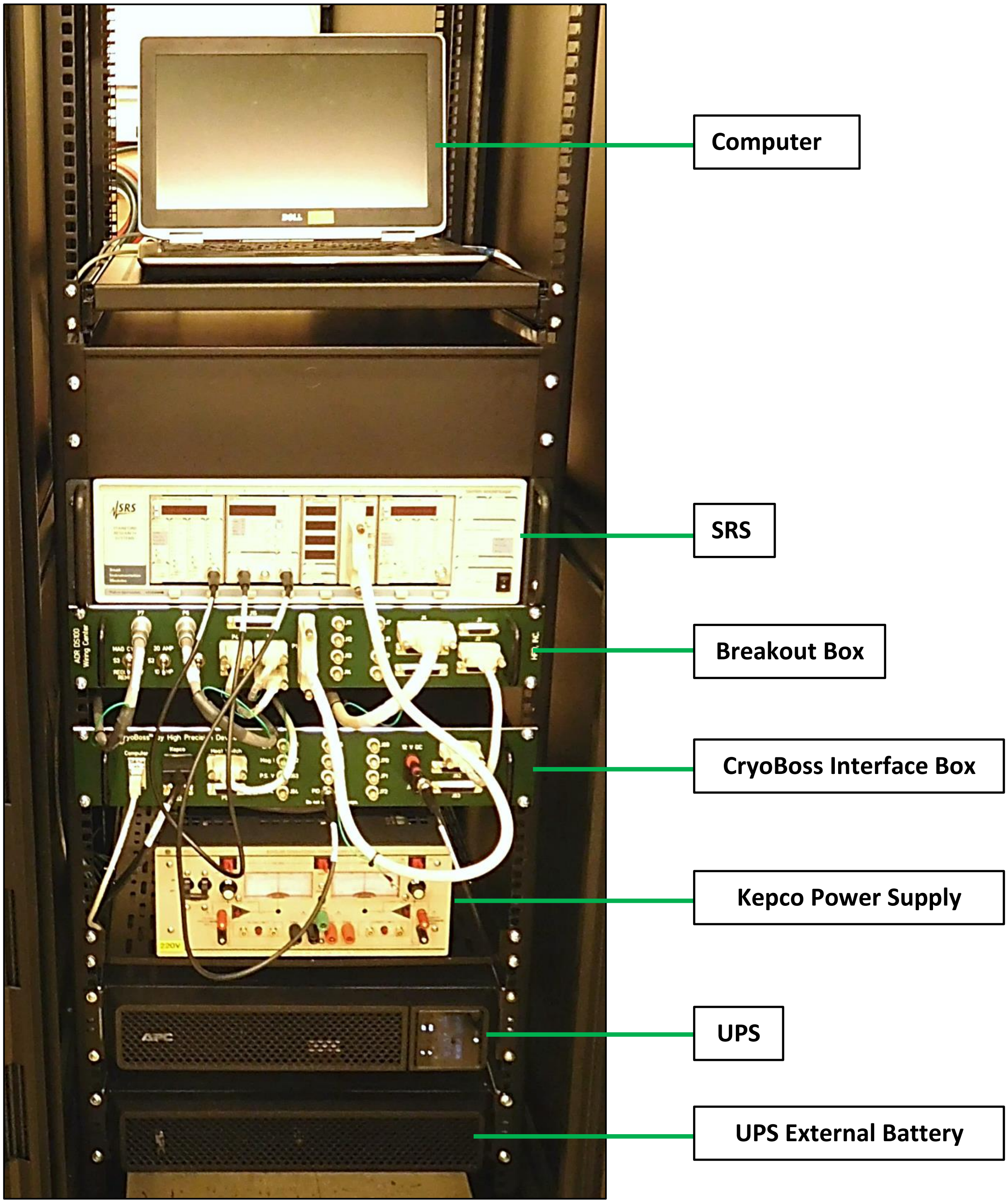


Figure 9: Model 151 ADR Control System

2.6. Vacuum System

During operation, the cryostat should be evacuated to high-vacuum (< 10^{-3} Torr). Ideally, the vacuum system for the cryostat should include the following items:

- Pumping Station
  - Ideally, a dry combination pumping station that includes a turbo pump backed by a scroll or diaphragm pump with a pumping rate of at least 200 l/s, N_2.
  - Or multiple pumps that include:
    - Roughing Pump- used to pump the cryostat down to rough-vacuum (10^{-3} Torr). Examples: rotary vane, scroll, and diaphragm pumps.
    - High-vacuum Pump- used to pump the cryostat down to high-vacuum. Turbo pumps are most commonly used.
- Vacuum Gages
  - Ideally, a wide-range combination gauge that can read from atmospheric pressure down to high-vacuum (e.g. convection and ionization combined gauge)
  - Or multiple vacuum gauges including:
    - Rough-vacuum gauge (e.g. thermocouple and Pirani)
    - High-vacuum gauge (e.g. hot filament ion gauge and cold cathode)
- Vacuum hoses, valves, and piping used to connect the vacuum system to the cryostat. HPD uses standard NW type flanges.

2.7. Rapid Cooldown System

The RapidCool system is standard on the 103 RapidCool Cryostat (103 RCC) and is available as an option on other cryostat models. The RapidCool sytem allows the operator to use liquid nitrogen flowing through heat exchangers to accelerate the cooldown from room temperature and give shorter turnaround time on experiments. A standard pulse tube only cooldown from 300 K to 4 K takes about 14 hours, the Rapid Cool system will shorten the cooldown to 4 K to about 4 hours.

- The RapidCool system is composed of an integrated liquid nitrogen line that enters the cryostat through a standard NW type vacuum port in the 300 K plate, travels through a heat exchanger on the 60 K plate, through another heat exchanger on the 3 K plate, and then exits the cryostat again through another NW port the 300 K plate. See Figure 10. During cooldown liquid nitrogen flows continuously through this heat exchange system to quickly cool both the 60 K and 3 K plates directly. Inlet and outlet lines on the on the cryostat are insulated to prevent frost formation during cooldown. The system also includes a vacuum insulated flex line to connect the liquid nitrogen dewar to the inlet bayonet on the cryostat, and a Helium Flush Manifold to allow introduction of helium to flush nitrogen from the RapidCool system. See Figure 11 and Figure 12.

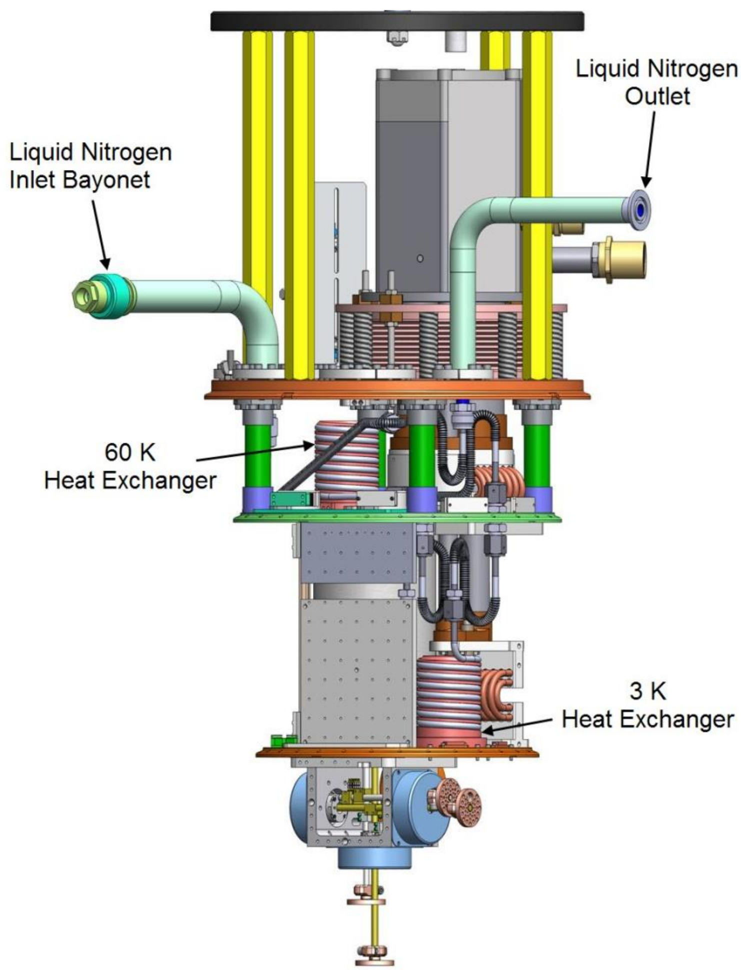


Figure 10: Rapid Cooldown System

Figure 11: Liquid Nitrogen Inlet Line

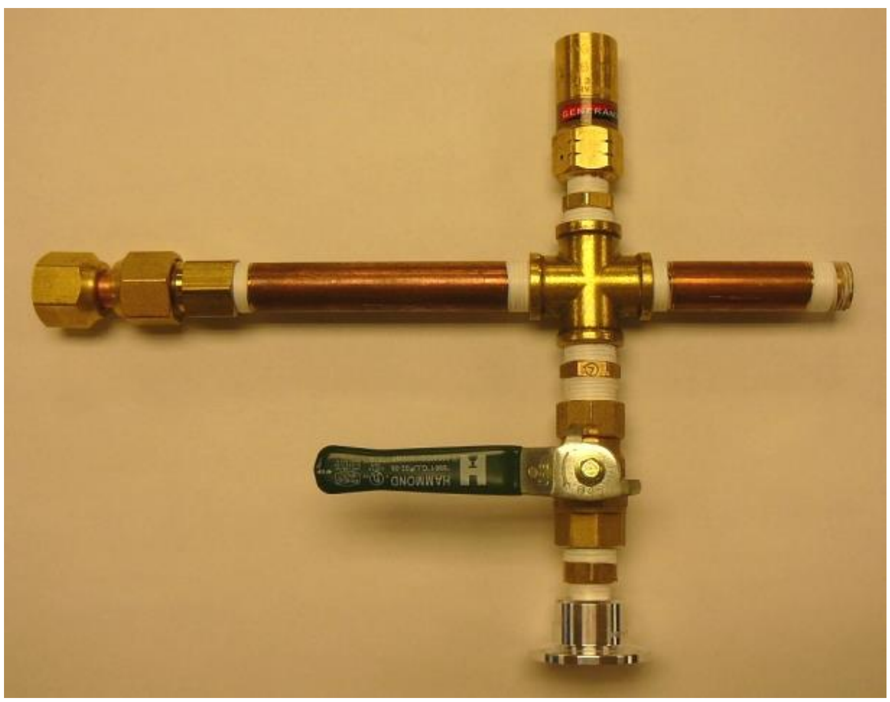


Figure 12: Helium Flush Manifold

3. Specifications (also refer to Cryomech manuals)

	Model 102 Denali	Model 103 Rainier	Model 103 RCC Active Shield	Model 103 RCC Passive Shield	Model 104 Olympus	Model 106 Shasta
Cool Down Time (300 K to 3 K)	14 hrs	15 hrs	4 Hrs	5 Hrs	19 hrs	15 hrs
No Load FAA Cooling Capacity	~100 mJ regulating @ 100 mK					
No Load GGG Cooling Capacity	~ 1.0 J from base temperature to 1 K					
Allowable Experiment Mass	2 kg					
Experimental Volume (cm)*	26 x 24 x 14	Ø 26 x 25 Tall	Ø 26 x 25 Tall	Ø 26 x 25 Tall	Ø 44 x 60 Tall	Ø 34 x 21 Tall
Vacuum Jacket Size (cm)	33 x 22 x 66	Ø 35 x 69 Tall	Ø 35 x 69 Tall	Ø 35 x 69 Tall	Ø 55 x 110 Tall	Ø 44 x 65 Tall
VAC	230					
HZ	50/60					
Amps	7					

*The experimental volume is the volume within the 3 K shield. Components of the ADR occupy some of the experimental space.

Table 3: Cryostat Specifications

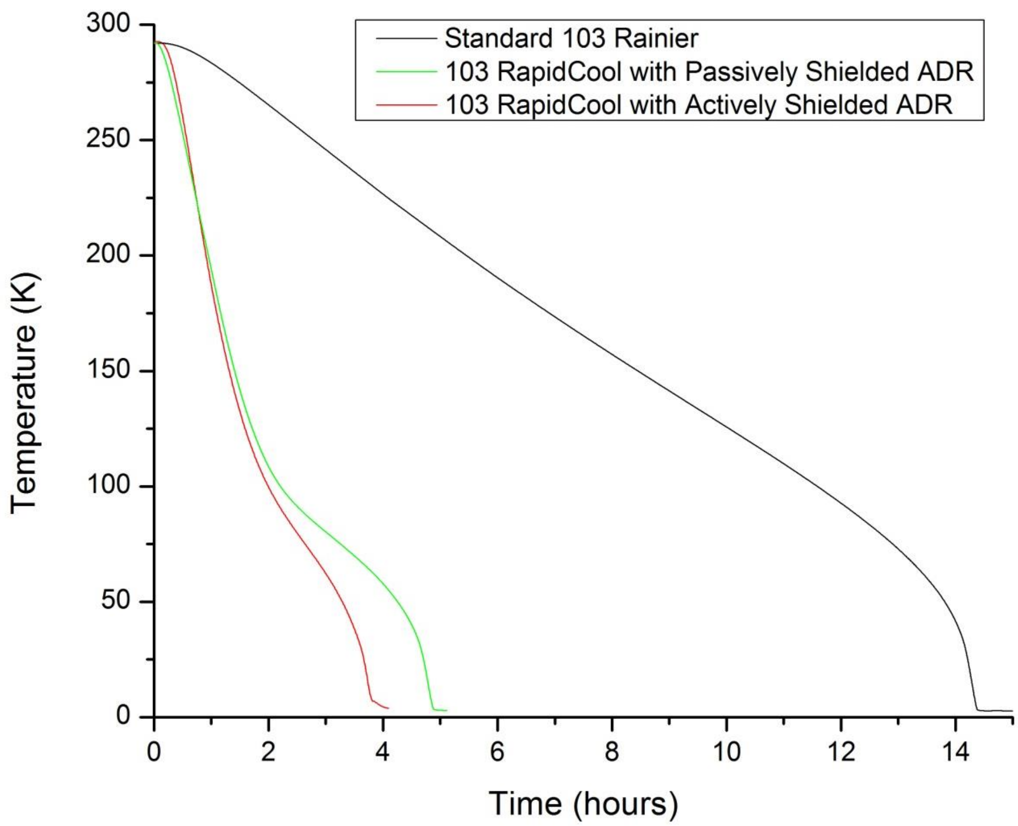


Figure 13: Model 103 Rapid Cooldown Comparison

4. Installation

4.1. Cryostat Installation

The location of installation of the cryostat should be carefully chosen to avoid potential problems during operation. Some important factors to consider when selecting an installation location are:

- Availability of electrical power
- Availability of cooling water for water-cooled compressors
- Availability of vacuum pumps
- Compressor noise (some customers install the compressor in an adjacent room)
- Ventilation (particularly important if using an air-cooled compressor)
- Enough height to remove vacuum jackets
- Enough space to work on the cryostat
- Space for electronics (power supply, temperature readers, magnet controller, etc.)

4.1.1. Mounting the Cryostat

Cryostat weight is greater than 150 lbs. Operator must lift cryostat with a crane. The ADR cryostats include a hitch plate assembly on the top with a ball hitch in the center for mounting as shown in Figure 14. The ball hitch is meant to be used to attach the cryostat to the optional HPD service stand; however, an interface drawing is included in section *9.3 Hitch Plate Interface Drawing* for customer use. When securing the Cryostat to the Hitch Plate ensure the center Eyebolt is fully seated. Align the three Hitch Plate screws with the Cryostat top plate screw holes. Ensure all three bolts are hand tight. The hitch plate assembly can be removed and the mounting screw holes can be repurposed for custom mounting scenarios. For customers that are particularly concerned about vibrations, the cryostat should be mounted rigidly to a solid surface. If using the optional service stand, operator must adjust the load to the lowest position when traveling. Do not install on an uneven surface. No incline more than 10% grade.

Figure 14: Cryostat hitch plate assembly

NOTICE	Customers have mounted their cryostats to custom frames attached to walls or the floor. Many customers use extruded aluminum structural framing or Unistrut to build their mounting frames.

4.1.2. Mounting the Remote Motor

HPD offers an optional remote motor stand for mounting the remote motor of the pulse-tube. The remote motor should be mounted in such a way that the flex line connecting the valve to the cold head is bent 90° as shown in Figure 15. The flex line stretches with each pulse and the bend in the line helps minimize the amount the line pushes against the cryostat. The remote motor should also be mounted in such a way that it remains electrically isolated from the cryostat.

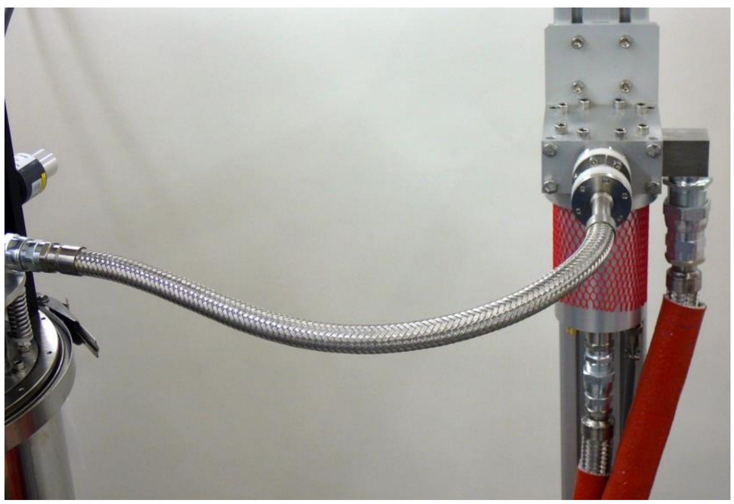


Figure 15: Remote Motor on Valve Stand with 90° Bend

4.1.3. Travel Limiters on the Pulse-tube Cold Head Bellows

The cold head attaches to the top of the cryostat through a bellows assembly. Springs prevent the bellows from collapsing completely while under vacuum. The amount of expansion and contraction of the bellows is limited by screws with two brass nuts: one nut on top limits the bellows expansion, and one nut on the bottom limits contraction. Each brass nut is backed by a stainless steel jam nut. A picture of the bellows showing the travel limiting and jam nuts is shown in Figure 16. The cryostat is shipped with the bellows locked down at the level of contraction seen under vacuum. If the customer would like the bellows to be free to float during operation to reduce vibration transfer, the nuts must be backed away from the flange. The nuts should be returned to the locked down position before breaking the vacuum. HPD recommends that the cryostat be operated with the bellows locked down in the case that vibrations are not a significant concern.

CAUTION	The top travel limiting nuts are the only restraint preventing the bellows from being pushed apart by the springs. Do not remove the nuts completely or back them off excessively when the cryostat is in use as the bellows will expand significantly when the cryostat is no longer under vacuum. Damage to the bellows and/or the jumper cables may occur if the bellows are allowed to expand too far.

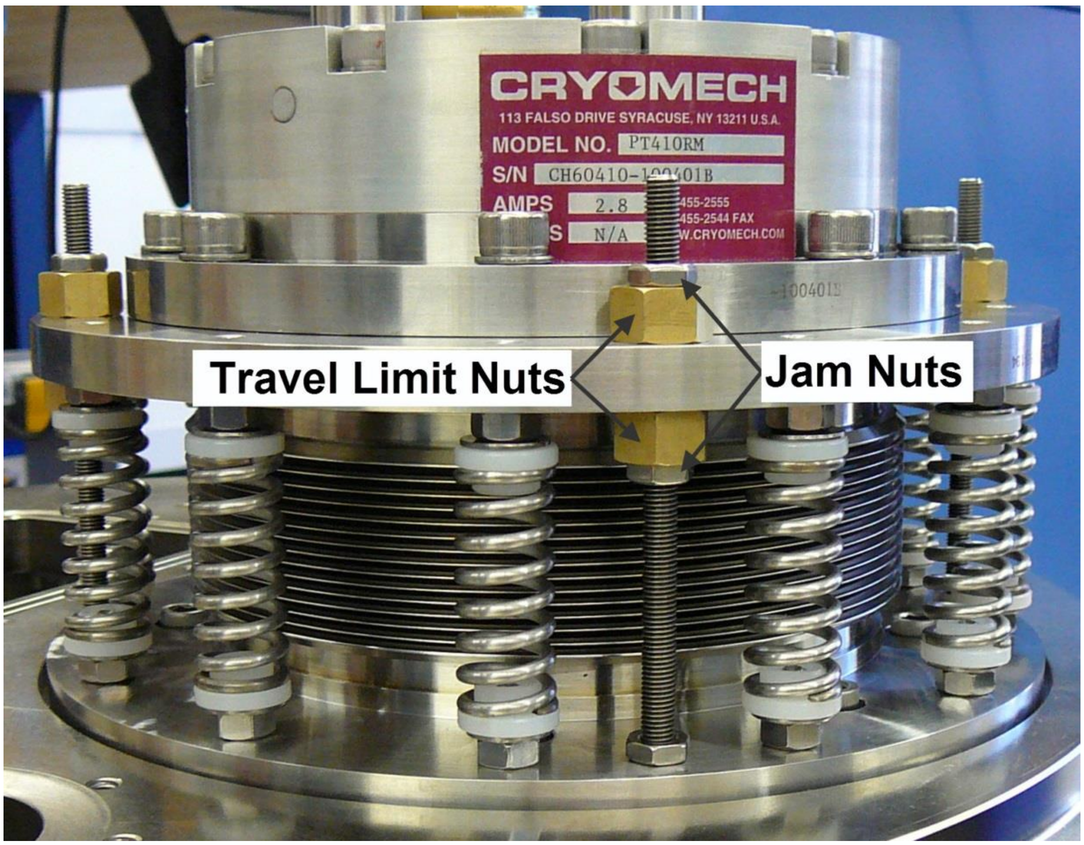


Figure 16: Pulse-Tube Bellows

4.2. Pulse-Tube Compressor Installation

A general description of the steps required to install your Cryomech pulse-tube refrigerator is provided below. Please consult the Cryomech manual provided with your PTR for detailed installation instructions.

4.2.1. Electrical Power

The pulse-tube compressor supplied with your cryostat will be specified per the country of service and the power available. Voltage and frequency options are shown in the table below. Confirm that the compressor runs on the power available before putting into service. Because the type of plug need varies greatly from facility to facility, the compressor will be shipped without a plug attached. The end user will have to attach a plug that is appropriate for the socket available at their location.

Voltage	Frequency	Phasing
220/230	60 Hz	3 phase
460	60 Hz	3 phase
200/220	50 Hz	3 phase
380/420	50 Hz	3 phase

Table 4: Available Pulse-Tube Compressor Voltages and Frequencies.

NOTICE	After wiring the compressor to the appropriate plug, turn on the compressor main breaker and power switches. The system should go through an initialization and indicate whether the 3-phase wires are properly connected. In the case there is an error signal regarding the sequence, switch any two of the three power wires. Ground should always remain ground.

4.2.2. Cooling Water Supply

The majority of the systems are supplied with water-cooled compressors; however, air-cooled compressors are available. Please consult the Cryomech manual for your compressor model for acceptable input water temperatures and flow rates.

NOTICE	Care should be taken when adding antifreeze to the cooling water loop for water chillers that operate outdoors in cold climates. Antifreeze will decrease the cooling efficiency of the water supply, possibly causing the system to overheat and shutdown. Please consult Cryomech if you are planning to use such a system.

4.2.3. Compressor Lines and Remote Motor Control Line

The PTR will include two compressor lines used to connect the compressor to the remote motor. Different length lines are available. Please consult HPD or Cryomech for available lengths. Optional silicone jacketed lines and quiet lines are also available. The low-pressure side hose has ¾" Aeroquip fittings on both ends. The high-pressure side hose has one ¾" Aeroquip fitting on one end and one ½" Aeroquip fitting on the other end. An electrical cable (the same length as the compressor lines) for powering and controlling the remote motor is also included.

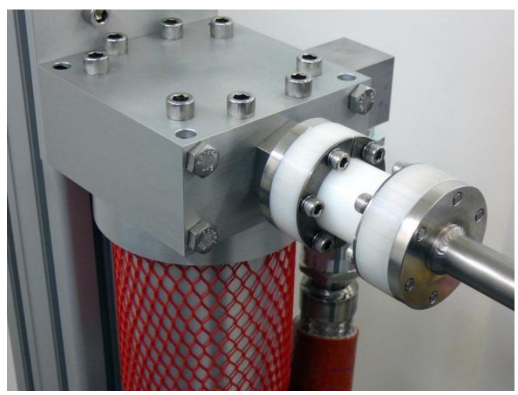
CAUTION	The Aeroquip connections at the end of the compressor lines require lubrication before every connection or reconnection. The proper lubricant is provided by Cryomech in the compressor tool kit. Care should be taken to prevent lubricant from getting on the sealing faces at the ends of the hose which could cause contamination of the helium supply. To help prevent lubricant from contaminating the lines, the threading of the fitting should be started first, then the lubricant should be applied, and finally the fitting should be threaded on completely. Use the lubricant sparingly. Please refer to the Cryomech manual for more information.

The following connections must be made between the compressor and the remote motor:

- To help ensure that the hoses are connected properly, HPD suggests that you begin by connecting the ½" Aeroquip end of the high-pressure side hose to the ½" Aeroquip fitting labeled "high" on the remote motor. The ¾" Aeroquip end of the high-pressure side hose must then be connected to the port labeled "high" on the front of the compressor.
- One end of the low-pressure side hose must be connected to the port labeled "low" on the front of the compressor and the other end must be connected to the port labeled "low" on the remote motor.
- The electrical power and control cable must be connected between the compressor connector labeled "Cold Head Power" and the electrical connector on the remote motor. The cable has different sized connectors on each end and can only be connected one way.

A single hose, permanently attached to the remote motor, connects the valve to the pulse-tube cold head. Do not attempt to remove this hose from the cold head. The ½" Aeroquip fitting on the free end of the hose must be connected to the ½" Aeroquip port on the top or side (depending on the model) of the pulse-tube cold head.

CAUTION	Do not disconnect the pulse-tube head from the remote motor or the compressor lines from the compressor or remote motor when the system is cold. The helium gas in the pulse-tube head expands out of the head back into the compressor during warming. If the pulse-tube head is disconnected before warm-up, helium gas will vent to atmosphere out of the high-pressure safety valve requiring a recharging before the next use.

NOTICE	The remote motor supplied with the cryostat includes an electrically insulating break in the hose that attaches it to the cold head as shown in the picture below. This break prevents the cryostat from being electrically grounded through the connection to the compressor which could potentially create a ground loop. The Teflon connector should not be removed as helium gas will escape. 

Some pulse-tube models (PT410 and PT415) require external ballast tanks, shown in Figure 17, that attach to the cold head. The cryostat will normally be shipped with the ballast tanks attached, however, if the tanks are shipped separately, they will have to be attached to the ¼" Aeroquip fittings on the top of the cold head.

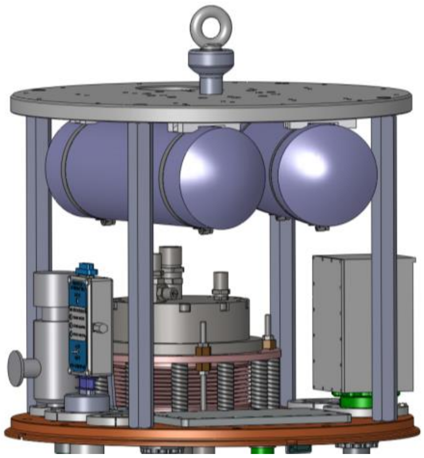


Figure 17: Ballast Tanks Mounted to the Hitch Plate Underside and Disconnected Tank

4.3. HPD Control System Installation

This section refers specifically to systems that were purchased with the optional HPD CryoBoss Control System. Users who did not purchase a control system from HPD should still find useful information and guidelines in this section that will help in setting up and controlling their system.

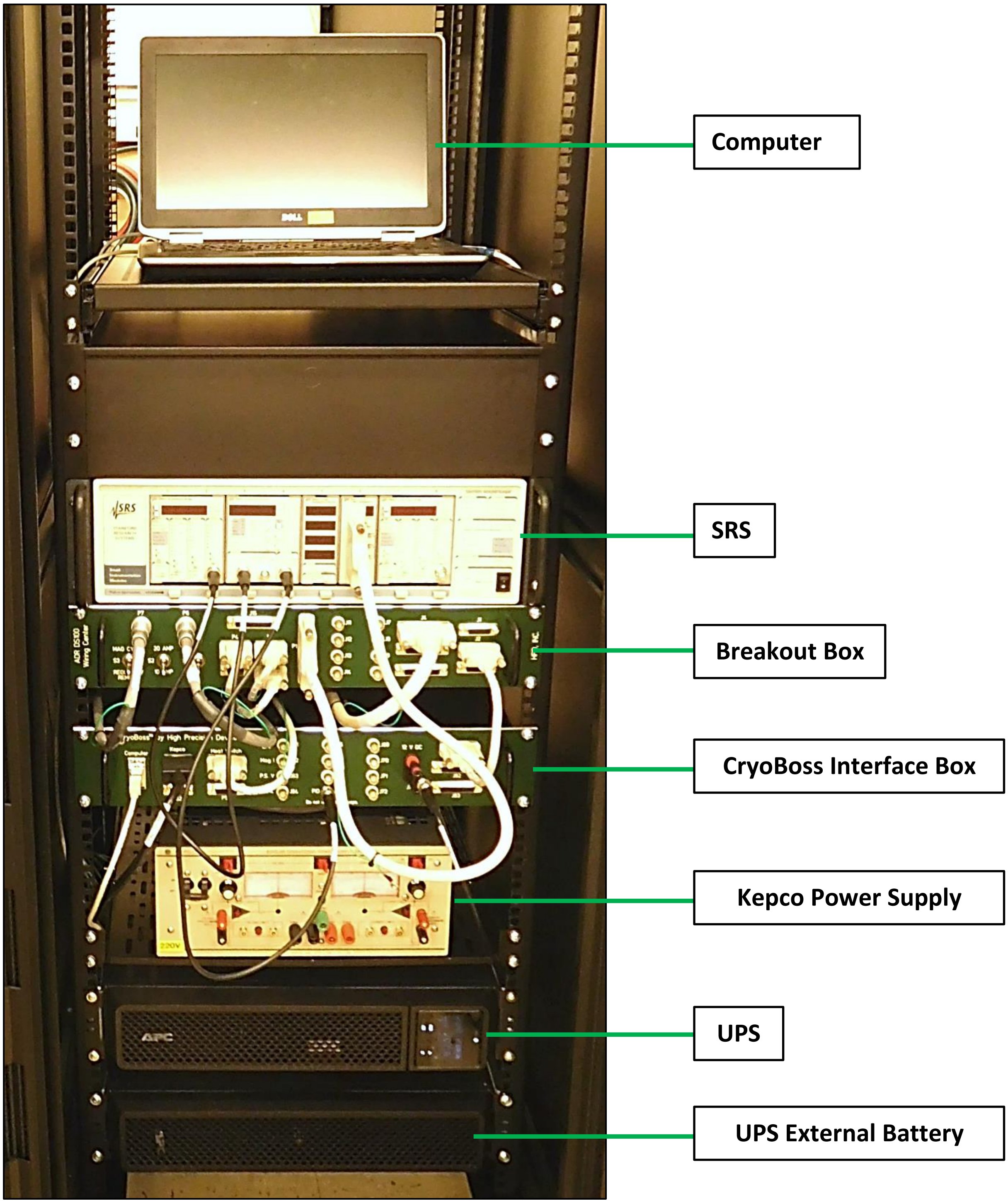


Figure 18: Model 151 ADR Control System

The specific components and connectivity of each control system is detailed in the Wiring Schematics documents provided with each system. To assist in connecting the control system, cables are shipped with labels on each end that match labels on the cryostat 300 K plate, the Break Out Box, the Kepco and the SRS system. See Section 2.5 and Figure 19. Control system should be installed in the electronics rack as shown in Figure 18. Rack input power is 230VAC, 50/60 Hz, 7amps. All equipment in rack must be connected as indicated in supplied Wiring Schematics and in accordance with Manual. Rack must be powered with supplied power cord or with one rated per local codes and jurisdictions. Operator must wear properly grounded wrist strap when rack is open. Do not install on an uneven surface.

Figure 19: Cryostat Connectors

4.4. Grounding

	Electrostatic Sensitive Device: To prevent equipment damage use proper grounding techniques. Electromagnetic Environment. The Cryostat system is intended for use in a controlled electromagnetic environment. Higher levels of RF interference may degrade performance of sensitive measurement circuitry.

HPD has implemented a star grounding scheme, illustrated in Figure 20, to help eliminate ground loops and sources of electromagnetic interference in the cryostat system wiring. The top plate of the cryostat serves as the central ground plain in this implementation. The top plate includes a grounding stud and the cryostat ships with a grounding strap. The grounding strap should ideally be connected to a true earth ground or (less desirably) connected to electrical ground.

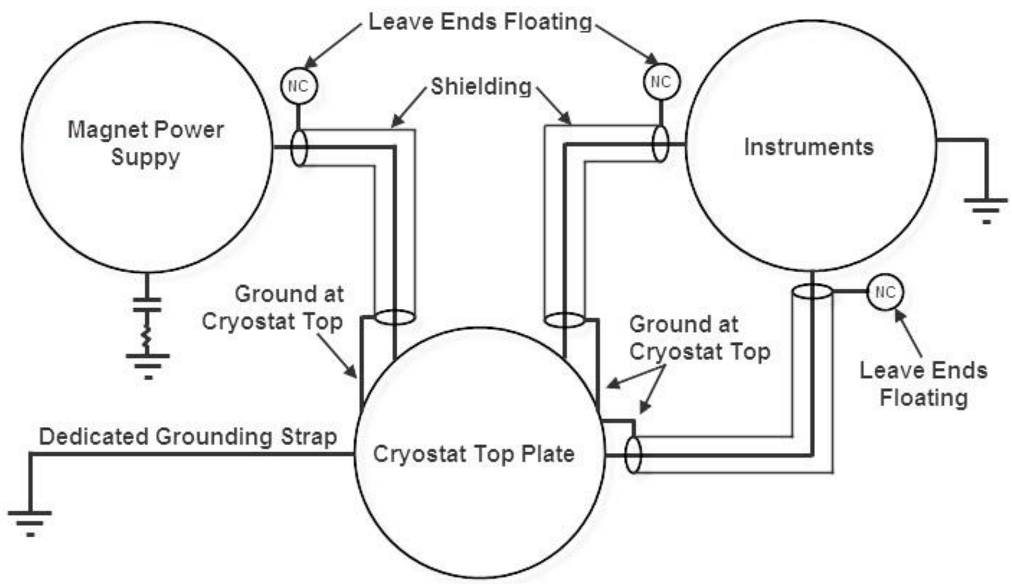


Figure 20: Star grounding scheme

Many cables shipped with the HPD CryoBoss Control System have a single-ended shield. HPD suggests that any experimental wiring added by the end user should follow the same grounding scheme.

NOTICE	Depending on laboratory set-up, connecting the SRS Mainframe Chassis Ground to a true earth ground may eliminate noise in the SRS system.

4.5. Tips for Experimental Installation

- Please refer to the books listed in the section Suggested Further Reading and Useful Websites on page 63 for useful information on low-temperature methods.
- Carefully heat sink all wiring and experimental components such as circuit boards and connectors.
- The FAA and GGG cold rods are made from gold plated annealed copper and can be bent easily. Avoid cantilevering heavy masses off the rods.
- The payload mass should be limited to 2 kg.

5. Operation

Parameter	Value
Ambient Temperature Range	45° to 81° F
Acceptable Location	Indoors only
Maximum Altitude for Use	6560 ft
Environment	Pollution Degree 2
Installation	Category II
Maximum Relative Humidity	80% for T < 81° F Decreasing linearity to 50% at104°F

Table 5: Operating Parameters

5.1. Table Vacuum Jacket and Thermal Shields

The cryostat includes a vacuum jacket, 60 K shield, and a 3 K shield that must be installed prior to operation. The vacuum jacket has an upper and lower section and a removable bottom cover. The vacuum jacket uses Viton O-rings to seal the vacuum space, and metal Spira seals to seal against RF radiation. The O-rings should be inspected prior to installing the vacuum jacket to ensure they are free of damage or dirt that could lead to a vacuum leak. The Model 103 and Model 106 cryostats use quick release clamps to attach the vacuum jacket, and the Model 102 and Model 104 cryostats use screws. The Model 104 cryostat has captive vacuum jacket screws. The Model 103 and Model 106 vacuum jackets include a removable clocking tooth that can be used to set the clocking of the vacuum jackets if desired. The upper and lower sections of the vacuum jacket can be removed and installed in sections or as a complete set.

The 60 K shield also consists of an upper and lower section and a removable bottom cover (except the 102, which has a solid bottom). The shield attaches with screws, and the Model 104 and Model 106 cryostat have captive screws. The shield should be handled with gloves to prevent fingerprint build up that can affect the pump-out time and the quality of the vacuum. The upper and lower sections of the 60 K shield can be removed and installed in sections or as a complete set with the exception of the Model 102 cryostat, where the upper section must be installed first, before the 4 K or 60 K lower shields are installed. The reverse is true for removal of the Model 102 shields.

The 4 K shield consists of a single section with a removable bottom cover (except the 102, which has a solid bottom). The shield attaches with screws, and the Model 104 and Model 106 cryostat have captive screws. The shield should be handled with gloves to prevent fingerprint build up that can affect the pump-out time and quality of the vacuum.

CAUTION	The vacuum jacket and shield screws ship with a small amount of Apiezon vacuum grease applied to them. To prevent galling, more grease should be added to the screws if needed (e.g. if the grease wears off). Only a very small amount of grease is necessary.

5.2. Vacuum Pump-Down

The Dewar space must be under vacuum during operation. To achieve proper vacuum:

- Using first a rough pump then a high vacuum pump, pump on the system through the vacuum valve until the vacuum is (ideally) better than 1 x 10^{-3} Torr.
- Begin initial cool down of the system after high vacuum is reached and continue pumping on the system during the initial cool down period.

NOTICE	If the system has been opened in a humid environment or has been exposed to helium gas (as used for accelerated warm-up), it may be helpful to pump out the system and back fill it with nitrogen gas. To do this, pump out the system until it reaches a vacuum of 100 microns (1 x 10^{-1} Torr), and then back fill with nitrogen gas. Please see warning below regarding over-pressurization.

CAUTION	Care should be taken to avoid positively pressurizing the system with gas when backfilling. This can be accomplished by placing a tee in the plumbing circuit with the extra branch of the tee facing upward and omitting the clamp on the blank cover as shown below. This way the blank cover will lift off when there is any positive pressure. 

5.3. Initial Cool Down from Room Temperature

To cool the cryostat down from room temperature, follow the subsequent steps in order:

- Verify that the system has reached a sufficiently low vacuum level (< ~10^{-3} Torr).
- Close the Heat Switch. (When first connecting electrical power to the electronic heat switch control box, the heat switch must be opened first before it can be closed.)

NOTICE	The three touch sensor lights on the heat switch control box will illuminate when the heat switch is closed. At zero field, the touch sensor lights are normally an accurate reflection of the state of the heat switch. When the magnet is energized, the touch lights may illuminate due to normal touches caused by the deflection of the suspension system that are unrelated to the state of the heat switch and may no longer accurately reflect the state of the heat switch.

- Begin cooling water flow through the compressor (if using a water-cooled compressor).
- Start the pulse-tube compressor. Turn on the compressor in the following order: Main Breaker, Power Switch, and then Compressor.
- After the 3 K stage temperature has fallen below 50 K, close the vacuum valve. The system will now cryo-pump better than the vacuum pump is able to pump. Closing the vacuum valve at this point is also important to prevent back streaming of oil if a “wet” vacuum pump is being used. The vacuum pump can now be turned off.

5.4. Initial Cool Down from Room Temperature using RapidCool system.

WARNING	**Liquid Nitrogen Outlet (RCC Cryostats Only)** Extreme cold. Operator must wear approved personal protective equipment (PPE). • Safety Goggles (unvented)-required at all times. • Face Shield-required when pouring or filling. • Insulated Gloves- gloves should be loose fitting enough so they can be quickly removed if liquid should pour in them. You can also purchase elastic cuff insulated gloves- gloves are required. • A lab coat with long sleeves is required to minimize skin contact. Also, pants should be worn on the outside of shoes or boots to prevent shoes from filling in the event of spillage. • When handling large quantities of LN2, an apron should be used as well. The release of nitrogen can also displace oxygen in a room and cause asphyxiation. If dewars and insulated flasks containing liquid nitrogen are left uncovered for extended periods of time, liquid oxygen can build up to levels which may cause violent reactions with organic materials (i.e. severe clothing fire could result). HPD recommends Research Labs use Oxygen Monitors in Cryostat areas.

CAUTION	It is imperative that no steps are taken that would result in liquid cryogens being contained in a volume that does not include a relief device. This means that care must be taken during the cooldown sequence to avoid any cryogens being trapped in a closed volume. Pressure relief devices must remain in place and be fully operational.

To operate RapidCool System a standard storage dewar containing > 100 liters liquid nitrogen is required. Dewar should be stored at low pressure until ready for cooldown.

To achieve the fastest cooldown from room temperature, follow the subsequent steps in order.

- The operator can choose how to balance the trade-off between cooldown speed and nitrogen consumption. A high nitrogen flow rate, as described below, will achieve the fastest cooldown but will use a large amount of nitrogen. A lower flow rate will use less nitrogen but the cooldown will be slower.

Rapid Cooldown from Room Temperature:

- Pump down the cryostat to a vacuum level of < ~10^{-3} Torr.
- Close the Heat Switch. (When first connecting electrical power to the electronic heat switch control box, the heat switch must be opened first before it can be closed.)

NOTICE	The three touch sensor lights on the heat switch control box will illuminate when the heat switch is closed. At zero field, the touch sensor lights are normally an accurate reflection of the state of the heat switch. When the magnet is energized, the touch lights may illuminate due to normal touches caused by the deflection of the suspension system that are unrelated to the state of the heat switch and may no longer accurately reflect the state of the heat switch.

- Attach nitrogen dewar to Inlet Bayonet on Cryostat using the Vacuum Insulated Flex Line and a Helium Flush Manifold at the dewar end of the flex line, as in Figure 21 and Figure 22.
- Use LN_2 dewar pressure builder to increase dewar pressure to 70 psi.
    - Pop-Off Valve on Helium Flush Manifold will release at 75 psi.

CAUTION	Delivery pressure to cryostat liquid nitrogen line should not exceed 75 psi. Over pressurizing liquid nitrogen line could cause rupture of bellows.

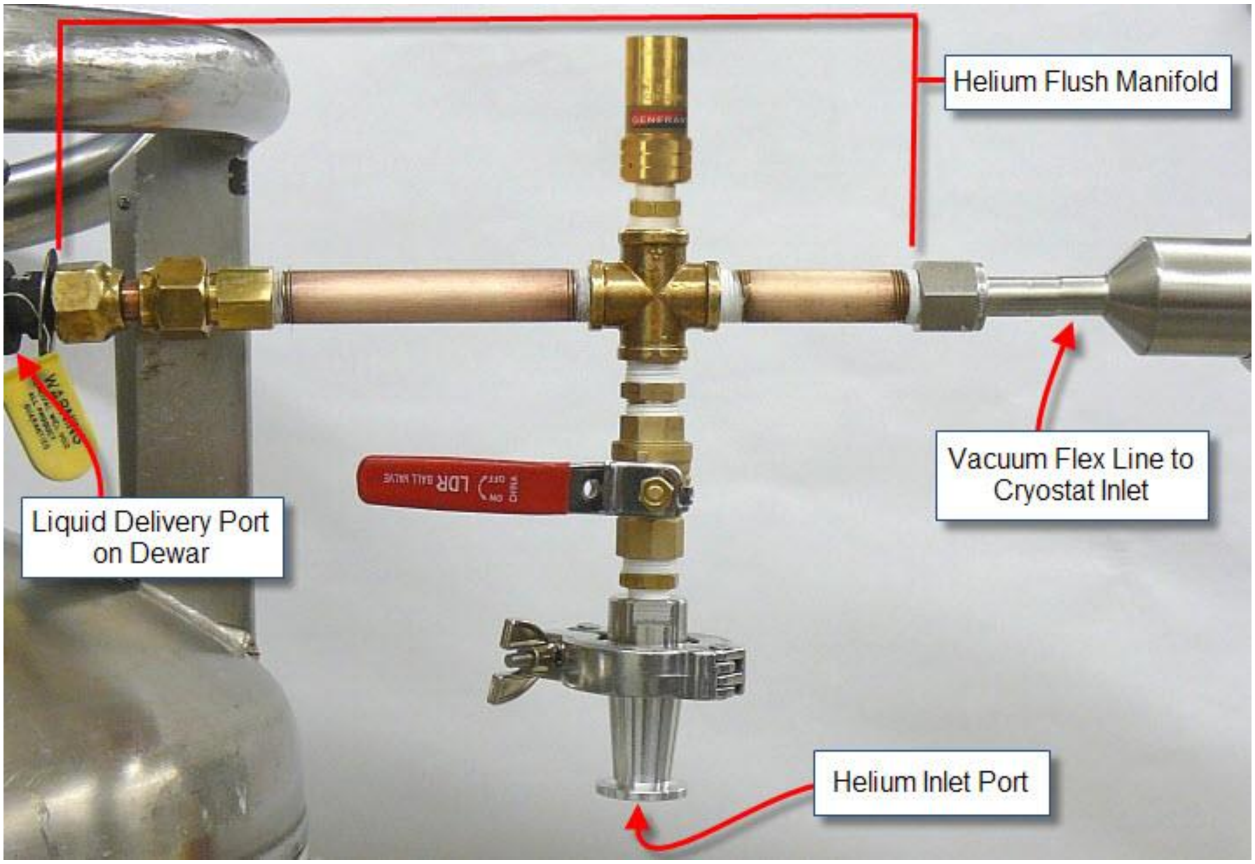


Figure 21: Helium Flush Manifold, flex line attachment to dewar

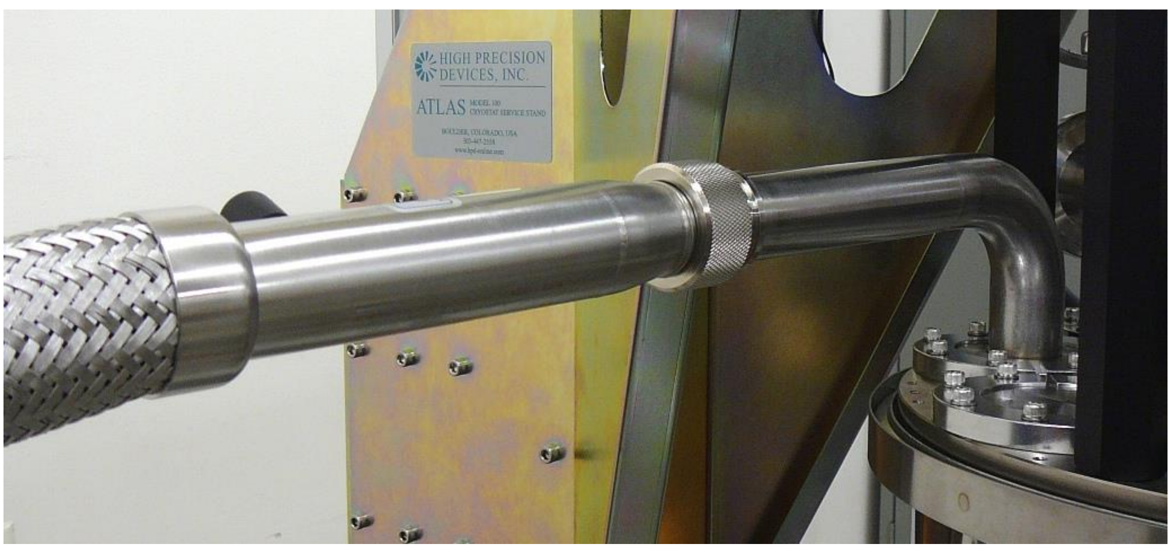


Figure 22: Flex Line attached to Cryostat inlet bayonet

- Attach helium supply line to Helium Flush Manifold, see Figure 21.
- The cryostat nitrogen outlet should be connected to a tube to vent used nitrogen outside the building (both liquid and gaseous nitrogen will be exiting outlet tube.)

NOTICE	At a high flow rate LN_2 will be exiting the cryostat outlet and can be collected in an open mouth dewar for re-use.

- Begin cooling water flow through the compressor (if using a water-cooled compressor.)
- Start the pulse-tube compressor. Turn on the compressor in the following order: Main Breaker, Power Switch, and then Compressor.
- Open liquid supply valve on nitrogen dewar all the way to begin liquid nitrogen flow through RapidCool system.
    - The dewar pressure builder should be open to keep the dewar pressure above 40 psi for the duration of LN_2 flow.
- Run nitrogen though RapidCool system until the magnet temperature reaches 135 K, typically about 90 minutes.
- Frost will develop on cryostat nitrogen outlet, inlet and on Helium flush manifold during normal operation.

To stop nitrogen flow, follow the steps below. The faster these steps are completed the less disruption to the cool down.

- Set helium tank pressure to 25 PSI.
- Turn off dewar liquid supply valve.
- Open Helium Flush Manifold valve to allow helium to flow though the RCC system **for only 10 seconds**, then close helium supply valve.
- Remove Flex Line from cryostat inlet bayonet, and then cap cryostat inlet bayonet, see Figure 22 and Figure 23.
- Remove the exhaust line from the cryostat nitrogen outlet.

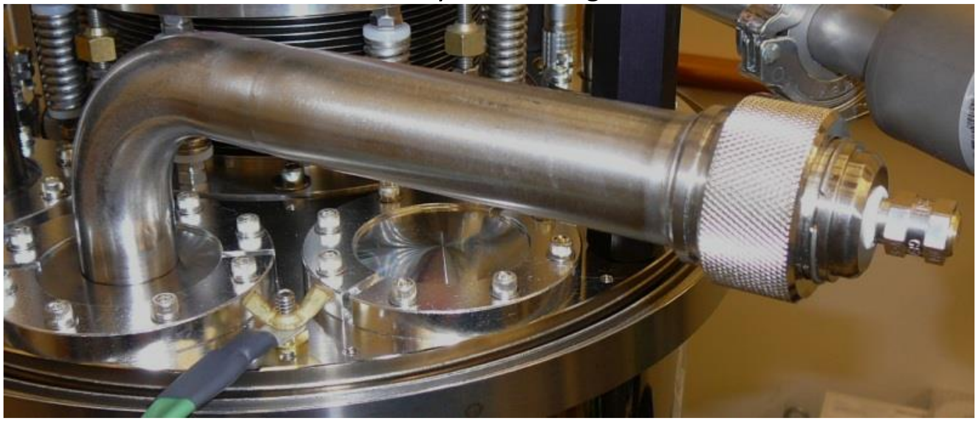


Figure 23: Inlet Bayonet Capped

- Attach vacuum valve and rough pump to cryostat nitrogen outlet (vacuum valve and rough pump are not included with the system).
- Pump down Cryostat RapidCool nitrogen line for 15 minutes, then close vacuum valve and disconnect rough pump.
- The cryostat will now continue to cool down using the pulse tube only.

After the 3 K stage temperature has fallen below 50 K, close the main vacuum valve. The system will now cryo-pump better than the vacuum pump is able to pump. Closing the vacuum valve at this point is also important to prevent back streaming of oil if a "wet" vacuum pump is being used. The vacuum pump can now be turned off.

- Cryostat will reach 4 K four hours from cooldown start.

5.5. Manual ADR Operation with HPD Control System

This section refers specifically to systems that were purchased with the optional HPD control system. Users who did not purchase a control system from HPD should still find useful information and guidelines in this section that will help in setting up and controlling their system.

CAUTION	Delivery pressure to cryostat liquid nitrogen line should not exceed 75 psi. Over pressurizing liquid nitrogen line could cause rupture of bellows.

WARNING	Do not unplug the magnet power cable or the cable plugged into cryostat connector 2 when the magnet is energized. Serious injury, and/or damage to the system may result.

WARNING	Risk of electrical shock! Any modification made to the electrical system should be performed by a qualified electrician.

5.5.1. Before Magnetization

When the temperature of the ADR magnet is at the base temperature of the PT (~3 K), the ADR may be cycled. The ADR cycle should never be started before all the 3 K stage thermometers reach base temperature. For maximum performance on the first mag cycle, it is advised that the compressor runs for ~20 hours before starting an ADR cycle to allow for better thermal equilibration of the salt pills, etc.

Prior to applying power to the ADR magnet, measure the magnet circuit resistance by plugging the end of the magnet power cable at the Kepco power supply outputs into a Multimeter. Alternately, the lead resistance can be calculated from the voltage/current output of the power supply during a manual magnet cycle when the voltage across the magnet voltage taps is 0 Vdc. From this resistance you can calculate (using V = IR) the voltage required to get to the target current of 9.44 A for a 10 A system or 18.88 A for a 20 A system.

5.5.2. Manual Magnetization

To manually magnetize the ADR magnet, follow the subsequent steps in order:

- After initial cool down from room temperature, cycle (open and close) the heat switch to ensure functionality before beginning the first magnetization cycle.
- If this is a first magnetization cycle after cool down, keep the heat switch closed. If this is a re-magnetization cycle, close the heat switch during the magnetization cycle after the pill temperatures are warmer than the PT second stage temperature. (This

approach will hasten the pills reaching thermal equilibrium by preventing heat from flowing into the pills from the PT stage.)

- Put the PID controller in manual output mode and set the manual output value to 0 Vdc, and then turn on the ADR magnet power supply.
- Set the mag cycle/regulate switch on the break out box (shown in Figure 24) to **mag cycle**.

Figure 24: Break Out Box Mag Cycle/Regulation Switch

- Slowly increase the current to the magnet by increasing the PID output voltage with the arrow buttons in 10 mVdc increments, without exceeding 250 mVdc back EMF across the voltage taps (indicated at postion 1 on the SRS voltmeter), until reaching full field (9.44 A for a 10 A system or 18.88 A for a 20 A system). (This should take about one-half hour.)

CAUTION	Care should be taken to not change PID controller settings while the magnet is energized. Incorrect changes can quench the magnet.

CAUTION	The magnet will spontaneously quench if driven with too high of a current (Above 9.5 A for a 10 A system and above 19.0 for a 20 A system).

  - While increasing the magnet current, after a step increase in driving voltage you should observe a step increase in back EMF across the magnet taps followed by a gradual increase in current through the magnet. The back EMF will slowly decay towards zero as the current increases.
  - If the magnet current decreases with the driving voltage held constant, this may suggest a problem with the magnet circuit. A slight decrease in magnet current over time at full field due to heating of the cabling is normal and does not indicate a problem with the system.

NOTICE	Circuit resistance will increase (current decrease) slightly as the magnet circuit wiring warms.

- When at full field (9.44 A for a 10 A system or 18.88 A for a 20 A system), cycle (open then close again) the heat switch to relieve any stresses in the heat switch mechanism and Kevlar suspension system.
- Optional: For the Model 102 Denali, about one-half hour prior to starting de-magnetization, open and close the heat switch to relieve any remaining stress in the heat switch mechanism. It is advisable to close the heat switch gently at this time to reduce vibrations during the final opening before de-magnetization.
- After 1 to 4 hours at full field, the ADR is ready for de-magnetization. The length of soak time at full field can be varied depending the desired hold time and base temperature. The salt pills will equilibrate with the 3 K stage more completely with longer soak times with diminishing returns as the soak time is increased past 4 hours. The FAA and GGG pill temperatures should have fallen to approximately the base temperature of the PT before de-magnetization.

5.5.3. Manual De-magnetization

To manually de-magnetize the ADR magnet, follow the subsequent steps in order:

- Open the heat switch.
- Note the temperatures of the FAA & GGG stages (these may be slightly higher than the PT stage or the temperatures observed prior to opening heat switch).
- If desirable, turn on data logging.
- The Kevlar suspension system of the ADR will deform when the ADR magnet exerts a force on the FAA and GGG pills, usually leading to touches between the stages. Note any touches as indicated on the heat switch control box. If touches exist at full field, monitor touch indicators and note at what current the touches go away.

NOTICE	Touches are normal at full field. The suspension system of the ADR includes electrically conductive travel limiters that have a low thermal conductivity to limit displacement of the stages while still indicating a touch with limited heat leak. Touches at zero field indicate a problem.

- Using the PID arrow buttons, begin reducing the magnet current in 10 mVdc increments without exceeding 125 mVdc back EMF across the magnet voltage taps. It should take about one hour to reach zero field. The magnet current will asymptotically approach zero after the voltage is reduced to zero. To drive the magnet current to zero more quickly, the driving voltage can be run negative. When the magnet current reaches zero, the PID driving voltage should be quickly set to zero using the arrow keys so that the magnet voltage, PID voltage, and magnet current are all simultaneously zero.

5.5.4. Convert from Magnetization Cycle to Temperature Regulation

To convert from a magnetization cycle to temperature regulation, follow the subsequent steps in order:

- Ensure that the Lower Limit of the PID controller is set to -0.100 Vdc. This will prevent the controller from trying to drive the magnet voltage negative.
- Ensure that P and I gains are entered as described in the section *9.2 Normal Stanford Research Systems Control System Settings* on page 58.
- When the magnet current has reached zero, and the voltage across the magnet is zero, flip the mode switch on the breakout box (shown in Figure 24) from **Mag Cycle** to the **Regulate** setting. This will switch a resistor into the magnet power circuit to increase the dynamic range of the power supply during regulation.
- Begin control cycle.
    - Adjust the PID internal set point to be slightly above the current FAA temperature. The PID controller represents the temperature in kelvin as volts.
    - Switch to PID mode (Bottom-right corner of the **Output** section of the SIM960 as shown in Figure 25).
    - Slowly increase the internal set point in 1 mV (equivalent to 1 mK) steps to the desired temperature (e.g. 100 mK), while limiting the back EMF voltage to 150 mVdc. Pressing shift and then one of the arrow keys allows the user to shift the active digit of the set point value left or right.
    - After reaching the desired temperature, begin logging data if desired (and if not already logging). (The logged data could be temperature or magnet current.)

5.5.5. Convert from Temperature Regulation to Magnetization Cycle

To convert from temperature regulation to a magnetization cycle, follow the subsequent steps in order:

CAUTION	When switching out of PID mode, it is vital to transfer the current output voltage of the PID controller to the manual output value before switching from PID mode to Manual mode as described below. Proper transfer will prevent quenching of the magnet.

- Under the display (Not Output!), select Manual mode. See Figure 25.
- Push and hold the On/Off button for one second, to transfer the current output voltage value from the PID output to the manual output.
- Switch the Output from PID to Manual mode.
- Drive magnet current manually to zero as described in the manual de-mag procedure.
- When magnet current is at zero, change the mode switch on the breakout box (shown in Figure 24) from **Regulate** to **Mag Cycle**.
- The system is now ready for a new magnetization cycle.

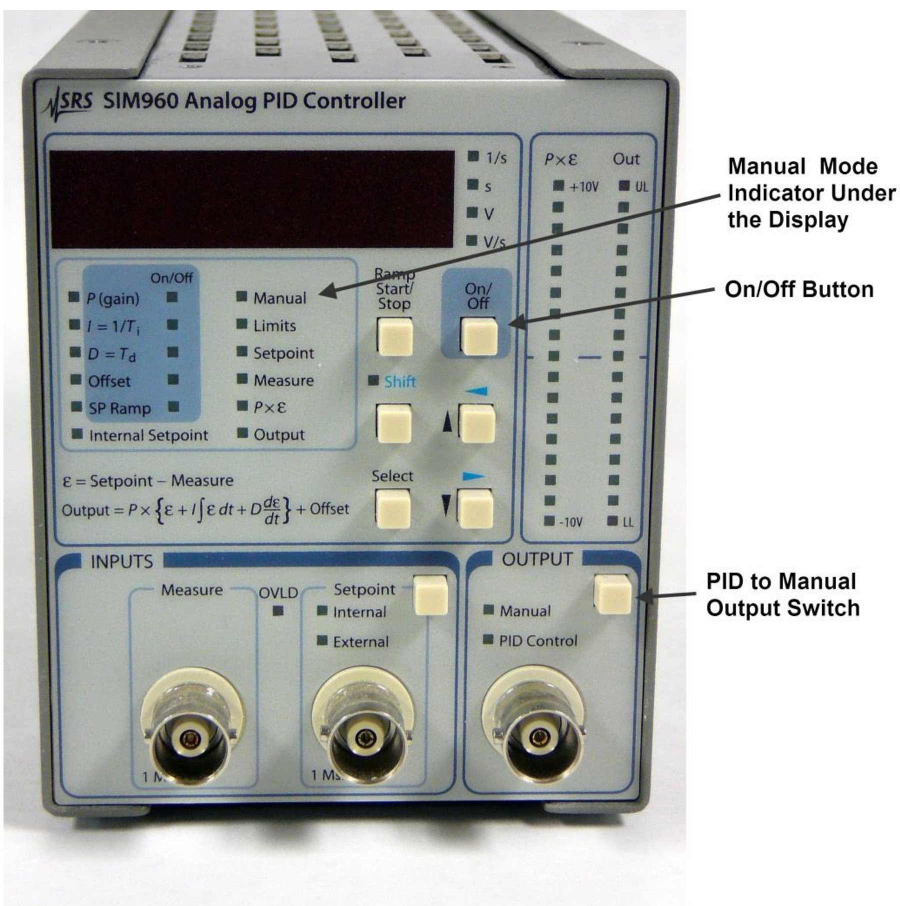


Figure 25: PID Controller Front Panel

5.5.6. Turning the System Off

To turn the system off, follow the subsequent steps in order:

- If the magnet is at field as part of a magnetization cycle or is regulating, reduce the magnet current to zero by following the instructions in the section *Manual De-magnetization* if in a magnetization cycle or the instructions in the section *Convert from Temperature Regulation to Magnetization Cycle* if regulating.
- When the magnet is at zero power, turn off the magnet power supply if it is on.
- Turn off the pulse-tube refrigerator.
- Turn off the cooling water supply.
- Allow the system to warm-up completely to room temperature before opening. The vacuum space will need to be vented to atmospheric pressure before the vacuum jacket can be removed. The vacuum space can be vented to air, or, preferably, to dry nitrogen. Please see information below on venting and accelerated warm-up using a transfer gas.

NOTICE	A transfer gas may be used to spoil the vacuum to increase the cryostat warm-up rate. When the cryostat is off but still cold, a small amount of nitrogen (~ 1 liter at STP) may be added to spoil the vacuum. Once the system warms to the point where all thermometers read 77 K (the temperature where N_2 vaporizes) or higher, the system can be back filled with additional nitrogen, to atmospheric pressure or lower. Please read the following warning regarding over-pressurization of the vacuum jacket. A similar small amount of helium may be added to the system when cold, instead of nitrogen, to increase the warm-up rate further, however this technique is not recommended because the helium can permeate some of the cryostat materials and negatively affect future pump-downs.

CAUTION	Do not disconnect the pulse-tube cold head from the compressor when the system is cold unless instructed to do so by HPD or Cryomech. The cold helium gas trapped in the cold head will expand and vent out of the overpressure safety valve of the cold head during warm up if the head is left unconnected.

To avoid positively pressurizing the system either from the purge gas tank pressure or from expanding transfer gas during warm-up, care should be taken when backfilling the system. This can be accomplished by placing a tee in the vacuum circuit with the extra branch of the tee facing upward and omitting the clamp on the blank cover as shown below. This way the blank cover will lift off when there is any positive pressure. When employing the tee, the vacuum valve must also be left open.

6. K2 He-3 ADR Cryostat

The Model 107 K2 adiabatic demagnetization refrigerator (ADR) is specially designed for experiments needing high cooling power. By employing a Helium-3 cooler that offers a low 300 mK intercept, more of the ADR cooling power can go towards your experiment. This mid-sized research cryostat features an experimental volume of 34 cm in diameter and 20 cm tall.

- Helium-3 backed, single stage ADR (Adiabatic Demagnetization Refrigerator) cryostat with high-powered 300 mK intercept
- Kevlar FAA suspension
- 30 mK stages Optimized for versatility and flexibility
- 5X NW50 ports on top flange (2 available to user)
- 2X NW40 port on top flange (2 available to user)
- 3X NW25 port on top flange (1 available to user)
- 1X Ø150 mm port on vacuum jacket bottom flange
- Nickel plated aluminum thermal shields (50 K, 4 K)
- Quick release vacuum jacket flanges
- Electronically controlled motorized heat switches
- Vibration minimizing design
- Remote rotary valve motor
- Custom service stand (option) allows for transport & servicing with 76 cm of height adjustment

Specifications:

- Large cooling capacity (~20 Joules) at 300mK
- Large capacity FAA salt pill (~70cc)
- Pulse-tube stage temperatures of ~50K and ~2.7K
- 1 Watt (at 4 K) Cryocooler (Cryomech PT410 Pulse Tube)
- ADR base temperature of <30mK
- >150 hour no-load regulation at 100mK

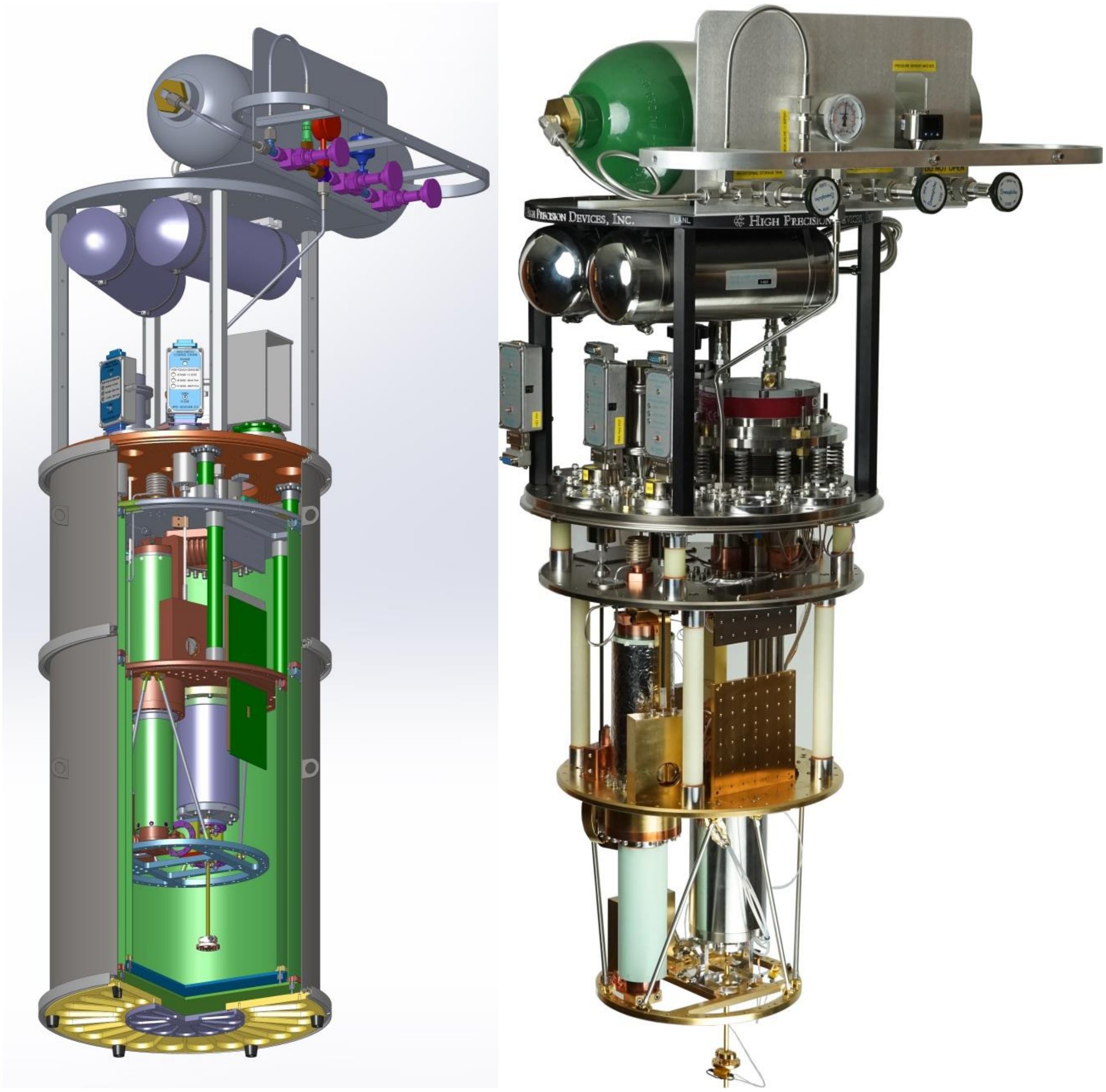


Figure 26: K2 He3 Cryostat

Gas Handling

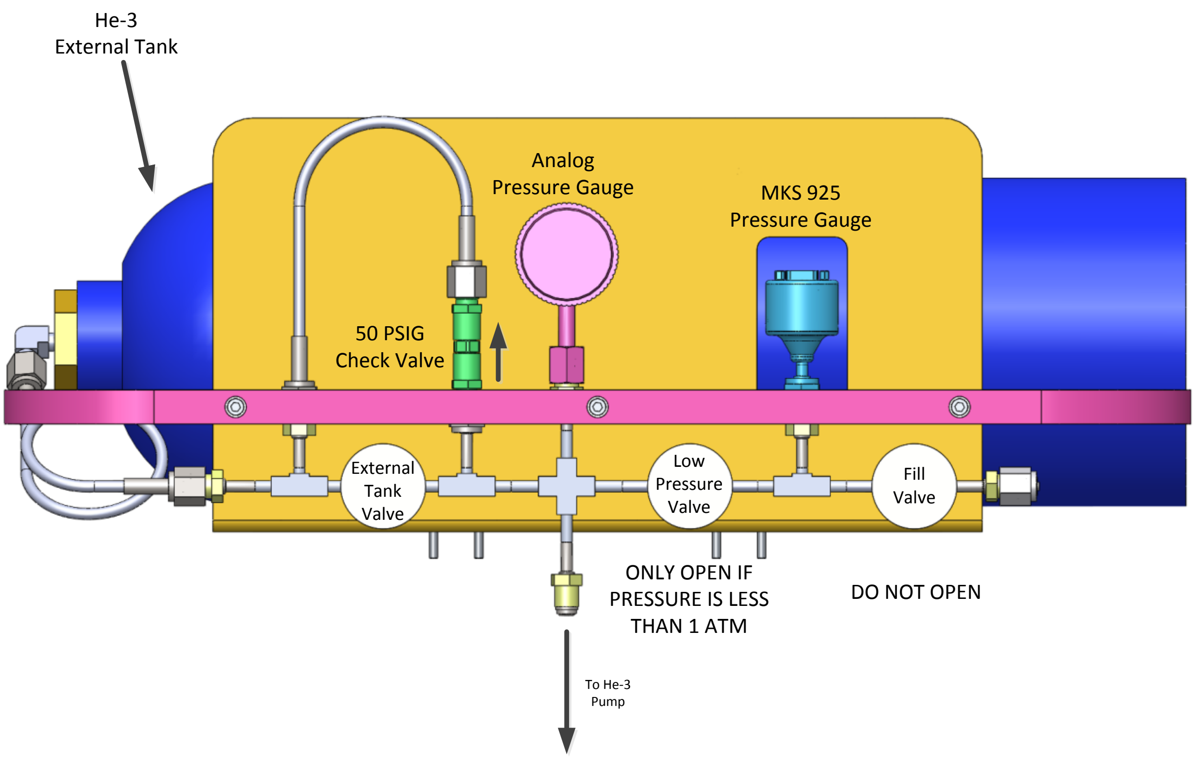


Figure 27: Gas Handling System

The K2 He-3 cooler uses a closed loop He-3 system. When the cryostat is warm He-3 gas is stored in the external storage tank housed on top of the cryostat. During pulse tube cooldown the He-3 is drawn into the He-3 Pump on the 3K Plate and can then be used to cool the 300mK plate to its base temperature.

- THE ONLY VALVE THAT SHOULD BE USED DURING NORMAL CYROSTAT OPERATION IS THE EXTERNAL TANK VALVE.
- During cooldown and warmup the External Tank Valve must be open. Close the External Tank Valve when the cryostat is cold (1st Stage Plate at 50K and 2nd Stage Plate at 3K.)
- Only open the Low Pressure Valve when the cryostat and pump are cold and the He-3 system is at low pressure. This should not be necessary unless troubleshooting the system.
- **DO NOT OPEN THE FILL VALVE.**

He-3 and ADR System

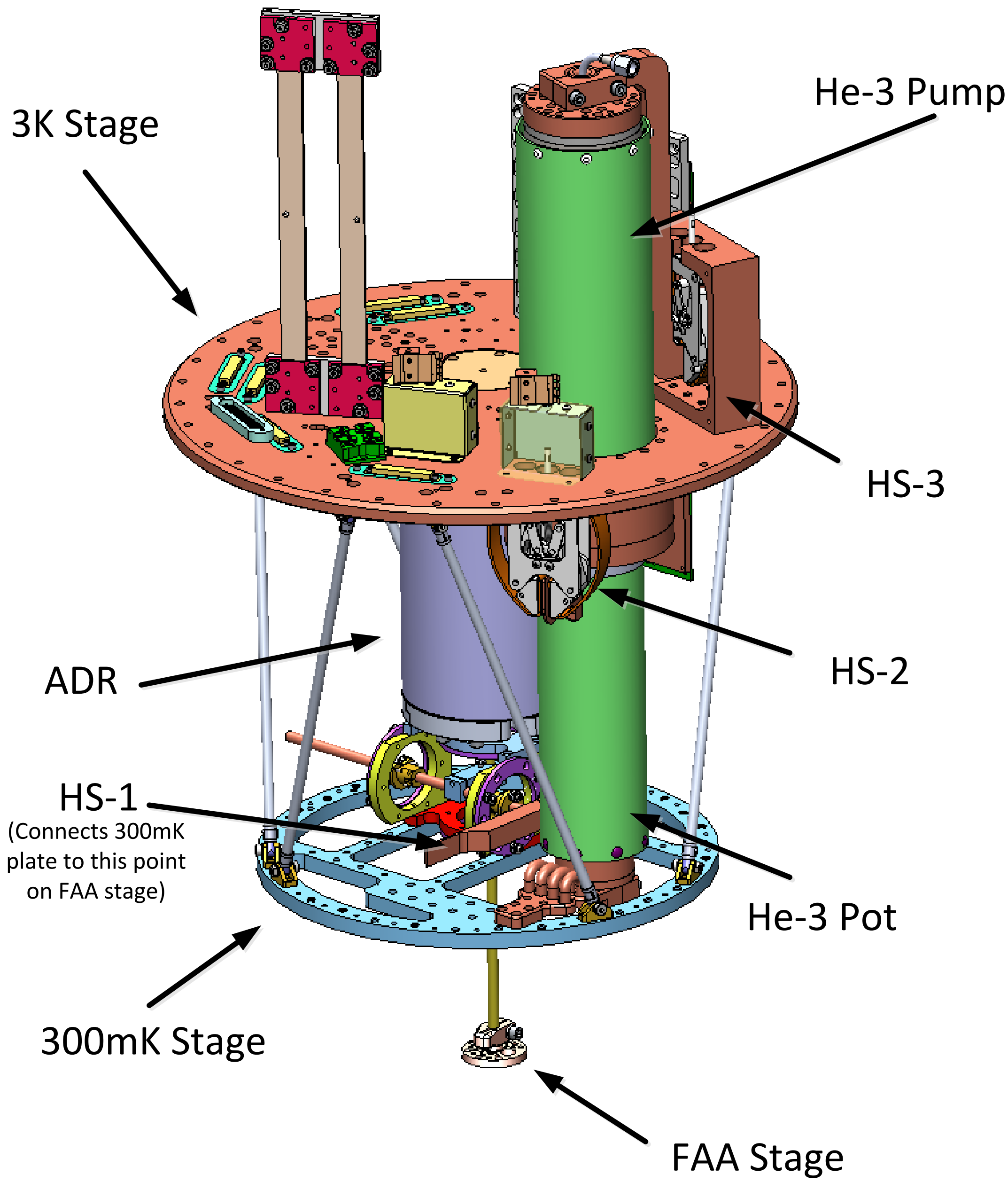


Figure 28: He-3 and ADR Systems

Below the 50K and 3K Pulse Tube cooled stages the K2 He-3 ADR Cryostat houses a He-3 cooled 300mK stage plate. The FAA stage is suspended from the 300mK stage.

Three Heat Switches are used to operate the He-3 and ADR cycles. See Figure 28 and Figure 29.

- Heat Switch 1 connects the FAA Stage to the 300mK Stage
- Heat Switch 2 connects the He-3 Pot and 300mK Stage to the 3K Stage.
- Heat Switch 3 connects the 3K Stage to the He-3 Pump.
- All Heat Switches are closed during cooldown.

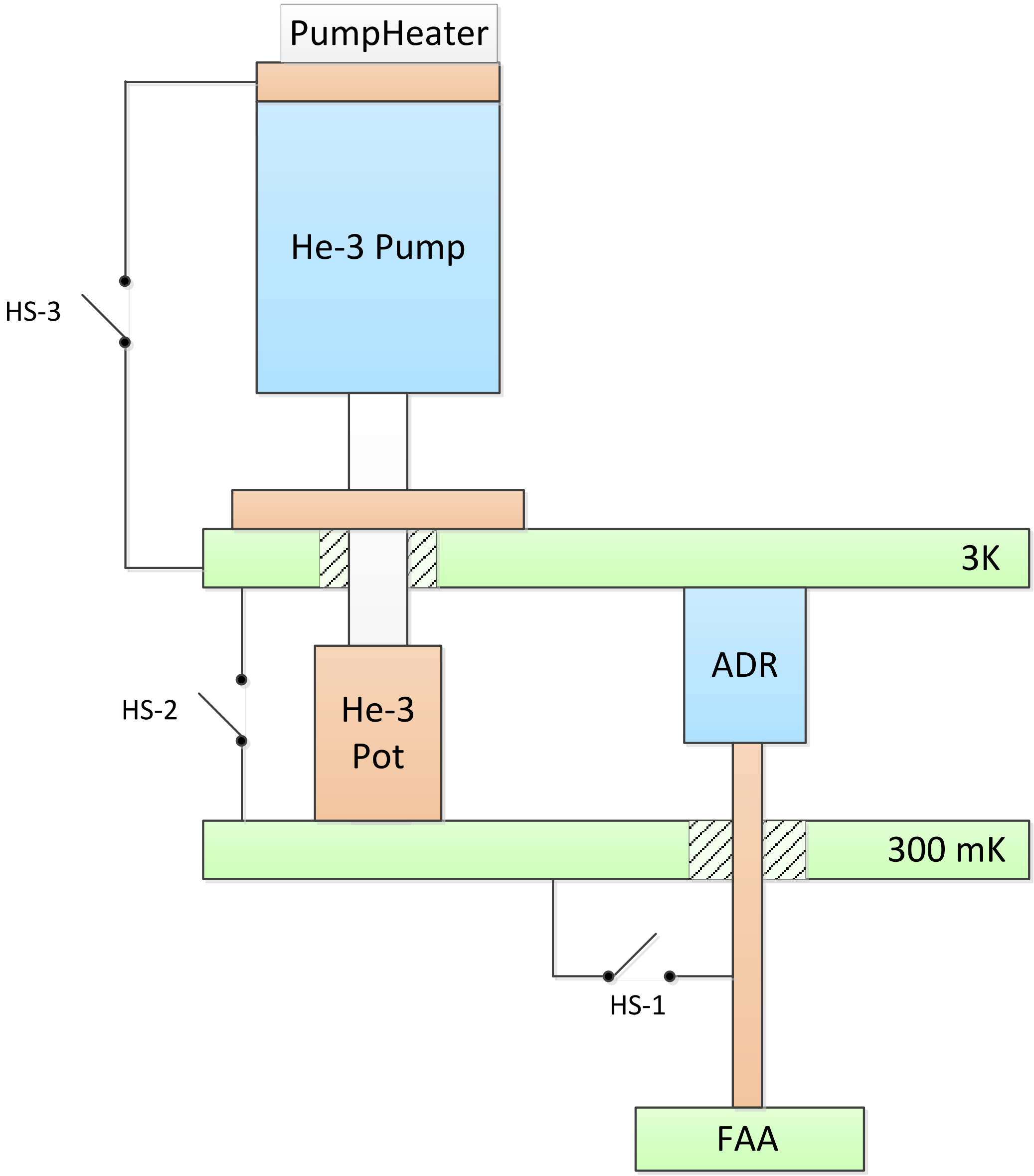


Figure 29: Heat Switch Schematic

He-3 and ADR Cycle

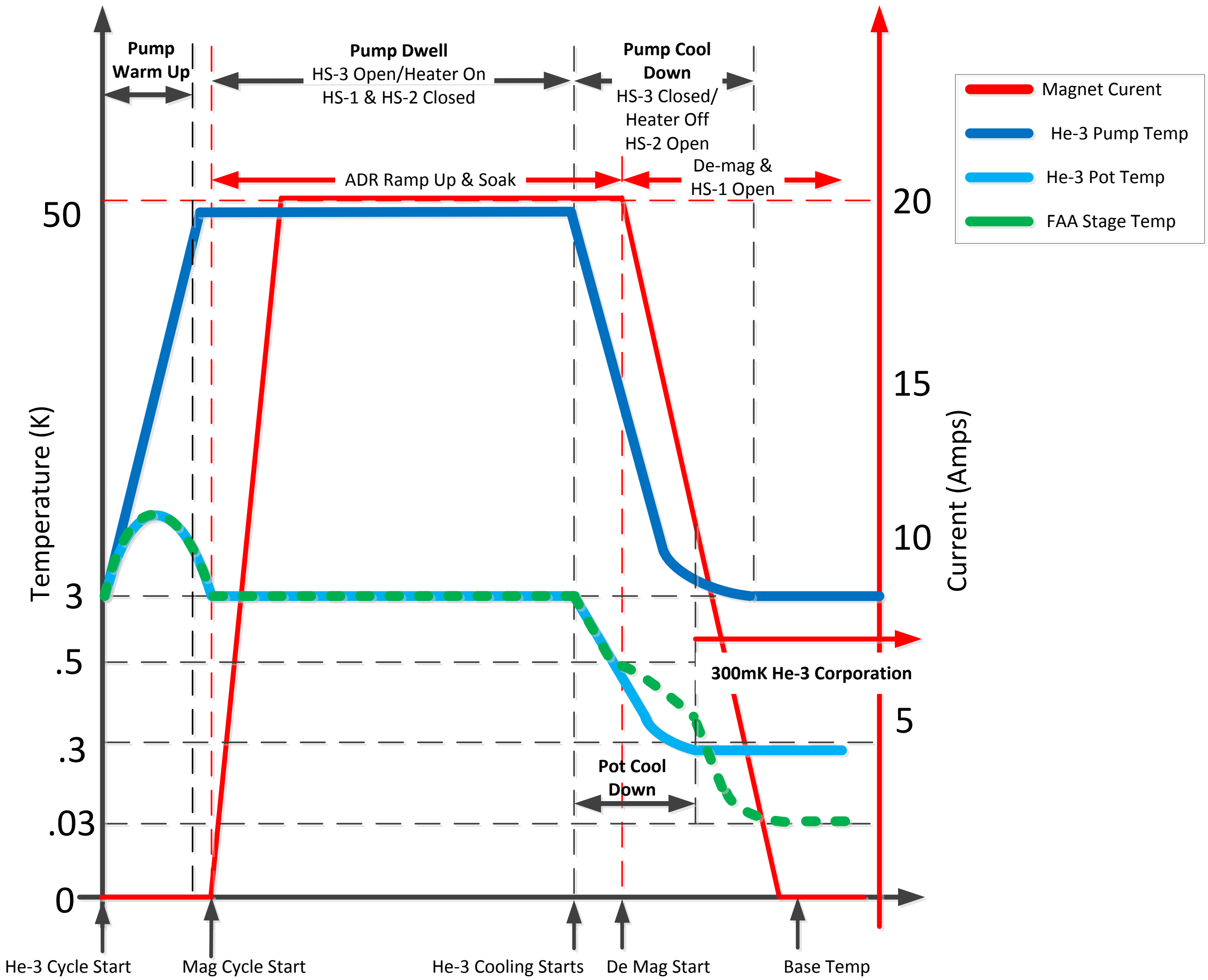


Figure 30: He-3 and ADR Cycle

The Parallel He-3 and ADR Cooling Cycle is shown above in Figure 30.

1. Condensation Stage.
    a. This stage begins with opening Heat Switch 3 to isolate the He-3 Pump from the 3K Plate.
    b. The He-3 Pump Heater is then turned on. This will bring the Pump temperature up and drive the He-3 out of the Pump so that it condenses in the He-3 Pot.
    c. The heat generated by the Pump Heater temporarily raises the temperature of the 3K Stage, the He-3 Pump and the FAA Stage (all of which are thermally connected at this point.) Once this heat is removed by the pulse tube the ADR cycle begins.

2. ADR Mag Up
    a. The ADR Magnet is now brought to full field and remains at full field with Heat Switch 1 closed so the pulse tube can remove the heat generated in Mag Up.
3. Evaporation Stage
    a. After the He-3 is driven out of the pump and is condensed as liquid He-3 in the Pot the Evaporation Stage can begin.
    b. The Pump Heater is now turned off.
    c. Heat Switch 2 is now opened to isolate the Pot and 300mK Plate from the 3K Stage.
    d. Heat Switch 3 is closed to bring the Pump temperature down to 3K and begin pumping of He-3 out of the Pot. The evaporation of He-3 from the liquid in the Pot cools the Pot and attached 300mK plate to its base temperature.
4. ADR De-Magnetization
    a. 300mK plate and FAA stage are cooled during the Evaporation Stage, once they reach a temperature of ~0.5K the ADR Ramp Down begins.
    b. Heat Switch 1 is opened to isolate the FAA Stage from the 300mK Plate.
    c. Magnet current is brought down to zero cooling the FAA Stage to its base temp of <30mK.
5. Temperature Regulation
    a. Temperature Regulation can now begin.

7. Servicing and Maintenance

Refer to Cryomech manual for pulse tube system maintenance.

Minimal maintenance is required for the cryostat. For the main cryostat vacuum chamber, care should be taken that the vacuum sealing surfaces are protected and that the o-rings are kept clean and properly greased with a very thin layer of Apiezon high vacuum grease. If any of the o-rings are damaged, they should be replaced as needed with new Viton o-rings. Refer to Table 6 for O-Ring sizes. If the o-ring is not listed, please contact HPD for that information.

Description	Supplier	Part Number
Model 102		
Vacuum Jacket O-Ring (Viton size -277)	McMaster-Carr	9464K575
Quick-Shield	Spira	NM-.103 NC-11.97-.060
Model 103		
Vacuum Jacket O-Ring (Viton size -280)	McMaster-Carr	9464K577
Quick-Shield	Spira	NM-.06 x 46.25”
Model 104		
Bottom Plate, Center Cover Quick-Shield	Spira	NM-.06 NC x 35.5”
Bottom Plate, Center Cover Vacuum Jacket O-Ring (Viton size -275)	McMaster-Carr	9464K573
Bottom Plate Quick-Shield	Spira	NM-12 NC.140 x 72”
Bottom Plate Vacuum Jacket O-Ring (Viton size -391)	McMaster-Carr	9464K656
Model 106/ Model 107		
Vacuum Jacket O-ring (Viton size -283)	McMaster-Carr	9464K581
Quick-Shield	Spira	NM-.06 x 56”
Ports-All Models		
Centering Ring Asm, Alum/Viton, NW25	MKS Instruments	100312603
Centering Ring Asm, Alum/Viton, NW40	MKS Instruments	100312605
Centering Ring Asm, Alum/Viton, NW50	MKS Instruments	100312606
Centering Ring Asm, Alum/Viton, NW 63	MKS Instruments	100760606
Centering Ring Asm, Alum/Viton, NW 80	MKS Instruments	100762808
Shield, 2.56 ID, for NW 50	Spira	NM-12-NC-2.56”
Shield, 3.38 ID, for NW 63	Spira	NM-12-NC-3.38”
Shield, 3.88 ID, for NW 80	Spira	NM-12-NC-3.88”

Table 6: Cryostat O-Rings, Shields, and Centering Rings

8. Troubleshooting

Engineers and scientists are available at HPD during normal business hours (9 a.m. and 6 p.m. Mountain Time USA, GMT -7) to assist customers in the event there is a problem or question with a cryostat. The troubleshooting guide is meant to provide general suggestions for possible causes of problems that commonly occur. Please feel free to contact HPD with specific questions or problems. Contact info is provided in section 0 on page 9.

1. **The cold head stages do not reach expected base temperatures/The cold head stages take longer than expected to reach base temperature.**
    a. Is the system under high vacuum (less than 1 x 10^{-3} Torr)? The location of the vacuum gauge is important. Having the gauge near the vacuum pump may give a false low reading.
    b. Was the heat switch closed during cool down from room temperature?
    c. Are the thermal shields installed?
    d. Has the thermal mass of the stages or items attached to the stages increased?
    e. Might there be loose fasteners in the system?
2. **The ADR stages have poor hold times/The ADR won't reach the expected base temperature.**
    a. Were large amounts of experimental wiring installed?
    b. Was the correct wire type used? (e.g. proper wire gage, proper wire material)
    c. Are any items attached to the stages not properly heat sunk? (e.g. dangling wire connectors, loosely attached or dangling circuit boards)
    d. Are there light leaks into the 3 K experimental space? (e.g. open ports, missing or loose screws)
    e. Is the system under high vacuum (less than 1 x 10^{-3} Torr)?
    f. Is the temperature reading accurate?
        i. Do any ground loops exist?
        ii. Are the correct calibrations for thermometers loaded?
        iii. Thermometer self-heating?
        iv. Bad temperature sensor?
3. **The touch lights on the heat switch control box stay on at zero magnetic field with the heat switch open.**
    a. Are the heat switch fingers touching or bent?
    b. Are any ADR screws loose? (e.g. heat switch finger screws, cross clamp screws)
    c. Do any of the pucks have broken Kevlar strands?

9. Appendices

9.1. Normal Operation

9.1.1. Average Cryostat Performance under no load.

	Model 102 Denali	Model 103 Rainier	Model 104 Olympus	Model 106 Shasta
1st Stage Base Temperature	66 K	52 K	47 K	57 K
2nd Stage Base Temperature	2.8 K	2.7 K	2.7 K	2.7 K
GGG Stage Base Temperature	< .500 K			
FAA Stage Base Temperature	< .050 K			
Hold Time at 100 mK	> 150 hrs			
Cool Down Time from 300 K	14 hrs	15 hrs	19 hrs	15 hrs

Table 7: Average No Load Cryostat Performance

9.1.2. Normal Operating Noises

The cryostat will make some noises during normal operation summarized below:

- Pulse-tube refrigerator
  - The compressor will emit a loud constant hum.
  - The remote motor will emit a loud chirp approximately twice a second
- Heat Switch
  - The heat switch motor will whine during opening and closing.
  - The heat switch will make a clicking noise when fully open at the end of an opening event.
  - The heat switch motor whine will decrease in pitch at the end of a heat switch close.

9.2. Normal Stanford Research Systems Control System Settings

- SIM921 Resistance Bridge settings:
  - Range: 20 kΩ (value should be adjusted based on thermometer resistance)
  - Excitation: 100 µV (value should be adjusted based on thermometer resistance)
  - Mode: Voltage
  - Time Constant: 3 seconds
  - Autorange: Display
- SIM922 Diode Temperature Monitor sensors:
  - T1 – First Stage (60 K) of PT
  - T2 – Magnet
  - T3 – Second Stage (3 K) of PT
  - T4 – Spare channel
- SIM970 Quad Digital Voltmeter channels:
  - Channel 1 – Voltage Across Magnet (Voltage Taps)
  - Channel 2 – Magnet Current
  - Channel 3 – Spare channel
  - Channel 4 – Spare channel
- SIM925 Octal Four-wire Multiplexer channels:
  - Channel 1 – FAA (50 mK)
  - Channel 2 – GGG (1 K)
  - Channel 3 – Magnet RTD
  - Channels 4 through 8 – Spare channels
- SIM960 Analog PID Controller settings (For manual mag-up and mag-down)
  - Output: Manual
  - Mode: Manual
  - Setpoint: Internal
  - Lower Limit: -0.100 V
  - P Gain: 1.6 E1
  - I Gain: 0.2 E0

9.3. Hitch Plate Interface Drawing

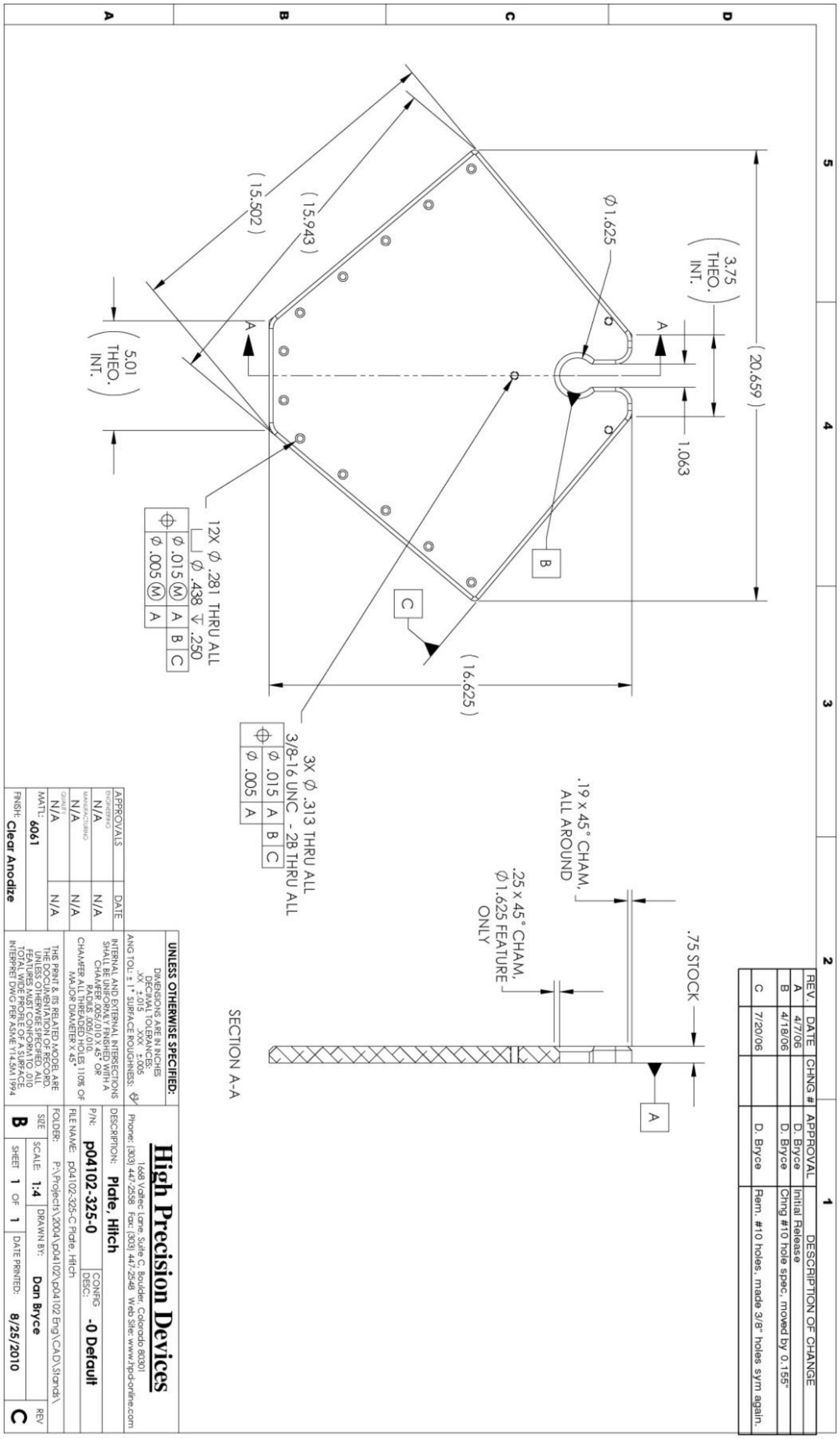
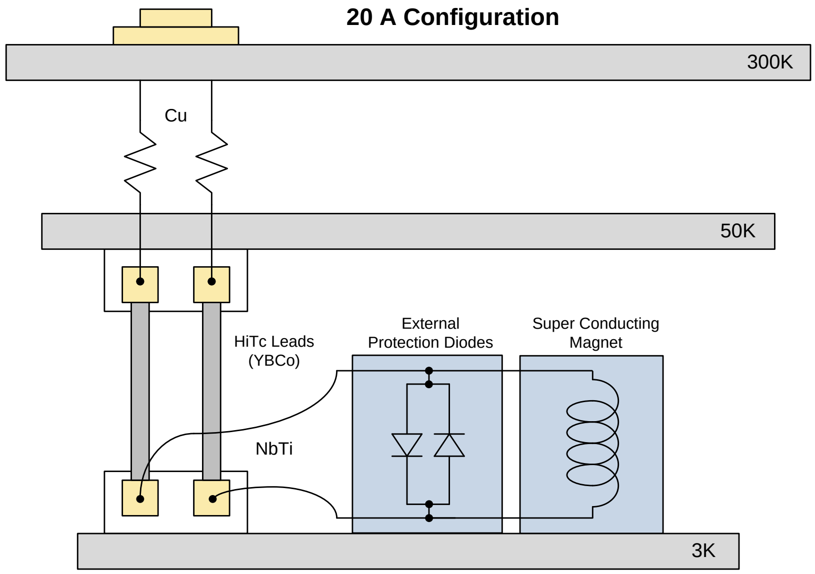


Figure 31: Hitch Plate Drawing

9.4. ADR Magnet Wiring Schematic



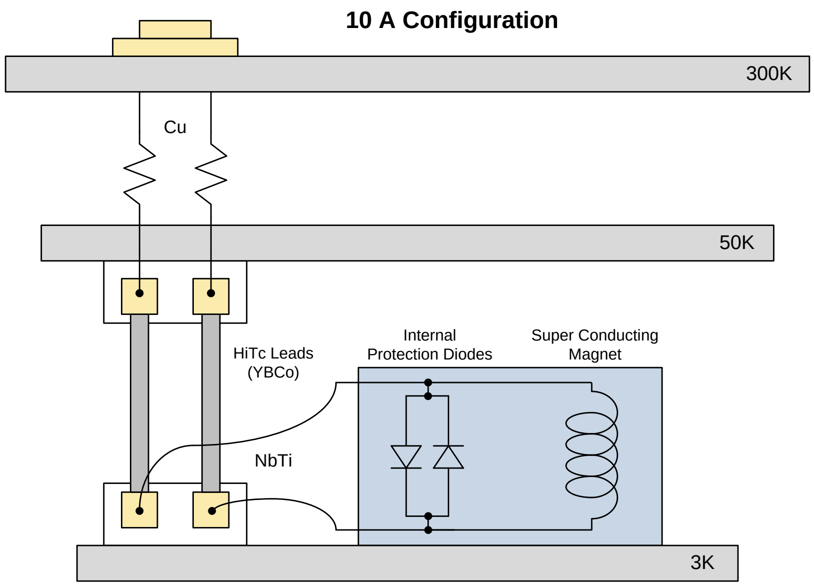


Figure 32: ADR Wiring

The wiring for the ADR magnet is copper from the connector on the 300 K plate down to the beginning (top end) of the High T_c Leads, at the underside of the 50 K plate. The High T_c Leads made from YBCO tape carry the current from the 50 K plate to the 3 K plate. The wiring switches to niobium titanium after (below) the High T_c Leads for the remainder of the circuit. For the 20 A system, the magnet protection diodes sit on top of the 3 K plate and for the 10 A system, the magnet protection diodes are internal to the magnet. The High T_c Leads and the niobium titanium wires are superconducting.

9.5. Recommended Ideal ADR Magnetization Cycle

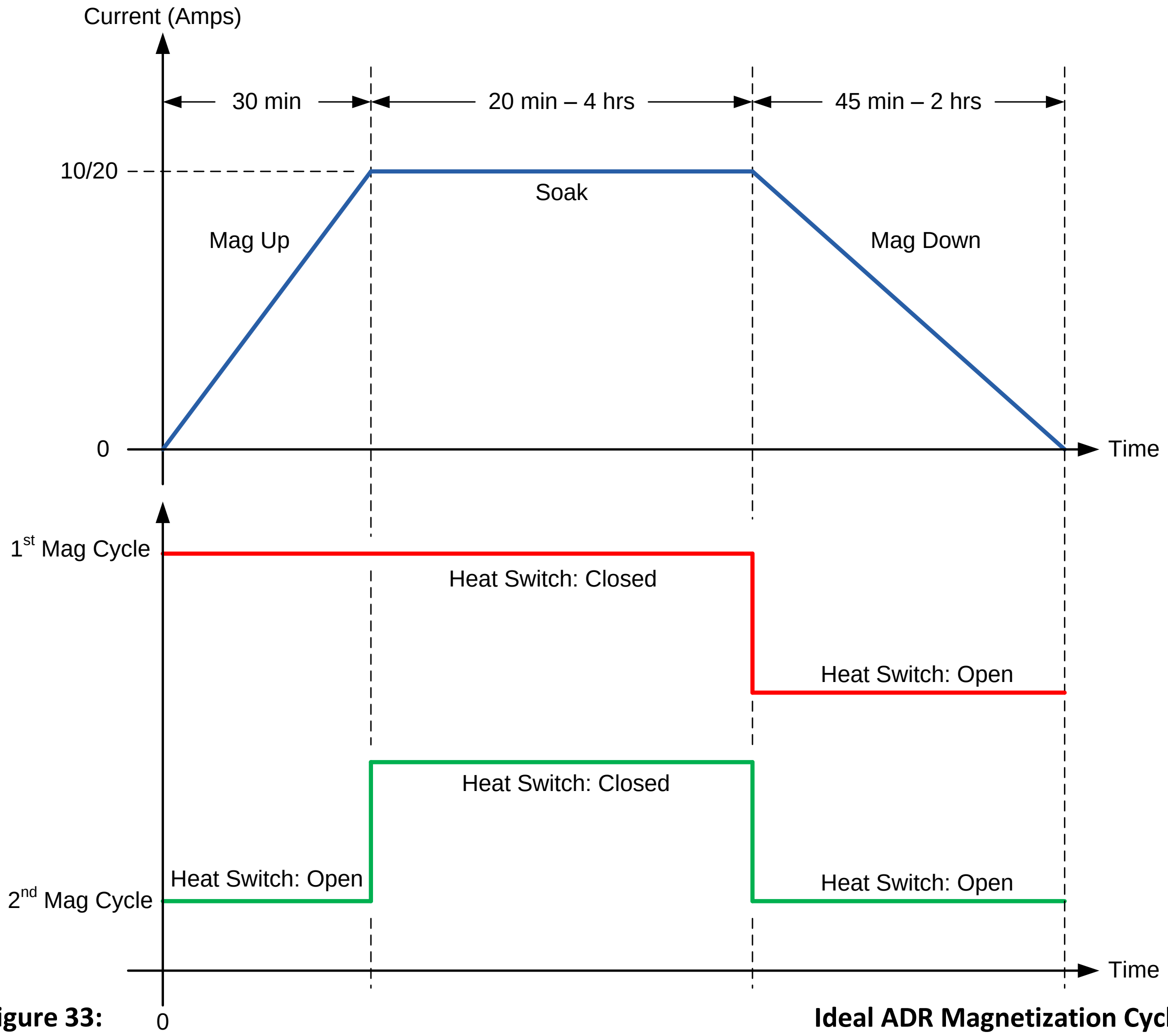


Figure 33: Ideal ADR Magnetization Cycle

Once the 60 K and 3 K stages have reached base temperature and the ADR magnet temperature is below 4 K, an ADR magnetization cycle can be performed. The plot above shows a schematic representation of the recommended ideal ADR magnet cycle. There are three steps to an ADR magnet cycle:

1. Mag up: Current to the magnet is increased from 0 to 9.44 A for a 10 A system, or 18.88 A for a 20 A system, over a period of 30 minutes. For a first magnet cycle, where the salt pills are thermalized to the 3 K stage, the heat switch should be closed during mag up. For a subsequent mag cycle, where the pills are at a lower temperature (100 mK for example), the heat switch can be left open until full field is reached or at least until the temperature of the pills is above the 3 K stage temperature.
2. Soak: To allow for the equilibration of the salt pills, the magnet is kept at full field with the heat switch closed for 20 minutes to 4 hours. The salt pills will equilibrate with the 3 K stage more completely with longer soak times with diminishing returns as the soak time is increased past 4 hours.

3. Mag down: The heat switch is opened, and the current to the magnet is decreased from full field to zero field over a period of 40 minutes to 2 hours. Slower mag down rates tend to decrease the base temperature and increase the ADR hold time due to reduced eddy currents in the FAA pill can and better equilibration of the ballast masses.

9.6. Paramagnetic Salt Pill Cooling Cycle

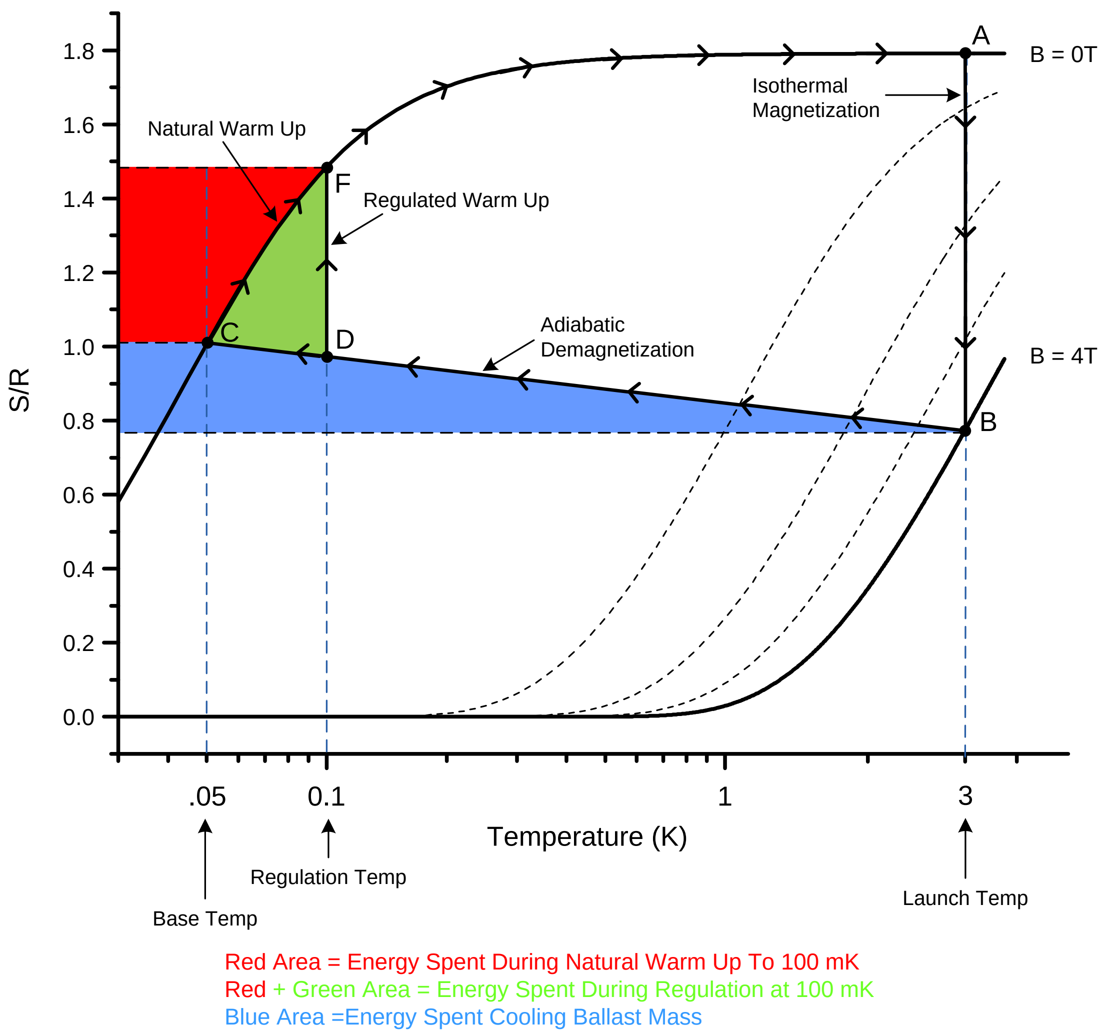


Figure 34: Paramagnetic Salt Pill Cooling Cycle Schematic

The plot above schematically shows a series of entropy over R curves as a function of time and magnetic field for a paramagnetic salt pill (in this case FAA). The cycle progresses in three steps. At the start of step one, the salt pill is thermally sunk to the 4 K stage with the ADR magnet at zero field (labeled “Before Mag Up” above). The first step involves isothermally magnetizing the pill from zero field to 4 T ending at the point labeled “At Field After Dwell”.

During the second step, after thermally isolating the pill from the 3 K stage by opening the heat switch, the pill is adiabatically demagnetized to zero field reaching the base temperature of the pill (in this example 50 mK). During the demagnetization, heat is absorbed from the surrounding ballast mass spending the energy represented by the area shaded blue. The third step involves either allowing the salt pill to warm up naturally along the line labeled B = 0 T or regulating the temperature of the pill (in this example at 100 mK) by regulating the magnetic field. During natural warm up, the cooling power of the pill is given by the area shaded red. During a regulated warm up, the cooling power of the pill is given by the area shaded in red plus the area shaded in green. The green area is the “bonus” entropy gained by regulating at a temperature instead of allowing the system to warm-up naturally.

9.7. Suggested Further Reading and Useful Websites

9.7.1. Useful Books

- Matter and Methods at Low Temperatures by Frank Pobell
- Experimental Techniques for Low-Temperature Measurements by Jack Ekin
- Experimental Techniques in Condensed Matter Physics at Low Temperatures by Robert Richardson and Eric Smith
- Experimental Principles and Methods Below 1 K by O.V. Lounasmaa
- An Introduction to Millikelvin Technology by David Betts

9.7.2. Useful Websites

- NIST Cryogenics Technology Group at: www.cryogenics.nist.gov
- Quantum Design’s Thermal Conductance Calculator at: www.qdusa.com/techsupport/thermalCalculator.html
- Lakeshore Cryogenics thermometer installation guide at: www.lakeshore.com/Documents/LSTC_appendixC_l.pdf

9.8. Safety Symbol Definitions

	Electrostatic Sensitive Device: To prevent equipment damage use proper grounding techniques. Electromagnetic Environment. The Cryostat system is intended for use in a controlled electromagnetic environment. Higher levels of RF interference may degrade performance of sensitive measurement circuitry.
NOTICE	**NOTICE:** Used to address practices not related to personal injury. Risk of damage to equipment. Additional information to aid the operator.
CAUTION	**CAUTION:** This warning is used without the safety alert exclamation point, and addresses practices not related to personal injury.
⚠ CAUTION	**CAUTION:** Used with the safety alert symbol, indicates a hazardous situation which, if not avoided, **could result in minor or moderate injury**. Care must be taken to prevent potentially significant damage to equipment and ensure safety of operator. Consult manual.
⚠ WARNING	**WARNING:** Used to indicate a hazardous situation which, if not avoided **could result in death or serious injury**.

9.9. List of Operation Manual Safety Warnings, and Notices

Page 9

CAUTION	**Control Rack** For operating parameters refer to Table 5: Operating Parameters. Rack input power is 230VAC, 50/60 Hz, 7amps. All equipment in rack must be connected as indicated in supplied Wiring Schematics and in accordance with Manual. Rack must be powered with supplied power cord or with one rated per local codes and jurisdictions. Operator must wear properly grounded wrist strap when rack is open. Do not install on an uneven surface.
WARNING	**Cryostat** Cryostat weight is greater than 150 lbs. Operator must lift Cryostat with a crane.
CAUTION	**Service Stand** Operator must adjust the load to the lowest position when traveling. Do not install on an uneven surface. No incline more than 10% grade.
WARNING	**Liquid Nitrogen Outlet (RCC Cryostats Only)** Extreme cold. Operator must wear approved personal protective equipment (PPE). • Safety Goggles (unvented)-required at all times. • Face Shield-required when pouring or filling. • Insulated Gloves- gloves should be loose fitting enough so they can be quickly removed if liquid should pour in them. You can also purchase elastic cuff insulated gloves- gloves are required. • A lab coat with long sleeves is required to minimize skin contact. Also, pants should be worn on the outside of shoes or boots to prevent shoes from filling in the event of spillage. • When handling large quantities of LN2, an apron should be used as well. The release of nitrogen can also displace oxygen in a room and cause asphyxiation. If dewars and insulated flasks containing liquid nitrogen are left uncovered for extended periods of time, liquid oxygen can build up to levels which may cause violent reactions with organic materials (i.e. severe clothing fire could result). HPD recommends Research Labs use Oxygen Monitors in Cryostat areas.

Page 16

CAUTION	The temperature of the FAA salt pill must NEVER exceed 104° F (40° C, 313 K). Permanent damage will result.

Page 25

NOTICE	Customers have mounted their cryostats to custom frames attached to walls or the floor. Many customers use extruded aluminum structural framing or Unistrut to build their mounting frames.

Page 26

⚠ CAUTION	The top travel limiting nuts are the only restraint preventing the bellows from being pushed apart by the springs. Do not remove the nuts completely or back them off excessively when the cryostat is in use as the bellows will expand significantly when the cryostat is no longer under vacuum. Damage to the bellows and/or the jumper cables may occur if the bellows are allowed to expand too far.

Page 27

NOTICE	After wiring the compressor to the appropriate plug, turn on the compressor main breaker and power switches. The system should go through an initialization and indicate whether the 3-phase wires are properly connected. In the case there is an error signal regarding the sequence, switch any two of the three power wires. Ground should always remain ground.

Page 27

NOTICE	Care should be taken when adding antifreeze to the cooling water loop for water chillers that operate outdoors in cold climates. Antifreeze will decrease the cooling efficiency of the water supply, possibly causing the system to overheat and shutdown. Please consult Cryomech if you are planning to use such a system.

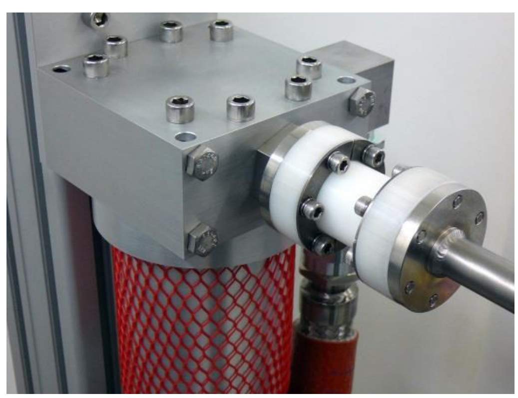
Page 28

CAUTION	The Aeroquip connections at the end of the compressor lines require lubrication before every connection or reconnection. The proper lubricant is provided by Cryomech in the compressor tool kit. Care should be taken to prevent lubricant from getting on the sealing faces at the ends of the hose which could cause contamination of the helium supply. To help prevent lubricant from contaminating the lines, the threading of the fitting should be started first, then the lubricant should be applied, and finally the fitting should be threaded on completely. Use the lubricant sparingly. Please refer to the Cryomech manual for more information.

Page 29

CAUTION	Do not disconnect the pulse-tube head from the remote motor or the compressor lines from the compressor or remote motor when the system is cold. The helium gas in the pulse-tube head expands out of the head back into the compressor during warming. If the pulse-tube head is disconnected before warm-up, helium gas will vent to atmosphere out of the high-pressure safety valve requiring a recharging before the next use.

Page 29

NOTICE	The remote motor supplied with the cryostat includes an electrically insulating break in the hose that attaches it to the cold head as shown in the picture below. This break prevents the cryostat from being electrically grounded through the connection to the compressor which could potentially create a ground loop. The Teflon connector should not be removed as helium gas will escape. 

Page 32

	Electrostatic Sensitive Device: To prevent equipment damage use proper grounding techniques. Electromagnetic Environment. The Cryostat system is intended for use in a controlled electromagnetic environment. Higher levels of RF interference may degrade performance of sensitive measurement circuitry.

Page 33

NOTICE	Depending on laboratory set-up, connecting the SRS Mainframe Chassis Ground to a true earth ground may eliminate noise in the SRS system.

Page 34

CAUTION	The vacuum jacket and shield screws ship with a small amount of Apiezon vacuum grease applied to them. To prevent galling, more grease should be added to the screws if needed (e.g. if the grease wears off). Only a very small amount of grease is necessary.

Page 35

NOTICE	If the system has been opened in a humid environment or has been exposed to helium gas (as used for accelerated warm-up), it may be helpful to pump out the system and back fill it with nitrogen gas. To do this, pump out the system until it reaches a vacuum of 100 microns (1 x 10^{-1} Torr), and then back fill with nitrogen gas. Please see warning below regarding over-pressurization.

Page 35

CAUTION	Care should be taken to avoid positively pressurizing the system with gas when backfilling. This can be accomplished by placing a tee in the plumbing circuit with the extra branch of the tee facing upward and omitting the clamp on the blank cover as shown below. This way the blank cover will lift off when there is any positive pressure. 

Page 36

NOTICE	The three touch sensor lights on the heat switch control box will illuminate when the heat switch is closed. At zero field, the touch sensor lights are normally an accurate reflection of the state of the heat switch. When the magnet is energized, the touch lights may illuminate due to normal touches caused by the deflection of the suspension system that are unrelated to the state of the heat switch and may no longer accurately reflect the state of the heat switch.

Page 37

	**Liquid Nitrogen Outlet (RCC Cryostats Only)** Extreme cold. Operator must wear approved personal protective equipment (PPE). • Safety Goggles (unvented)-required at all times. • Face Shield-required when pouring or filling. • Insulated Gloves- gloves should be loose fitting enough so they can be quickly removed if liquid should pour in them. You can also purchase elastic cuff insulated gloves- gloves are required. • A lab coat with long sleeves is required to minimize skin contact. Also, pants should be worn on the outside of shoes or boots to prevent shoes from filling in the event of spillage. • When handling large quantities of LN2, an apron should be used as well. The release of nitrogen can also displace oxygen in a room and cause asphyxiation. If dewars and insulated flasks containing liquid nitrogen are left uncovered for extended periods of time, liquid oxygen can build up to levels which may cause violent reactions with organic materials (i.e. severe clothing fire could result). HPD recommends Research Labs use Oxygen Monitors in Cryostat areas.

Page 37

	It is imperative that no steps are taken that would result in liquid cryogens being contained in a volume that does not include a relief device. This means that care must be taken during the cooldown sequence to avoid any cryogens being trapped in a closed volume. Pressure relief devices must remain in place and be fully operational.

Page 38

	The three touch sensor lights on the heat switch control box will illuminate when the heat switch is closed. At zero field, the touch sensor lights are normally an accurate reflection of the state of the heat switch. When the magnet is energized, the touch lights may illuminate due to normal touches caused by the deflection of the suspension system that are unrelated to the state of the heat switch and may no longer accurately reflect the state of the heat switch.

Page 38

CAUTION	Delivery pressure to cryostat liquid nitrogen line should not exceed 75 psi. Over pressurizing liquid nitrogen line could cause rupture of bellows.

Page 40

NOTICE	At a high flow rate LN_2 will be exiting the cryostat outlet and can be collected in an open mouth dewar for re-use.

Page 41

CAUTION	Delivery pressure to cryostat liquid nitrogen line should not exceed 75 psi. Over pressurizing liquid nitrogen line could cause rupture of bellows.

Page 41

WARNING	Do not unplug the magnet power cable or the cable plugged into cryostat connector 2 when the magnet is energized. Serious injury, and/or damage to the system may result.

Page 41

WARNING	Risk of electrical shock! Any modification made to the electrical system should be performed by a qualified electrician.

Page 42

CAUTION	Care should be taken to not change PID controller settings while the magnet is energized. Incorrect changes can quench the magnet.

Page 42

CAUTION	The magnet will spontaneously quench if driven with too high of a current (Above 9.5 A for a 10 A system and above 19.0 for a 20 A system).

Page 43

NOTICE	Circuit resistance will increase (current decrease) slightly as the magnet circuit wiring warms.

Page 43

NOTICE	Touches are normal at full field. The suspension system of the ADR includes electrically conductive travel limiters that have a low thermal conductivity to limit displacement of the stages while still indicating a touch with limited heat leak. Touches at zero field indicate a problem.

Page 45

CAUTION	When switching out of PID mode, it is vital to transfer the current output voltage of the PID controller to the manual output value before switching from PID mode to Manual mode as described below. Proper transfer will prevent quenching of the magnet.

Page 46

NOTICE	A transfer gas may be used to spoil the vacuum to increase the cryostat warm-up rate. When the cryostat is off but still cold, a small amount of nitrogen (~ 1 liter at STP) may be added to spoil the vacuum. Once the system warms to the point where all thermometers read 77 K (the temperature where N_2 vaporizes) or higher, the system can be back filled with additional nitrogen, to atmospheric pressure or lower. Please read the following warning regarding over-pressurization of the vacuum jacket. A similar small amount of helium may be added to the system when cold, instead of nitrogen, to increase the warm-up rate further, however this technique is not recommended because the helium can permeate some of the cryostat materials and negatively affect future pump-downs.

Page 46

CAUTION	Do not disconnect the pulse-tube cold head from the compressor when the system is cold unless instructed to do so by HPD or Cryomech. The cold helium gas trapped in the cold head will expand and vent out of the overpressure safety valve of the cold head during warm up if the head is left unconnected.

Page 47

	To avoid positively pressurizing the system either from the purge gas tank pressure or from expanding transfer gas during warm-up, care should be taken when backfilling the system. This can be accomplished by placing a tee in the vacuum circuit with the extra branch of the tee facing upward and omitting the clamp on the blank cover as shown below. This way the blank cover will lift off when there is any positive pressure. When employing the tee, the vacuum valve must also be left open.