Storage Cryostat Operations

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Contents

1 Overview

The storage cryostat is an integral component of the *HDice* target system. The goal of the system is the production and use of frozen-spin polarized deuterium hydride ice targets for nuclear physics experiments. The storage cryostat holds the HD ice target while the target is stored and shipped between laboratories. In order to understand how the storage cryostat accomplishes its mission, a brief review of the target system is required.

1.1 HD Target

The current target design is for a 50 mm long by 15.0 mm diameter cylinder of HD ice. That cylinder is contained between two, 0.5 mm thick pCTFE cups, one inside the other. The outer one is 86.2 mm long and the inner one is 26.1 mm long. The inner, shorter cup is 26.2 mm OD and ends in a 45 degree cone with a 3 mm hole at its vertex. The 1.03 grams of HD liquid enters the target via this hole. The outer cup is enlarged to 29.7 mm ID in the region of the inner one to create a 1.75 mm gap. The gap is sealed at the top of the cups by the copper target support ring to which both cups are attached. Roughly 700 aluminum cooling wires, 51 microns in diameter are soldered to the support ring and extend through the gap down into the HD ice cylinder. The target support ring has a central clearance of 24.5 mm in order for the gamma ray beam to traverse the length of the target. The outer surface of the ring has a right-handed M35x1.0 thread for attachment of the ring into each of the four cryostats mentioned above. The inner surface of the ring has a left-handed M26x1.0 thread. This allows the transfer cryostat to attach to the ring with the left-handed inside thread and then unscrew the right-handed outside thread to release the target when the attachment screw of the transfer cryostat rotates counter-clockwise (as seen from above) or to attach the ring inside the appropriate cryostat and then detach from the transfer cryostat with clockwise rotation.

In order for the unsealed target not to sublime appreciably, its temperature must be maintained below 5 Kelvin, although brief excursions up to 7 Kelvin are tolerable. Table 1 gives the vapor pressure inside and sublimation rate from our HD target with its 3 mm hole.

It is even more important to maintain the target at cold temperatures in order to reduce the rate of polarization loss as we shall see in the next section.

1.2 Target Cycle

The target is filled with HD by condensing HD vapor at just above the triple point of HD, 16.6 K. This temperature regime is reached with a specialized cryostat called the production cryostat (in IceMaker mode), or by utilizing the vertical temperature

Table 1: HD vapor pressure and sublimation rate vs. temperature

Temperature	Vapor Pressure	Sublimation Rate
7 K	7.8×10^{-4}torr	181 milli-gm/day
5 K	4.4×10^{-7}torr	123 micro-gm/day
4.216 K	3.9×10^{-9}torr	1.16 micro-gm/day

gradient in a dilution refrigerator with its inner vacuum filled with exchange gas. After filling, the target is attached to a He3-He4 dilution refrigerator with a 10 mK base temperature and a 17 Tesla superconducting solenoid (DeepFreeze). With the aid of a 10^{-3} doping of metastable ortho-H2, the H reaches equilibrium polarization of up to 80% within two days. This polarization can be transferred to the D with an adiabatic fast passage technique and the H repolarized. Repeating the fast passage transfer allows D polarizations of up to 50% to be reached. After 6 weeks of aging the ortho-H2 has decayed to such an extent that the polarization approach to equilibrium is extremely slow. This allows the target to be removed from such extremes of temperature and magnetic field. The target is transferred to the storage cryostat (IceChest), where the target is stored and shipped between laboratories, and then to the inbeam cryostat (IceBucket), where the target is exposed to the gamma beam while surrounded by the detector array. After the target polarization has decayed too low to be useful, it is transferred to the production cryostat (in De-Icer mode) for vaporization of the HD and re-generation of the ortho-H2 at room temperature. The HD gas is then ready to begin a new cycle. Table 2 gives the polarization lifetime for a fully aged target as a function of temperature for both H and D at the nominal fields of the three relevant cryostats : storage, inbeam and transfer.

Table 2: Typical H and D polarization lifetimes vs temperature

Field	10 Tesla (storage)		1 Tesla (inbeam)		0.03 Tesla (transfer)	
Temperature	H	D	H	D	H	D
4.2 K	8 days	24 days			0.1 days	0.3 days
1.5 K	81 days	240 days	4 days	12 days	0.8 days	2.4 days
0.4 K			35 days	100 days		

2 Storage Cryostat

Thus we see that in order for the storage cryostat to perform its job it must hold the target at temperatures downto 1.5 K and at magnetic fields up to 10 Tesla. Further, it must allow the target to be inserted and withdrawn, and it must be capable of being shipped between laboratories while holding a target (although not under long term storage conditions). The variable temperature dewar and the superconducting solenoid are commercial items manufactured by Janis and this document serves as an extension of the user manual supplied by Janis. In the following subsections, each of the components of the storage cryostat will be examined in detail (see Figures 1 and 2).

2.1 Target Vacuum Space

The storage cryostat is a series of concentric cylindrical or toroidal volumes, of which the center most is the target vacuum space. This volume extends some 1.5 meters, from the ISO-NW63 gate valve (MV2) at the top of the cryostat to the target pedestal on the space's bottom. Just below the gate valve is an adapting section to the ISO-NW80 flange on the top of the vari-temp space. This adapting section has an ISO-NW25 (KF25) connector to a KF25 cross carrying the pump out valve (MV3), pressure gauges and the check valve (RV6) to the target expansion volume, section 2.7.2. Additional connectors carry electrical feedthroughs into the vari-temp space for readout of thermistors mounted on the target pedestal and RF feedthroughs for crossed-coil NMR measurements on the target.

The bottom of the target vacuum space is sealed by an indium O-ring flange which carries the target pedestal and the electrical and RF feedthroughs from the vari-temp space into the target vacuum space. Besides the M35x1.0 right-handed threads for holding the targets, the target pedestal also contains the coils used for NMR on the targets and supports the shutter opener, which opens the 80 K radiation shutter on the transfer cryostat (see the Transfer Cryostat manual).

2.2 Vari-Temp Space

The target vacuum space is surrounded by an enclosing volume, termed the vari-temp space. This volume extends from the ISO-NW80 flange near the top of the cryostat down to just below the target vacuum space. The space is isolated from the LHe reservoir by vacuum. At the same time either of two capillaries leading to the LHe reservoir through separate needle valves (NV1,NV2) can be used to fill the vari-temp space with LHe or warmed helium vapor. At the top of the vari-temp space there is a KF40 pump out flange. A right-angle bellows valve (MV5) allows attachment of a pump to operate at reduced pressure and thus reduce the boiling point of LHe from 4.2 K to about 1.5 K. (Alternatively the pump can maintain a flow of helium vapor created by heaters in the capillaries in order to operate from 4.2 K up to about 40 K. This mode is not normally utilized in the SPHICE target system.) A small plug valve (MV6) connects the vari-temp space to the top of the LHe reservoir for venting purposes. A 4 psi relief poppet valve (RV5) protects the space from overpressure.

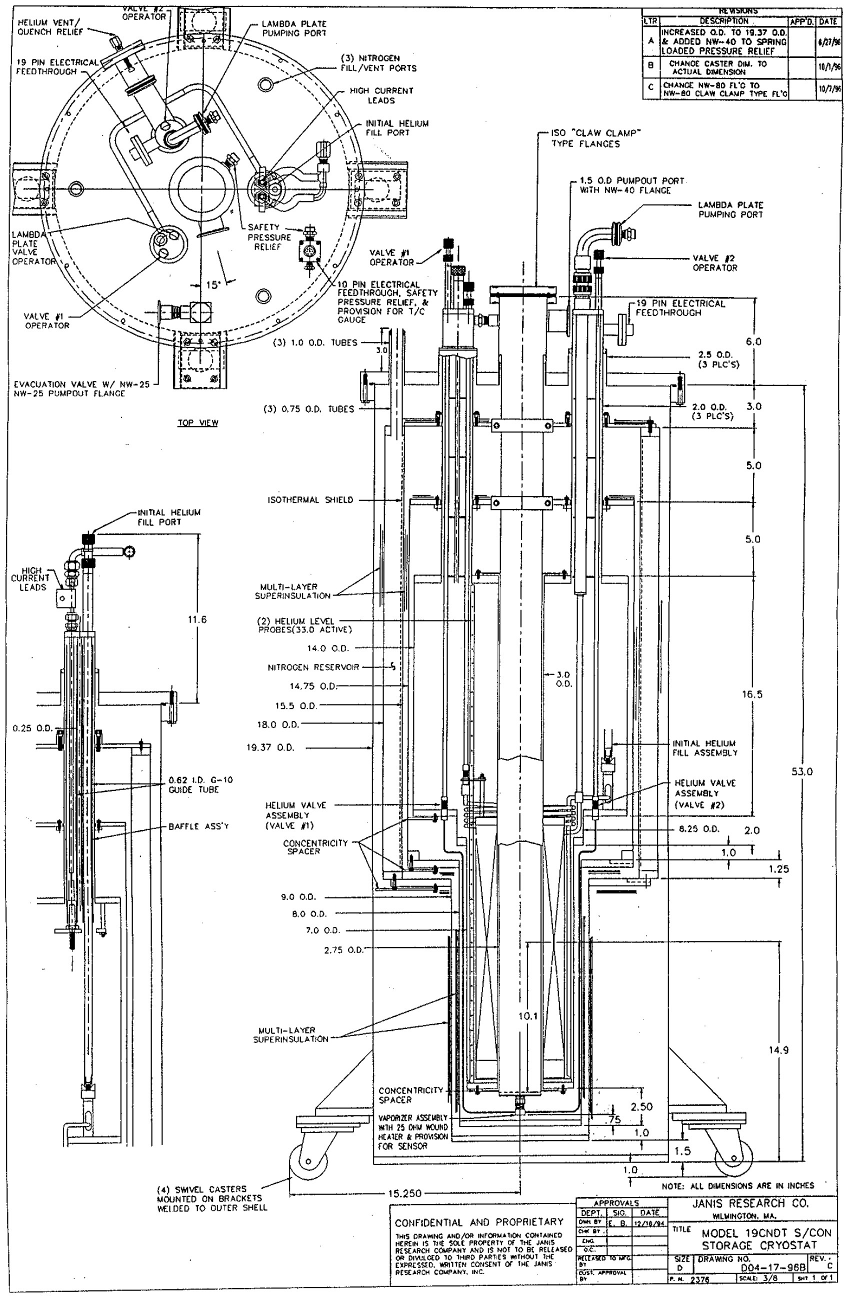

Figure 1: Storage Cryostat Drawing

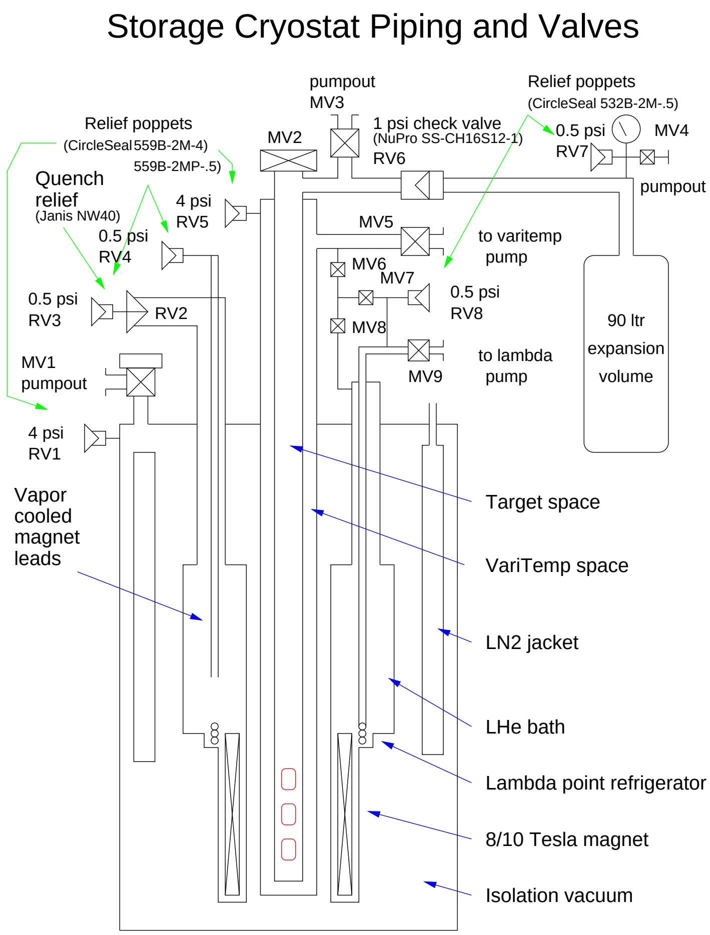

Figure 2: Storage Cryostat Piping and Valves Schematic

2.3 Cryostat Vacuum Space

The vari-temp space, the LN2 reservoir, and the LHe reservoir are contained within the cryostat vacuum space. The outside wall of this space is the room temperature outside of the cryostat. This vacuum space is evacuated through the KF25 exit flange of a right angle bellows valve (MV1) located on the top of the cryostat. A second brass adapter contains a pressure relief safety blowoff (RV1) and a ten pin electrical feedthrough for powering the capillary heater and measuring the resistance of a carbon thermistor.

2.4 LHe Reservoir

A toroidal reservoir for liquid helium (LHe) is contained in the cryostat vacuum space. This volume exhausts on the top of the dewar through a KF25 flange which is sealed by a low pressure quench relief valve (RV2) and two additional small poppet valves (RV3, RV4). It is filled through either of two 3/8 inch fill ports on the top of the cryostat in the access towers clockwise and counterclockwise to the helium exhaust port. The one on the clockwise access tower must be used for the initial fill since it connects to a guide cone that directs the incoming liquid below the magnet.

LHe from this reservoir is used in the vari-temp space. Two needle valves (NV1, NV2) are located on the bottom of the reservoir and lead to two heater equipped capillary tubes and thence to the vari-temp space. The controls for these valves are located on the access tower containing the helium exhaust port and the one counterclockwise to it. Heater leads are in the 10 pin connector on the cryostat vacuum pumpout valve. Leads for the helium level meter are in the 19 pin connector on the helium vent port tower. A small plug valve (MV8) allows use of the boiloff gas for venting purposes.

2.5 Superconducting Magnet

A superconducting magnet is mounted within the LHe reservoir. The magnet has a maximum central field of 8.0 Tesla at 4.2 K and 10.0 Tesla when cooled to 2.2 K. Stored energy of the magnet is 9.1×10^4J at 8 Tesla, corresponding to 35 liters of LHe, and 1.4×10^5J at 10 Tesla, corresponding to 55 liters of LHe. Terminal posts for the magnet leads are located on the tower on the top of the cryostat clockwise from the helium exhaust port. A persistent mode switch has been fitted in parallel with the magnet. This is a length of superconducting wire non-inductively wound around a heater. Applying current to the heater drives the wire normal and opens the switch. Allowing the wire to cool back down closes the switch. The leads for the heater are located in the 19 pin connector on the helium vent port tower. A lambda plate fridge has been fitted just above the magnet. This can cool the portion of the helium reservoir below it to the helium lambda point, 2.2 K. The fridge is a coil of tubing circling the reservoir into which LHe is admitted by a needle valve (NV3) and then pumped on to lower its temperature and provide cooling. The pumping port for this is on the same tower as the helium exhaust port and the needle valve control is on the counterclockwise one. The temperature of the magnet can be monitored with two carbon thermistors, mounted one at the top and one at the bottom of the magnet. The leads for them are located in the 19 pin connector on the helium vent port tower. A small plug valve (MV7) connects the lambda plate fridge pumping line to the top of the LHe reservoir for venting purposes.

2.6 LN2 Reservoir

A toroidal reservoir for liquid nitrogen (LN2) is contained in the cryostat vacuum space. Three symmetrically arranged access ports are on the top of the cryostat. One is used for the LN2 level meter and the other two serve as fill and vent ports.

2.7 Ancillary Equipment

2.7.1 Cryostat Cradle

A cradle has been constructed that holds the cryostat during shipment and provides shock and vibration protection. It utilizes air pillows and springs to cushion the dewar.

2.7.2 Cryostat Expansion Volume

A 90 liter liquid propane tank has been adapted to provide an expansion volume for 3 HD targets in the event that cooling is lost and the HD vaporizes. This volume is sufficient to maintain the pressure below atmospheric. It is coupled to the target vacuum space by a 1 psi check valve (RV6) and a two meter long, 1.9 cm diameter flexible hose. A manifold on top of the tank carries an 0.5 psi relief valve (RV7), a pumpout valve (MV4) and a pressure gauge for monitoring the status of the tank.

3 Procedures

Before attempting any of the procedures detailed in the following sections, all personnel should acquaint themselves with standard laboratory safety procedures, including vacuum pumping, liquid cryogen handling, magnetic field safety and proper hoist operation. All personnel must have read the Janis cryostat and magnet manual, the Oxford magnet power supply manual and this manual fully and must be certified by the head of the SPHICE target group at BNL. This equipment is for experimental use only and requires handling by trained personnel only.

3.1 Cooling to LN2

This procedure details cooling the cryostat from room temperature to that of liquid nitrogen, 77 Kelvin. Note that steps 1 through 12 can be done concurrently provided proper attention is paid to the vacuum prerequisites noted in each step.

1. Check the LN2 and LHe level meters to make sure both are connected and working properly.

2. Check the connections to the calibrated cermet, 150Ω, and the vaporizer heater, 25Ω, on the 10 pin feedthrough.

3. On the 19 pin feedthrough, check the connections to the two thermistors located on the magnet. Both resistors should be 150Ω.

4. Check the magnet leads, which should be 9.6Ω.

5. Record the time and resistance values in the cryostat logbook.

6. Verify rotation of the knobs of the two capillary needle valves, NV1 & NV2 and the lambda fridge needle valve, NV3. Leave them closed.

7. Attach a pumping station to the KF25 flange of the right angle bellows valve on the target space pumpout, MV3. Open MV3 and evacuate the target vacuum space to better than 8×10^{-6}torr. Close MV3 and remove the station.

8. Attach a turbo pumping station to the KF25 flange of the right angle bellows valve on the top of the cryostat, MV1. Open MV1 and evacuate the cryostat vacuum space to better than 8×10^{-6}torr. If necessary, close the valve and remove the station. It is better to leave the station attached and pumping through out the cool down process, Procedures 3.1 and 3.2.

9. Attach a roughing pump to the expansion volume pumpout, MV4. Confirm that the target space has at least been roughed out, since the 1 psi check valve, RV6, will open otherwise. Evacuate the tank to better than 50 microns. Close the pumpout valve, MV4, and remove the pump.

10. Insert a tee in the neoprene tubing vent manifold between valves MV6, MV7, and MV8. Attach a neoprene tube between this tee and one of the three vents on the LN2 reservoir. (One should already hold the LN2 level probe.). Place a rubber bung in the remaining port of the LN2 reservoir.

11. Insert a second tee in the neoprene tubing vent manifold between valves MV6, MV7, and MV8. Attach a helium gas supply cylinder with regulator and shutoff valve to this tee. Close the shutoff valve on the helium regulator.

12. *WARNING: Pumping on the LN2 or the LHe reservoirs with pressure in the cryostat vacuum space may result in severe damage.* Attach a roughing pump to the KF40 flange of the right angle bellows valve MV5 on the vari-temp space. Confirm that the cryostat vacuum has at least been roughed out. Open valves MV6, MV7, and MV8. Evacuate the LN2 reservoir, the LHe reservoir, the lambda fridge pumping line, and the vari-temp space to better than 50 microns. Close MV6 and MV7 and back fill the LN2 reservoir and the LHe reservoir with helium gas.

13. Close MV8 to isolate the LHe reservoir. Remove the tee and neoprene tube to the LN2 reservoir. Place a rubber bung in the now empty port of the LN2 reservoir.

14. Open the plug valves MV6 and MV7 on the vari-temp space and the lambda fridge pumping line to interconnect these two volumes. Confirm both capillary valves NV1 & NV2 and the lambda fridge needle valve NV3 are closed properly and the pump on MV5 is evacuating the vari-temp space and lambda fridge pumping line to better than 50 microns.

15. Briefly open each of the capillary valves and the lambda needle valves, NV1, NV2 & NV3, to confirm proper operation by seeing a pressure rise and hearing the roughing pump gurgle. This check should be repeated periodically during the cool down.

16. Insert the initial fill tube and connect a LN2 supply dewar to the initial helium fill port. Remove the quench relief assembly and use temporary tubing to direct the exhaust away from and below the top plate of the cryostat. Slowly open the valve on the LN2 supply dewar and adjust it to produce a steady light breeze out the exhaust. Record the time and readings in the logbook.

17. Monitor the progress of the magnet cooling by measuring its resistance (the thermistors also measure the temperature drop but because of turbulence and splatter, they are less reliable). The magnet should be cooled no faster than a tenth of an Ohm every 5 minutes during the initial phase.

18. After roughly one to two hours the magnet should have dropped to 8.5Ω, indicating it is at LN2 temperature and liquid should have begun accumulating. One may now safely increase the rate of transfer. Accumulate liquid to at least 10 cm above the magnet (or about 80 cm below the second helium fill port). This can be checked by briefly inserting a small diameter plexiglass rod into the second fill port, pulling it out and noting the point on the rod where the subsequent condensation occurs. Record the time and readings in the logbook.

19. Wait an additional hour of cooling, before starting the next step, transferring the LN2 from the LHe reservoir to the LN2 reservoir.

20. Connect between the initial helium fill tube and one of the LN2 ports with neoprene tubing. Use temporary tubing to direct the exhaust from the other LN2 port away from and down below the top plate (the third port has the level meter). Replace the quench relief assembly RV2. Use rubber bungs to disable the small poppet valve on the quench relief, RV3, and the relief valve on the magnet leads, RV4. Close MV6 and MV7 and open MV8 and the shutoff valve on the helium supply cylinder to pressurize the LHe reservoir with 2 to 3 psig of helium. This will force LN2 out of the LHe reservoir and into the LN2 one. Record the time and readings in the logbook.

21. When all the liquid has been transferred, there will be a sudden drop in helium pressure and an increase in flow. Continue flowing gas for another 3 to 5 minutes to remove the last drops of liquid. Close the shutoff valve on the helium gas supply. Record the time and LN2 level readings in the logbook. Remove the connection between the LHe and LN2 reservoirs. Stopper the LN2 fill port (allowing it to continue to exhaust through the other port).

22. Remove the rubber bungs and re-enable the relief valves, RV3 & RV4. Stopper the initial helium fill tube. Close MV7, open MV5, MV6 and MV8 and evacuate the LHe reservoir to better than 50 microns. If the pumping pauses, it probably means there is still some LN2 in the LHe reservoir. This must be removed by repeated flush and pump cycles. Note, while doing theis step, also perform Procedure 3.3 to top off the LN2 reservoir.

23. Close MV6 and open the shutoff valve on the helium gas supply to back fill the LHe reservoir with helium gas.

24. Close MV8. Remove the tee to the helium gas supply. Open MV6, to pump out the manifold and then open MV7.

The cryostat has now been pre-cooled to LN2 temperature and is ready to be cooled to LHe temperature.

3.2 Cooling to LHe

This procedure details cooling the cryostat from 77 Kelvin to that of liquid helium, 4.2 Kelvin. This procedure requires that Procedure 3.1 has been completed immediately prior to beginning this procedure.

1. If necessary, perform Procedure 3.3 to top off the LN2 reservoir.

2. Remove the quench relief assembly, RV2, attach temporary tubing to the helium reservoir KF40 exhaust port and direct the exhaust away from and below the top plate of the cryostat. Confirm the magnet lead exhaust is open. Confirm that the three cold needle valves, NV1, NV2 & NV3, and the second fill port are closed.

3. Un-stopper the initial helium fill tube and insert the helium fill lance. Slowly insert the helium supply lance into the liquid helium supply dewar and begin transferring at a rate of 1 to 2 liters of gas per minute. This should generate a barely perceptible breeze out the exhaust tubing.

4. Monitor the progress of the cooling by measuring the resistance of the magnet. Periodically briefly open each of the cold needle valves to confirm their operation.

5. After roughly 2 hours the magnet should go superconducting and liquid should begin accumulating. Increase the rate of transfer and fill the reservor to 30 inches or above as measured on the level meter.(33 inches is the top of the reservoir.) Be sure to set the meter for continuous readings.

6. Remove the fill lance and the initial fill tube from the initial fill port and plug the port. Set the level meter for intermittent readings. Record the time and cryogen levels in the log book.

7. After an additional hour, the blowoff will have stablized. Replace the quench relief assembly. Most of the exhaust should be directed out the magnet leads.

8. Close the vari-temp pumping valve MV5 to stop pumping on the vari-temp space and lambda fridge. Open the helium reservoir interconnect valve MV8 to back fill with helium gas and equilibrate the pressure in the vari-temp space and lambda fridge.

9. Slowly open one of the capillary needle valves, NV1 or NV2, to admit liquid helium to the vari-temp space.

10. Once the target vacuum space cools, open the valve 3 or 4 turns to maintain liquid helium in the vari-temp space.

11. Note the time, needle valve used, cryogen levels, etc. in the log book.

The cryostat is now at LHe temperature and can remain so indefinitely as long as the cryogens are replenished.

3.3 Replenishing LN2

This procedure details refilling the liquid nitrogen reservoir. This procedure requires that the cryostat be in normal operating condition following Procedure 3.1 or Procedure 3.2.

1. Remove the bung from the LN2 reservoir inlet and insert the transfer hose.

2. Open the valve on the LN2 supply dewar and begin the transfer.

3. When the LN2 level meter indicates 100%, stop the transfer. Remove the transfer hose from the reservoir inlet and replace the rubber bung.

4. Note the date, time, starting and ending level readings in the log book.

3.4 Replenishing LHe

This procedure details refilling the liquid helium reservoir. This procedure requires that the cryostat be in normal operating condition following Procedure 3.2. It also requires that the magnet be at low current or in persistent current mode (see Procedures 3.13 and 3.9).

1. Confirm that the magnet leads are carrying only a small amount of current (<40 amps) so that their cooling can be interrupted. Then and only then can the slight overpressure created by the exhaust poppet on the magnet leads be relieved by opening the second fill port.

2. Detach the fill lance from the transfer assembly and slowly insert it into the second fill port. When the blowoff begins to increase, stop inserting the lance and allow the lance to be cooled by the blowoff until the characteristic white flame appears at its tip, signaling that it is at liquid helium temperature. Relieve the pressure by opening the quench relief, RV2, on the helium exhaust port. Leave the helium exhaust open with the exhaust directed away from the top plate of the cryostat.

3. Repeat the previous step with the rest of the transfer assembly (withdrawl lance and flexible section) and the LHe supply dewar by inserting the withdrawl lance in the LHe supply dewar.

4. Join the fill lance and the flexible section and begin transferring by repressuring the supply dewar.

5. Monitor the progress of the fill with the LHe level meter. Note that the meter should be switched to continuous read mode in order to have prompt response.

6. When the meter indicates full, relieve the pressure on the supply dewar, detach the fill lance from the flexible section, remove the fill lance from the storage cryostat and seal the fill port. Remove the supply lance from the supply dewar. Return the level meter to intermittent mode.

7. When the boiloff has settled down, close the helium exhaust.

8. Confirm that the exhaust poppet on the magnet leads, RV4, opens and carries the exhaust from the reservoir.

9. Note the date, time, starting and ending level readings in the log book.

The LHe has now been replenished and magnet lead cooling re-established. Procedures 3.8 or 3.9 can be used to return the magnet to its previous state.

3.5 Running Vari-Temp

This procedure details filling and pumping the vari-temp space in order to maintain the temperature of the target vacuum space near 1.5 K. This procedure requires that Procedure 3.2 has been completed and that the cryostat and target vacuum space are at 4.2 K.

1. Turn on the vari-temp pump and pump down the pumping line with the pumping valve MV5 closed.
2. Close both capillary needle valves NV1 & NV2 and the plug valve MV6 to the helium reservoir.
3. Slowly open the pumping valve MV5 and reduce the pressure over the liquid helium in the vari-temp space to the low pressure limit of the pump.
4. In order to maintain the liquid helium in the vari-temp space, open one of the capillary needle valves about a quarter turn. This will require some adjustment in order not either to run out of liquid or to overfill and cause excessive boiloff that will raise the pressure and hence the temperature.
5. Note date, time, valve used, cryogen levels, etc. in the log book.

3.6 Stopping Vari-Temp

This procedure details steps necessary to return the cryostat to 4.2 K operation after running the vari-temp space at 1.5 K. This procedure requires that the vari-temp operation is occuring (see Procedure 3.5).

1. Close the vari-temp pumping valve, MV5.
2. If the magnet leads are carrying a current greater than 40 amps, put the magnet in persistent mode by executing Procedure 3.9.
3. Open the plug valve MV6 to the helium reservoir to backfill the vari-temp space.
4. Open the capillary needle valve to 3 or 4 turns to maintain liquid in the vari-temp space.
5. If necessary, undo step 2 with Procedure 3.10
6. Note date, time, valve used, cryogen levels, etc. in the log book.

3.7 Warming up the Cryostat

This procedure warms the cryostat to room temperature from that of liquid helium, 4.2 Kelvin. It is required that the cryostat not contain a target (see Transfer Cryostat Operations Manual), that the magnet be de-energized (see Procedure 3.13) and that the vari-temp is not in operation (see Procedure 3.6).

Stop replenishing the liquid cryogens and wait several days, depending on the cryogen levels. This is a long life system and, when full, should hold for 3 days. If a faster warmup is necessary, empty the LN2 reservoir by inserting a tube through one of access ports to the bottom of the reservoir and then pressurizing the reservoir. It is not recommended that the cryostat vacuum be softened by adding a small amount of helium as the dewar has a large amount of super insulation and it is difficult to pump the helium back out.

Note date, time, cryogen levels, etc. in the log book.

3.8 Energizing the Magnet

This procedure describes ramping up the superconducting magnet located in the LHe reservoir of the storage cryostat. It requires that the cryostat be cooled to at least LHe temperature (see Procedure 3.2).

1. Turn on the LHe level meter and confirm that the magnet is immersed in LHe by obtaining a reading of at least 20 inches. If there is not enough, go to Procedure 3.4.

2. Activate the sonic alarm function on the LHe level meter. If the LHe level drops below the bottom setpoint, the alarm will sound. The LHe reservoir should be immediately refilled (see Procedure 3.4) or the magnet de-energized (see Procedure 3.13).

3. If this is the first energizing of the magnet since cool down, measure the magnet resistance, which should be 0.34Ω, due to the resistance of the leads from room temperature into the helium reservoir.

4. Attach the cables between the magnet supply and the cryostat. Exercise caution not to short the terminals if the magnet is energized in persistent current mode. In that case the safety diodes will be attached.

5. If present, disconnect the safety diodes from between the magnet leads only after the leads to the supply have been attached.

6. Attach the switch heater leads (located in the cable containing the helium level probe leads) to the back of the supply.

7. Make sure the supply Voltage limit is set to 2 volts and the Trip/Limit toggle in limit mode. Confirm the sweep unit is engaged. Turn the supply on by pushing the AC button and then the start button.

8. If the magnet is in persistent current mode, use Procedure 3.10 to energize the leads.
9. If not done in step 8, turn on the switch heater. WAIT one full minute for the persistent mode switch to warm and open.
10. Set the ramp rate to 2 amps per minute. Set the desired current, by adjusting the multi-turn pots while holding the set toggle. Push the sweep-to-set-point button.
11. When the supply reaches the desired current and stops ramping, push the hold button.

These last two steps may be repeated as often as desired to energize the magnet at any desired field between 0 and 8 Tesla.

3.9 Entering Persistent Mode

This procedure describes putting the superconducting magnet in persistent mode and ramping down the power supply. It assumes that the magnet has been energized with Procedure 3.8 (Procedure 3.11 may have been performed as well).

1. Record the value of the current in the logbook.
2. Turn off the switch heater. WAIT one full minute for the switch to cool and close.
3. Set the ramp rate to 20 amps per minute. Push the sweep-to-zero button to run down the leads.
4. If the magnet is to be separated from the power supply, attach the safety diodes. Then and only then, turn off the magnet supply and, exercising extreme caution to avoid shorting the terminals, disconnect the cables. Detach the switch heater leads.

3.10 Leaving Persistent Mode

This procedure describes ramping up the power supply and taking the superconducting magnet out of persistent mode. It assumes that the magnet has been energized with Procedure 3.8 (Procedure 3.11 may have been performed as well) and then Procedure 3.9 used.

1. Confirm that the value of the current setting on the supply is the same as in the logbook. If not, adjust the setting to match the logbook.
2. Set the ramp rate to 20 amps per minute. Push the sweep-to-set-point button.
3. When the supply reaches the set current, push the hold button.
4. Turn the switch heater on. WAIT one full minute for the switch to warm and open.

3.11 Running the Lambda Fridge and Reaching Fields over 8 Tesla

This procedure details starting the lambda fridge pumping, cooling the superconducting magnet to 2.2 K, and ramping up the magnet from its 4.2 K maximum. It assumes that Procedure 3.8 has been performed to bring the magnet to 8 Tesla.

1. Confirm that the lambda fridge pumping line is crossconnected to the helium reservoir through valves MV7 and MV8.

2. Confirm that sufficient liquid helium is present in the reservoir to cool the magnet down and still cover it (at this time this value is not know). If there is not enough, go to Procedure 3.4.

3. Attach ohm meters to the carbon thermistors on the top and bottom of the magnet. The leads are in the cable containing the helium level probe leads.

4. Connect a pump to the lambda fridge line. Evacuate the line to the low pressure limit of the pump.

5. Close the plug valve crossconnect MV7 and open the lambda fridge pumping valve MV9.

6. Open the lambda fridge needle valve, NV3, 1 to 2 turns. Both thermistors should start cooling from their 4.2 Kelvin value of 1970Ω.

After the thermistors have reached their 2.2 K value of 10850Ω, the magnet may be raised to any field between 8 Tesla and its 2.2 K maximum of 10 Tesla.

1. If necessary, take the magnet out of persistent mode (Procedure 3.10).

2. Push the hold button. Set the ramp rate to 1 amp per minute. Set the desired current, by adjusting the multi-turn pots while holding the set toggle. Push the sweep-to-set-point button.

3. When the supply reaches the desired current and stops ramping, push the hold button.

3.12 Stopping the Lambda Fridge

This procedure details ramping down the magnet to its 4.2 K maximum and stopping the lambda fridge pumping. It assumes that Procedure 3.11 has been performed. If the magnet is in persistent current mode, perform Procedure 3.10.

1. Push the hold button. Set the desired current value to the 4.2 K maximum of 84.10 Amps. Set the ramp rate to 1 amp per minute. Push the sweep-to-set-point button.

2. When the supply reaches the target current and stops ramping, push the hold button.

3. Execute Procedure 3.9 to close the switch and remove current from the magnet leads.

4. Stop the lambda fridge pump and open the plug valves MV7 and MV8 to vent the line from the helium reservoir. This is likely to interrupt the magnet lead cooling, hence the instructions to put the magnet in persistent current mode.

5. Close the pumping valve MV9. If desired, the pump may now be removed.

Once venting through the magnet leads resumes, the magnet may be taken out of persistent current mode by Procedure 3.10.

3.13 De-Energizing the Magnet

This procedure describes ramping down the superconducting magnet located in the LHe reservoir of the storage cryostat. It assumes that the magnet has been energized with Procedure 3.8 and that Procedure 3.12 and Procedure 3.10 have been performed if necessary.

1. Push the hold button. Set the ramp rate to 2 amps per minute. Push the sweep-to-zero button.

2. When the supply reaches zero current and stops ramping, push the hold button.

3. Turn off the switch heater.

The supply may now be turned off.

3.14 Adding Exchange Gas

This procedure describes the steps required to add helium exchange gas to the target space of the storage cryostat. It assumes the storage cryostat is cold (see Procedure 3.2).

1. Attach a cross to the target space pumpout valve, MV3.

2. Attach a helium gas cylinder with regulator and shutoff valve to one arm of the cross.

3. Attach a pressure gauge to another arm of cross. The gauge should be of a type which is independent of gas type and capable of reading in the few Torr regime.

4. Attach a pump with shutoff valve to the remaining arm of the cross. Open the valve to the pump and evacuate the cross to better than 50 microns. Close the valve to the pump. Open MV3.

5. Crack open the valve to the helium gas cylinder and slowly raise the pressure to 2 or 3 torr. Close MV3.

6. Remove the cross, the helium gas cylinder, the pressure gauge and the pump.

3.15 Removing Exchange Gas

This procedure describes the steps required to remove helium exchange gas from the target space of the storage cryostat. It assumes the storage cryostat is cold (see Procedure 3.2).

1. Attach a pumping station to the target space pumpout, MV3.

2. Evacuate the target vacuum space to better than 3×10^{-6}torr through MV3.

3. Close MV3, and remove the station.

3.16 Target Transfer

This procedure describes the steps required to transfer a target into or out of the storage cryostat. It assumes the storage cryostat is cold and the magnet is on (see Procedures 3.2 and 3.8). This procedure requires that the transfer cryostat be cold and positioned on its cart ready to be lifted. (see the Transfer Cryostat manual).

1. If exchange gas is present, perform Procedure 3.15 to remove it.

2. If necessary, take the the magnet out of persistent mode (Procedure 3.10) and lower the field to 2 Tesla (see Procedure 3.8and, if necessary, Procedure 3.12).

3. Perform Transfer Cryostat Procedure 3.9 to attach the two cryostats.

4. Follow the Procedure for withdrawing a target, Transfer Cryostat Procedure 3.15, or inserting a target, Transfer Cryostat Procedure 3.16.

5. Perform Transfer Cryostat Procedure 3.10 to detach the two cryostats.

6. Perform Procedure 3.18 to return the storage dewar to storage mode.

3.17 Preparing for Transport

This procedure describes preparing the storage cryostat for transport in its transport cradle. It assumes the storage cryostat is cold and the magnet is on (see Procedures 3.2 and 3.8).

1. If exchange gas is not present, perform Procedure 3.14 to add it.

2. If necessary, take the the magnet out of persistent mode (Procedure 3.10) and lower the field to 2 Tesla (see Procedure 3.8 and, if necessary, Procedure 3.12).

3. Put the magnet in persistent mode (Procedure 3.9).

4. Attach the safety diodes beween the magnet leads. Then and only then, turn off the magnet supply and, exercising extreme caution to avoid shorting the terminals, disconnect the cables. Detach the switch heater leads.

5. If in use, stop the vari-temp (Procedure 3.6) and disconnect the pump.

The cryostat is now ready to be placed in its transport cradle.

3.18 Preparing for Storage

This procedure describes the steps for placing the storage cryostat in a status for long term storage of HD targets following either a transfer of one or more targets or a transport of the cryostat. It assumes the storage cryostat is cold and the magnet is on (see Procedures 3.2 and 3.8).

1. If exchange gas is not present, perform Procedure 3.14 to add it.

2. Return the storage cryostat to storage mode by raising the field to 8 Tesla or above and putting the magnet into persistent mode with Procedures 3.8 and 3.9. For operations above 8 Tesla, see Procedure 3.11.

3. If not in use, start the vari-temp (Procedure 3.5).