Production Cryostat Operations

August 4, 2016

Contents

1 Overview

The production 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 production cryostat freezes the HD gas to produce an ice target and vaporizes the ice target after the target polarization has decayed too much to be useful. In order to understand how the production 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 gradient in a dilution refrigerator with its inner vacuum filled with exchange gas.

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

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 Production Cryostat

Thus we see that in order for the production cryostat to perform its job it must hold the target at temperatures from 4.2 K up to room temperture. Further, it must allow the target to be inserted and withdrawn. It was also forseen that there might be a future need to do higher precision NMR on the targets in order to check for voids. For that reason the cryostat has a superconducting magnet with a 2 Tesla maximum field and two parts in 10^3 homogeneity. A need to visually inspect the targets for crystal quality is met by an optical access port at the bottom of the dewar. 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 production cryostat will be examined in detail (see Figures 1, 2 and 3).

2.1 Target Vacuum Space

The production 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 at the top of the cryostat, MV2, 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-NW16 (KF16) connector to a tee carrying the pump out valve, MV3, and the line to the gas recovery valve, MV8, and check valve, RV6, on the gas recovery manifold, section 2.7.1. 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. In the center of the flange is a 1.27 cm diameter saphire window to allow visual access to the target. Besides the M35x1.0 right-handed threads for holding the target, 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 a capillary leading to the LHe reservoir through a needle valve 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, MV4, allows attachment of a pump for operations at reduced pressure and thus reducing 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. A set of small valves, MV5 and MV6, connects the vari-temp space to the top of the LHe reservoir for venting purposes.

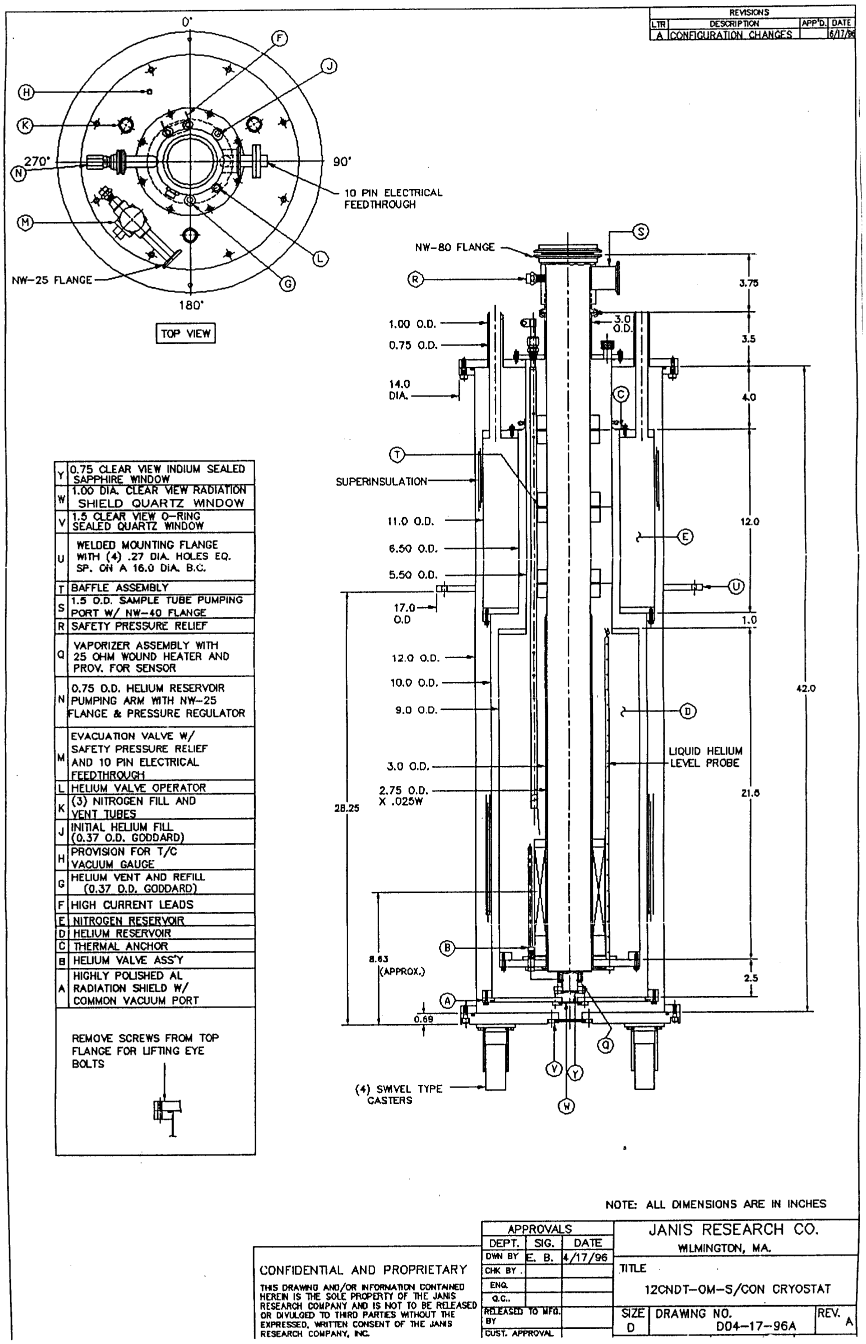

Figure 1: Production Cryostat Drawing

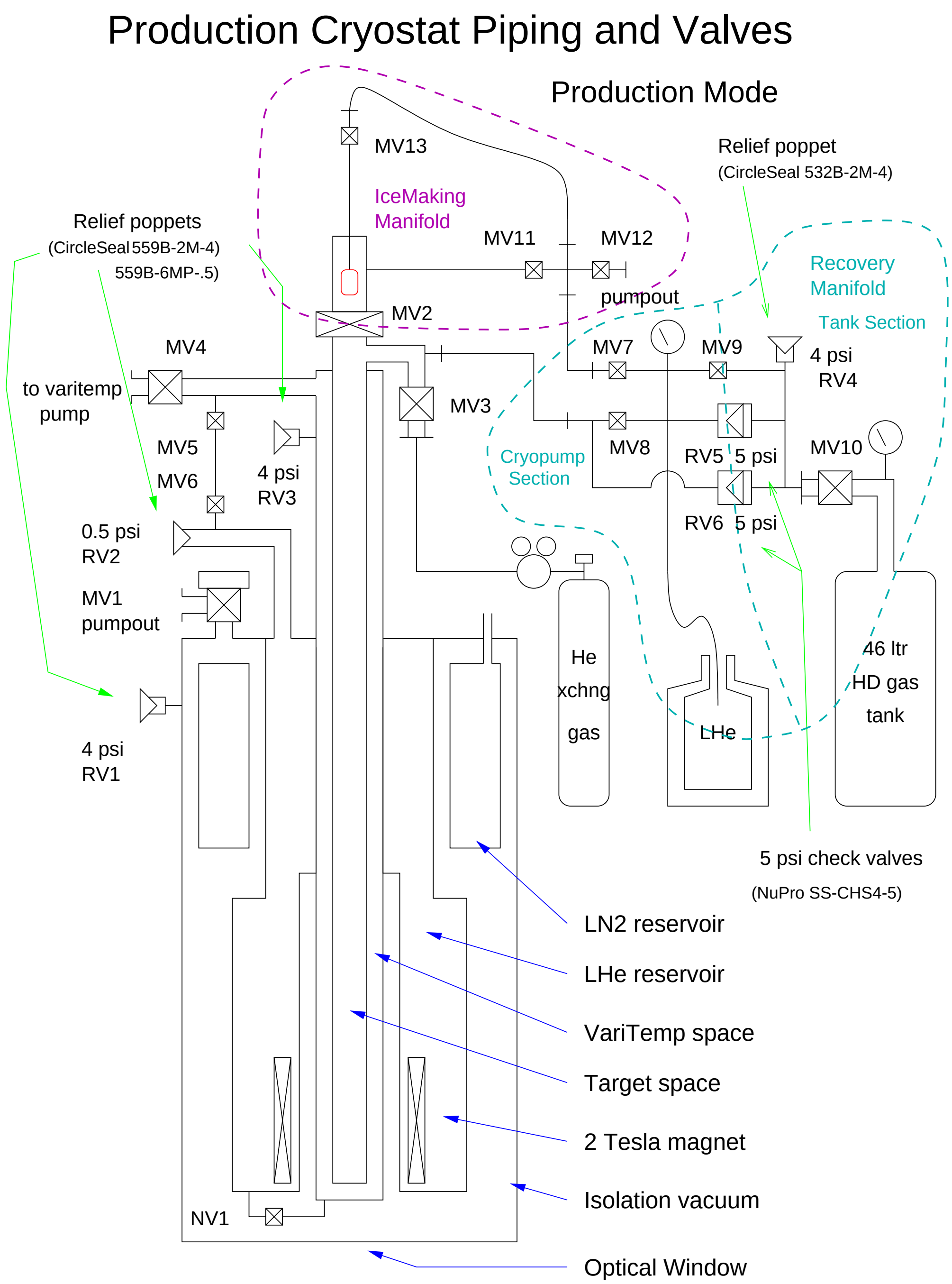

Figure 2: Production Cryostat Piping and Valves Schematic in Ice Production Mode

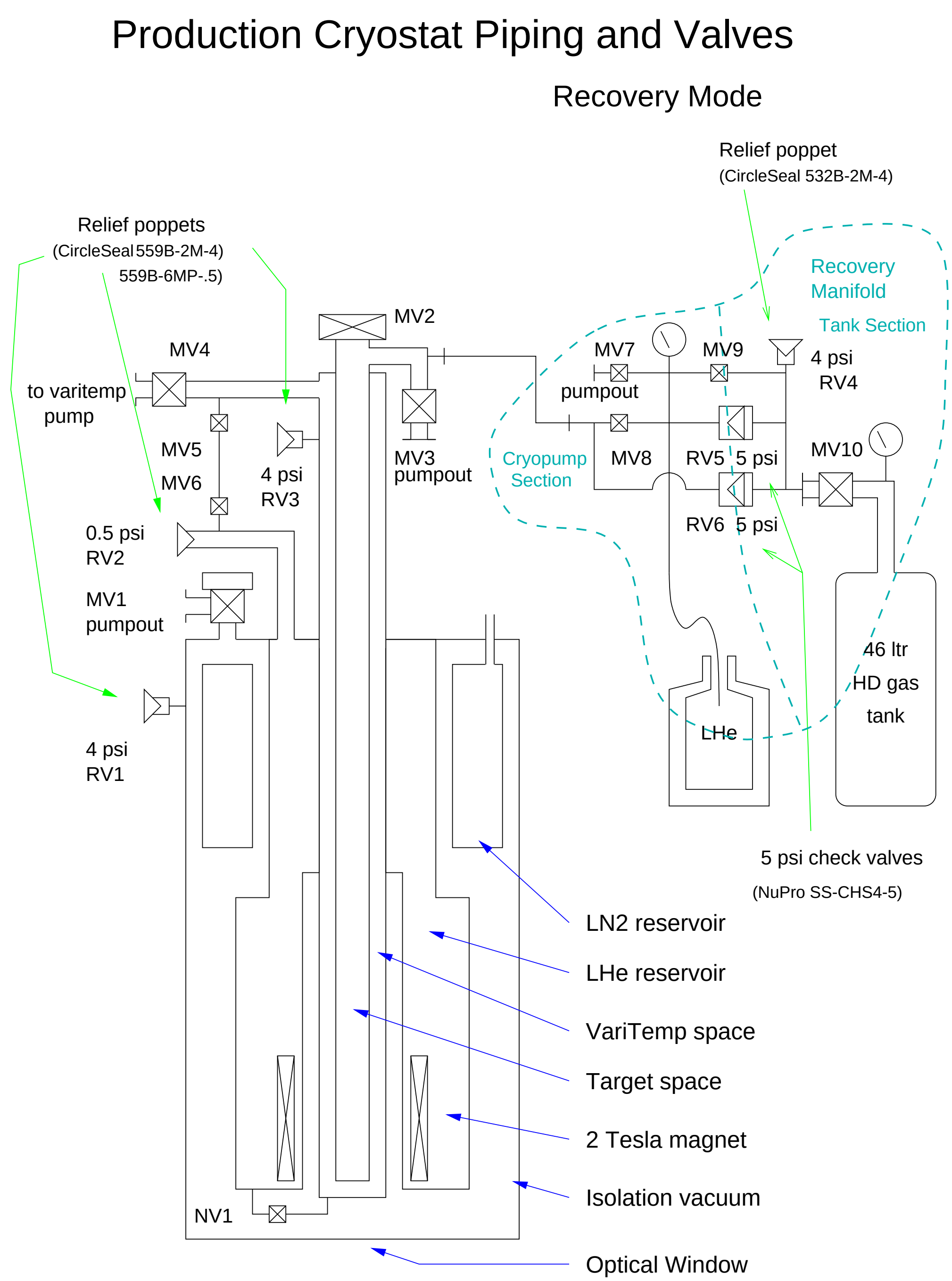

Figure 3: Production Cryostat Piping and Valves Schematic in Gas Recovery Mode

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 located on the top of the cryostat, MV1. The valve body contains a safety pressure relief, RV1, and a ten pin electrical feedthrough for powering the capillary heater and measuring the resistance of a Cernox(TM) 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 relief valve, RV2. It is filled through either of two 3/8 inch fill port. LHe from this reservoir is used in the vari-temp space. A needle valve is located on the bottom of the reservoir and leads to a heater equipped capillary tube and thence to the vari-temp space. Heater leads are in the 10 pin connector on the cryostat vacuum pumpout valve. Leads for the helium level meter are in the 10 pin connector opposite the helium vent port.

2.5 Superconducting Magnet

A superconducting magnet is mounted within the LHe reservoir. The magnet has a maximum central field of 2.0 Tesla at 4.2 K. With an inductance of 2.2 Henries and a full field current of 39.71 Amperes, the maximum stored energy is 1.7 kiloJoules or 0.67 liters of LHe. 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 a current of 55 mA 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 10 pin connector opposite the helium vent port.

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 Gas Recovery Manifold

There is no dedicated expansion volume for this dewar. Instead, one of the 46 liter HD storage vessels or two of the 23 liter HD tanks is attached to the gas recovery manifold prior to the introduction of HD to this cryostat. In ice production mode the same tank is also the source of the HD. In the event that cooling is lost and the HD vaporizes, this volume is sufficient to maintain the pressure below atmospheric.

The difference between the 46 liter volume and the 30 liters of HD gas constituting a target arises from the need during the ice making process to maintain the HD pressure well above the triple point and so the tanks are not completely emptied. The tanks have shutoff valves, labelled MV10 on the diagram, and pressure gauges. A 4 psi relief poppet valve, RV4, protects this section of the manifold, referred to as the tank section, and via the two check valves, RV5 and RV6, the cryopump section and the target space.

In order to scavenge as much HD as possible from the system a cryopumping section is included. The cryopump is a 3 meter long, 3 mm diameter, thin wall stainless steel tube that can be inserted into a liquid helium storage dewar. It couples to a section of the gas manifold having a pressure gauge, a 5 psi relief valve to the HD tank section, RV5, a valve to the target space, MV8, a valve to the tank section, MV9, and a pumpout valve, MV7. This portion of the manifold is referred to as the cryopump section.

2.7.2 Ice Making Manifold

The ice making manifold is a vacuum lock, three valves and interconnecting plumbing. It couples to the target space via the gate valve on top of the target space, MV2, and to the gas recovery manifold via valve MV7. Access to the vacuum lock volume above the gate valve is through MV11. It provides a new pumpout valve, MV12, and access to the target cell sealed on the end of the capillary is via valve MV13.

3 Procedures

Before attempting any of the procedures detailed in the following sections, all personnel must 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 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 11 can be done concurrently provide proper attention is paid to the vacuum prerequisites noted in each step. See Figure 4 for a diagram of the piping additions for this procedure made in steps 9 and 10.

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 on the insulating vacuum valve, MV1.

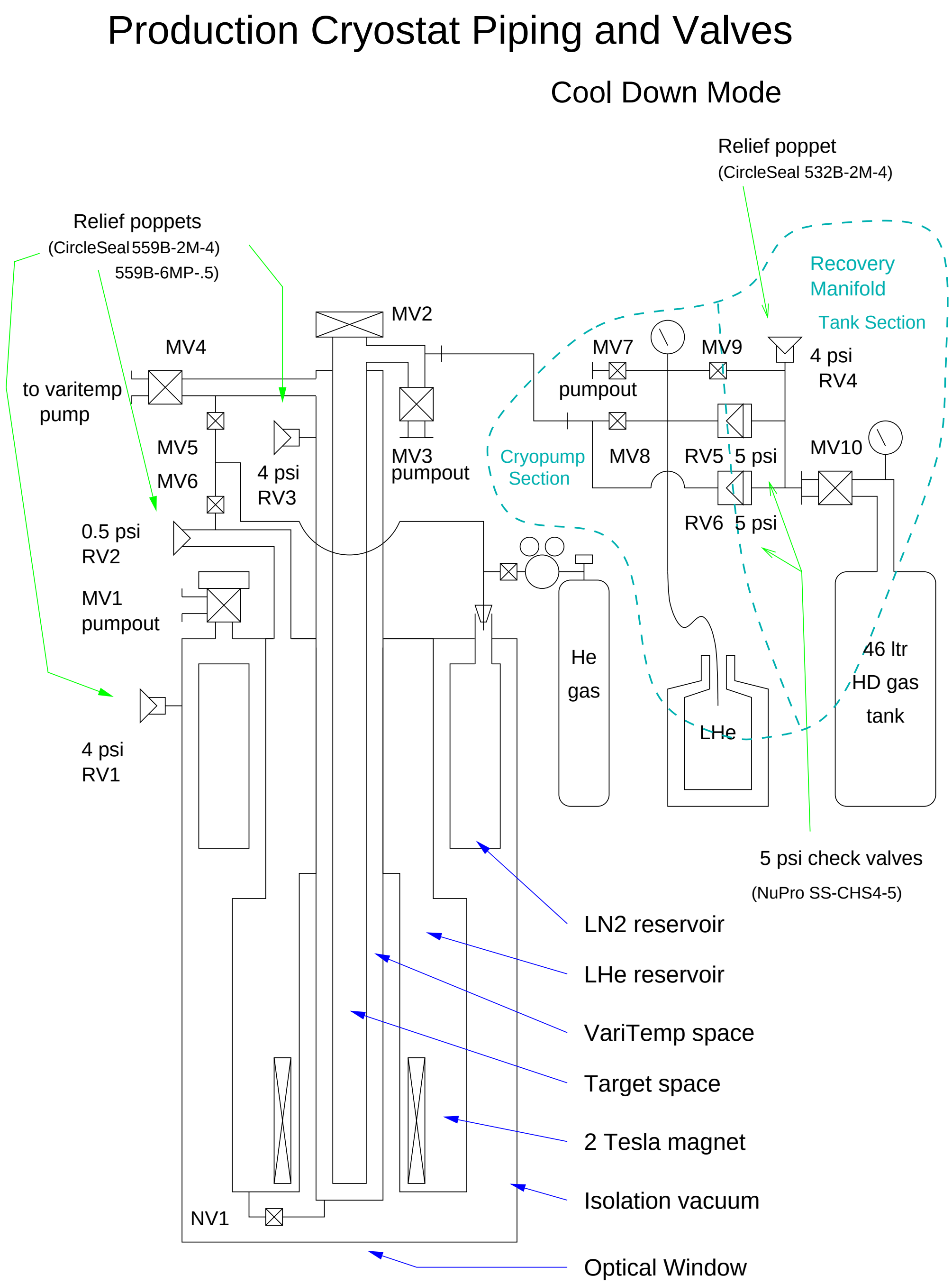

Figure 4: Production Cryostat Piping and Valves Schematic in Cool Down Mode, ready to perform Procedure 3.1, step 11.

3. Check the resistance of the magnet leads, which should be 9.6Ω.
4. Record the time and resistance values in the cryostat logbook.
5. Verify that the capillary needle valve, NV1, is not stuck and will turn freely. Leave it in the closed position.
6. Attach a pumping station to the target space pumpout, MV3. Close MV8, open MV3 and evacuate the target vacuum space to better than 8×10^{-6}torr. Close MV3 and remove the station.
7. 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.
8. Confirm that the target space has at least been roughed out, since the 5 psi check valve, RV6, will open otherwise. Attach a 46 liter or two 23 liter tanks to the manifold. Attach a pump to the gas recovery manifold pumpout, MV7. Close MV8, open MV7 and MV9, and evacuate both sections of the the manifold to better than 50 microns. Close valves MV7 and MV9. Open the tank valve(s) MV10, and remove the pump.
9. Insert a tee in the neoprene tubing vent manifold between valves MV5 and MV6. 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.
10. Insert a second tee in the neoprene tubing vent manifold between valves MV5 and MV6. Attach a helium gas supply cylinder with regulator and shutoff valve to this tee. Close the shutoff valve on the helium regulator.
11. *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 MV4 on the vari-temp space. Confirm that the cryostat vacuum has at least been roughed out. Open valves, MV4, MV5 and MV6, and evacuate the LN2 reservoir, the LHe reservoir, and the vari-temp space to better than 50 microns. Close MV5 and open the shutoff valve on the helium gas supply to back fill the liquid helium and liquid nitrogen reservoirs with helium gas. Close the shutoff valve on the helium regulator.
12. Close MV6 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.
13. Confirm the capillary valve NV1 is closed properly and the pump on MV4 is evacuating the vari-temp space to better than 50 microns through the open MV4.

14. Briefly open the capillary valve NV1 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.

15. Connect a LN2 supply dewar to the inital helium fill port. Remove the quench relief assembly, RV2, 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.

16. Monitor the progress of the magnet cooling by measuring its resistance. The magnet should be cooled no faster than a tenth of an Ohm every 5 minutes during the initial phase.

17. After roughly one hour 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 70 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.

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

19. 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 a rubber bung to disable the poppet valve on the quench relief. Open MV6 and the helium gas shutoff valve, and 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.

20. 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 regulator. 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).

21. Remove the rubber bung and re-enable the relief valve, RV2. Stopper the initial helium fill port. Open MV4, MV5 and MV6. Evacuate the LHe reservoir to better than 50 microns through MV4 and the venting manifold. 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 this step, also perform Procedure 3.3 to top off the LN2 reservoir.

22. Close MV5 and open the shutoff valve on the helium gas supply to back fill the liquid helium reservoir with helium gas. Close the shutoff valve on the helium regulator.

23. Close MV6. Remove the tee to the helium gas cylinder. Open MV5, to pump out the venting manifold through then open MV4.

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 that the cold needle valve, NV1, and the second fill port are closed.

3. Un-stopper the initial helium fill port 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 the cold needle valve, NV1, to confirm its operation.

5. After roughly one hour the magnet should go superconducting and liquid should begin accumulating. Increase the rate of transfer and fill the reservor to 18 inches or above as measured on the level meter. (20 inches is the top of the reservoir.) Be sure to set the meter for continuous readings.

6. After at least 10 inches have accumulated, begin to cool the vari-temp space as well. Close the vari-temp pumping valve MV4 to stop pumping on the vari-temp space. Open the helium reservoir interconnect valves MV5 and MV6 to back fill with helium gas and equilibrate the pressure in the vari-temp space and helium reservoir.

7. Open the capillary needle valve, NV1, to admit liquid helium to the vari-temp space.

8. Once the target vacuum space cools, open needle valve NV1 3 or 4 turns to maintain liquid helium in the vari-temp space.

9. Remove the fill lance 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.

10. Replace the quench relief assembly.

11. Note the time, 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 3.11 and 3.9).

1. 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.

2. Repeat step 1 with the rest of the transfer assembly (withdrawal lance and flexible section) and the LHe supply dewar by inserting the withdrawal lance into the LHe supply dewar.

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

4. 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.

5. When the meter indicates full, 20 inches, relieve the pressure on the supply dewar, detach the fill lance from the flexible section, remove the fill lance from the production cryostat and seal the fill port. Remove the supply lance from the supply dewar. Return the level meter to intermittent mode.

6. When the boiloff has settled down, close the helium exhaust by re-attaching the quench relief assembly, RV2.

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

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 MV4 closed.

2. Close the capillary needle valve NV1 and the plug valve MV5 to the helium reservoir.

3. Slowly open the pumping valve MV4 and reduce the pressure over the liquid helium in the vari-temp space to 7 or 8 torr.

4. In order to maintain the liquid helium in the vari-temp space, open the capillary needle valve NV1 about a quarter turn. This will require some adjustment in order neither to run out of liquid nor to overfill and cause excessive boiloff that will raise the pressure and hence the temperature.

5. Note date, time, 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, MV4.

2. Open the capillary needle valve NV1 to 3 or 4 turns to add liquid to the vari-temp space. With MV6 closed, open MV5 to monitor pressure in the vari-temp space.

3. When the pressure in the vari-temp space reaches atmospheric, open the plug valve MV6 to the helium reservoir.

4. Note date, time, 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 3.11) and that the vari-temp is not in operation (see Procedure 3.6).

Stop replenishing the liquid cryogens and wait one or two days, depending on the cryogen levels. This is not a long life system. 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 production 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 10 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 3.11).

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.

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

6. 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.

7. Turn on the switch heater. WAIT one full minute for the persistent mode switch to warm and open.

8. Set the ramp rate to 20 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.

9. 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 2 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.

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 100 amps per minute. Push the sweep-to-zero button to run down the 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 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 100 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 De-Energizing the Magnet

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

1. Push the hold button. Set the ramp rate to 20 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.

3.12 Adding Exchange Gas

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

1. Attach a pump to the gas recovery manifold pumpout valve MV7. Confirm MV8 and MV9 are closed. Evacuate the cryopump section of the manifold through MV7 and then close it.

2. Attach a helium gas cylinder and regulator to the target space pumpout valve, MV3. Purge the line by attaching and detaching it several times with the gas flowing.

3. Open MV8 to monitor the target space pressure with the gauge on the cryopump section.

4. Crack open MV3 and slowly raise the pressure to 2 or 3 torr. Close MV3.

5. Close MV8 and remove the helium gas cylinder and pump.

3.13 Removing Exchange Gas

This procedure describes the steps required to remove helium exchange gas from the target space of the production cryostat. This is needed following ice making. It assumes the production 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.

3.14 Transfering a Target

This procedure describes the steps required to prepare the production cryostat for inserting or removing a target. It assumes the production cryostat is cold (see Procedure 3.2). It assumes the transfer cryostat is cold and on its cart ready to be lifted (see the Transfer Cryostat Manual).

1. If target polarization is to be retained in the transfer, the magnet must be set to a 2 Tesla field. If the magnet is in persistant mode at a field other than 2 Tesla, take the magnet out of persistent mode (Procedure 3.10). Use Procedure 3.8 to set the magnetic field to 2 Tesla. If desired, Procedure 3.9 may be used to place the magnet in persistant mode.

2. If exchange gas is present, perform Procedure 3.13 to remove it.

3. Attach the transfer cryostat to the production cryostat by following the procedure in the transfer cryostat manual for attaching to the storage cryostat, Transfer Cryostat Procedure 3.9.

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

5. Detach the transfer cryostat from the production dewar by following the procedure for detaching the transfer cryostat from the storage dewar, Transfer Cryostat Procedure 3.10.

The cryostat is now ready to be warmed up or to proceed to make another target if a target was removed or to recover the gas if a target was inserted.

3.15 Making HD Ice

This procedure describes the steps required to transform 30 atmosphere liters of HD gas into 30 cc's of HD ice inside a target cell. It assumes the production cryostat is cold (see Procedure 3.2), that it does not contain a target, that the gas manifold is attached to the cryostat and that a full 46 liter HD tank or two full 23 liter tanks are connected to the gas recovery manifold.

1. If the vari-temp is operating, perform Procedure 3.6 to stop the vari-temp and equalize the LHe levels in the reservoir and in the vari-temp space.

2. Perform Procedure 3.12 to add exchange gas to the target space.

3. Confirm that valve MV10 is open and that there is at least a pressure present in the tanks of 0.9 bar absolute as read on the gauge in the cryopump section of the recovery manifold or 3 inches of Hg as read on the compound Bourbon tube gauge(s) on the tank(s). Confirm that MV8 and MV9 are closed. Vent the cryopump section of the gas recovery manifold by opening MV7.

4. Attach the ice making manifold with a target cell on the end of the capillary to the target space gate valve, MV2, and the pumpout of the gas recovery manifold, MV7. Close the ice manifold pumpout valve MV12. Attach a turbopump station to MV12. Attach a roughing pump to the sliding double O-ring seal at the top of the vacuum lock.

5. Check that valves MV8, MV9 and MV13 are closed and valves MV7 and MV11 are open. Slowly open MV12 and pump out the vacuum lock to 0.66 bar absolute only, as read on the gauge in the cryopump section. Close MV12.

6. Open MV13 to equilize the pressures in the target cell and vacuum lock. Close MV13.

7. Slowly open MV12 and pump out the vacuum lock to 0.33 bar absolute only. Close MV12.

8. Open MV13 to equilize the pressures in the target cell and vacuum lock. Close MV13.

9. Slowly open MV12 and pump out the vacuum lock to better than 0.001 bar absolute.

10. Close MV11 and open MV13. Note the pressure in the target cell. Monitor this pressure for 30 minutes to test the integrity of the target cell. If the pressure changes less than 1 milli-bar the target is considered sealed to the capillary.

11. Open MV11 to equilize the pressures in the target cell and vacuum lock. Pump out the two together to better than 1×10^{-5}bar absolute. Close MV12.

12. Close MV11. Bleed HD gas through MV9 to pressurize the target cell to 0.5 bar.

13. Open the gate valve, MV2.

14. Watching the rate of HD pressure drop, slowly insert the target into the target space. Add HD gas with MV9 as needed to stay near 0.5 bar. When the rate increases, stop. This should occur around 10 cm above the He liquid level in the bath.

15. Close MV9. Pull the target backout 1 cm and note the pressure rise, if any. If there is no significant rise, of order 0.05 bar, pull out an addition 1 cm. Continue pulling out a cm at a time until the pressure rises is of order 0.05 bar.

16. Slowly lower back in 1 cm and see the pressure fall back down to 0.4 bar.

17. Bleed in HD gas through MV9 to maintain a pressure of 0.5 bar until fully open. Continue until the pressure is 0.26 bar where the target is full, assuming 1 bar in the tanks to begin. Close MV9. If the condensation pauses before enough gas has been condensed to fill the target, 0.26 bar, push in another 5

mm. If the pressure is still constant, you have a block in the capillary. Go to Procedure 3.16, Dealing with a block.

18. Watch the pressure as the condensation stops and the heat input to the target falls. If the pressure falls below 0.13 bar, the target is below the triple point. In that case, slowly pull the target back out 3 mm at a time until the pressure reaches 0.15 bar.

19. Now make ice by slowly pushing back in, taking 5 minutes to reduce the pressure from 0.15 bar to 0.125 bar.

20. Close MV13. Taking care not to leak through the sliding double O-ring seal at the top, push the target cell down until it touches the pedestal.

21. Close MV7 and remove the small diameter line connection to MV13.

22. Turn the capillary counterclockwise until the 1 mm drop occurs, signaling the alignment of the M35x1 threads.

23. Turn clockwise a half turn and confirm the threads are engaged by trying to lift. Measure the height of MV13 above the double seal.

24. Turn clockwise until a sharp increase in torque is required. Measure the height of MV13 above the double seal again and confirm the target has threaded in at least 8 mm, or 8 turns.

25. Place a wrench on the capillary and turn it clockwise to break the seal between the capillary and the target. Continue turning and, as a result, rising until the 1 mm drop is felt, signaling the end of the M26x1 lefthand threads.

26. Pull the capillary up, directing a heat gun on the tube and the double sliding o-ring as necessary to prevent freezing of the o-rings. When the capillary is all the way up, close the gate valve, MV2.

27. Detach the pump from MV12. Detach the roughing pump from the sliding double O-ring seal at the top of the vacuum lock. Detach the ice making manifold, now without a target cell on the end of the capillary, from the target space gate valve, MV2, and the pumpout of the gas recovery manifold, MV7.

3.16 Dealing with a Block

This procedure describes the steps required to deal with a blockage in the capillary during step 17 of Procedure 3.15. It assumes the problem has just arisen and the cryostat is configured for that step.

1. Slowly, 2 to 3 mm at a time, pull the capillary up, watching the pressure and listening to the blowoff rate from the LHe reservoir from RV2. One of two things will happen. Either the pressure will suddenly rise indicating the block

has melted and been cleared or the blowoff will suddenly increase indicating that, under the increased internal pressure, the target cell has burst or the silicone seal between the target and the capillary has failed. If the block clears, return to step 17 of Procedure 3.15. Otherwise go on to step 2 of this procedure.

2. We now wish to recover the HD gas but must first deal with the helium exchange gas. Close MV9 to isolate the HD gas in the tank(s).

3. Confirm MV7 and MV13 are open and MV12 is closed. Open MV8 and MV11 to cryopump into the target space the HD gas in the capillary, ice manifold. and cryopump section of the recovery manifold.

4. Pull the capillary up, directing a heat gun on the tube and the double sliding o-ring as necessary to prevent freezing of the o-rings.

5. Close MV5 and open NV1 fully to lower the liquid helium level in the vari-temp space. Monitor the pressure in the target space. When it rises to 10 torr, open MV5 again to raise the liquid helium level back up. Wait 20 minutes for the levels in the reservoir and the vari-temp to equilize. All the HD gas is now concentrated at the bottom of the target space and at 4.2 Kelvin where it has a very low vapor pressure.

6. Close MV2 and MV7.

7. Detach the pump from MV12. Detach the roughing pump from the sliding double O-ring seal at the top of the vacuum lock. Open MV12 to vent the ice making manifold and detach it from the target space gate valve, MV2, and the pumpout of the gas recovery manifold, MV7.

8. Perform Procedure 3.13 to remove the helium exchange gas from the target space and the cryopump section of the recovery manifold.

9. Recover the HD gas to the HD gas tank(s) by performing Procedure 3.17.

3.17 Recovering HD Gas

This procedure describes the steps required to recover the 30 atmosphere liters of HD gas that make up the 30 cc's of HD ice in the target. It assumes the production cryostat is cold (see Procedure 3.2), that it contain a target, that the gas manifold is attached to the cryostat and that a 46 liter HD tank or two 23 liter tanks are connected to the gas recovery manifold with sufficient free volume to hold the HD in the cryostat and remain below one atmosphere. Recall that a target has 30 atmosphere liters of HD gas so the pressure in the tank(s) must be less than 0.348 bar or 264 torr or 19.5 inches to hold a full target.

1. Confirm the valve(s), MV10, to the tank(s) is open.

2. Check the pressure in the cryopump section of the gas recovery manifold. If needed, attach a pump to the pumpout valve MV7. Confirm MV8 and MV9 are closed. Evacuate the cryopump section of the manifold through MV7 and then close it. Remove the pump.

3. If the vari-temp is operating, perform Procedure 3.6 to stop the vari-temp and equalize the LHe levels in the reservoir and in the vari-temp space.

4. If helium exchange gas is present, perform Procedure 3.13 to remove the helium exchange gas from the target space.

5. Open MV8 to connect the target space and recovery manifold cryopump section.

6. Close MV5 and open NV1 fully to drive the liquid helium out of the vari-temp space. Monitor the pressure in the target space.

7. When the pressure in the target space starts to rise, all the liquid helium is out of the vari-temp space. Close needle valve, NV1 and open MV5 to equalize the pressures in the reservoir and the vari-temp space.

8. Continue to monitor the pressure. When it rises to a pressure comparable to the HD tank(s), open MV9 to connect the target space to the HD tank(s).

9. Continue to monitor the pressure. In three to five hours, it should stop changing, signaling the vari-temp space is at 30 to 40 Kelvin. Now we must cryopump out the rest of the HD. Close MV9.

10. Confirm MV8 is open and MV9 is closed. Slowly insert the long thin cryopump tube into a liquid helium supply dewar. Monitor the pressure to determine the pumping progress.

11. When the pressure has reached 1×10^{-3} bar absolute or the tube touches the bottom of the dewar, close MV8, open MV9 and pull the cryopump tube out of the liquid helium supply dewar. If necessary close MV9, open MV8 and go back to the previous step.

12. All the HD possible has been collected, close MV10.