A QUICK GUIDE TO CRYOGENS

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1. Introduction

Two cryogenic liquids are used with astronomical instruments at KPNO, liquid nitrogen (LN_2), and liquid helium (LHe). These cryogens are used to cool detectors and instrumentation to reduce dark current and thermal background for optimal sensitivity. The cryogen(s) used depend on the operational wavelength of the detector: visual detectors such as CCDs and the HgCdTe array in IRIM (sensitive from 1 - 2.5 microns) require only LN_2, whereas InSb detectors require a temperature of ~ 35 K for operation. In COB, SQIID, and PHOENIX, a mechanical refrigerator is used, but CRSP requires cryogenic liquids for cooling. In CRSP, the optics and inner shield are cooled with LN_2, and the LHe is used to cool the detector to its best operating temperature.

2. Liquid Nitrogen

Liquid Nitrogen is colorless, with a specific gravity of about 0.8. Its temperature at ambient pressure is about 77 K. The latent heat of vaporization is about 160 kJ/l, so a heat input of 1 watt will boil off about 23 cc of liquid per hour.

Procedures

For efficient storage and handling, LN_2 is kept in vacuum-insulated dewars of various sizes. The KPNO mountain supply is kept in a very large (~ 10000 l) tank by the maintenance area; from that tank it is transferred into 160 l dewars for transport to the telescopes; these dewars are used to fill smaller (4 - 20 l) dewars which can be carried directly to the instrument.

With the exception of "topping off" already cold IR instruments prior to initial mounting on the telescope, LN_2 is transferred to the CCD and IR array instruments under slight pressure. The 10 or 20 l "small" storage dewar is filled from a 160 l storage dewar through a rigid tube. The dewar being filled must be raised so the tube extends well into it so the liquid does not simply blow back out the top. Once this is done, the transfer assembly is attached to the top of the small dewar. Evaporation of LN_2 will slowly build up sufficient pressure (3 - 6 psi) to force the liquid through the flexible line when the valve is opened. Alternatively, a source of pressurized nitrogen gas can be attached to the small vent valve on the transfer assembly to force the liquid out of the dewar. This is illustrated in Figure 1.

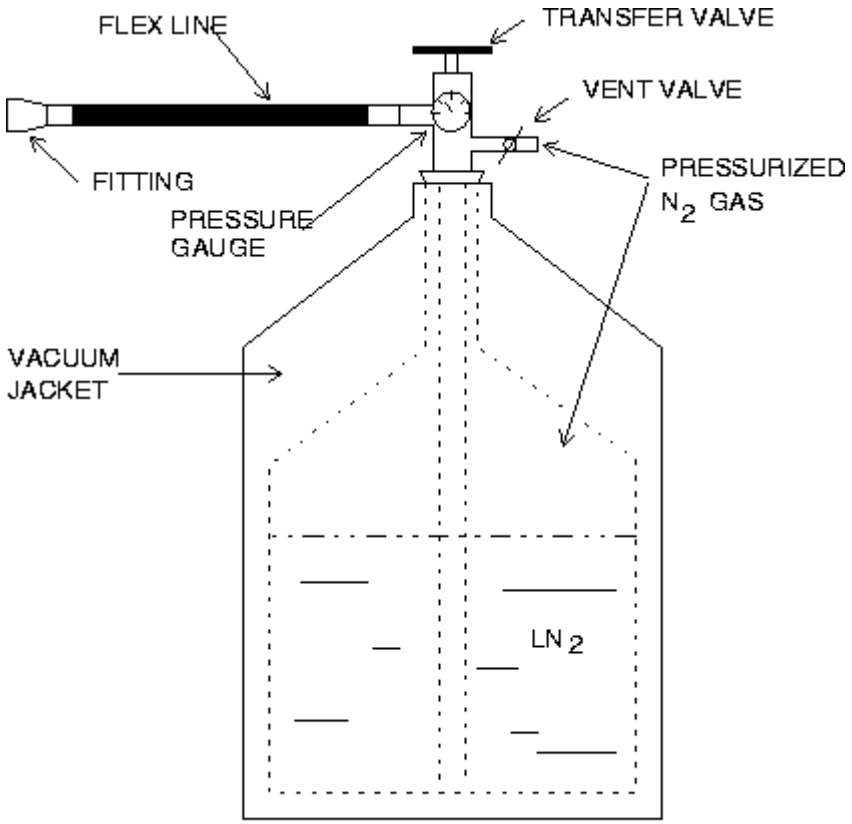

Figure 1

To fill an instrument dewar, position the storage dewar close enough so that the flexible stainless steel line can be attached to the fill port without excessive stretching or loading. One may "precool" the flexible line by opening the transfer valve and venting LN_2 into the room for a few seconds before closing the valve and attaching the line to the instrument. This may save some time and cryogen, particularly when filling the IR array instruments. The IR array instruments have two similar fill lines, but only one will have a screw fitting which matches the threads on the LN_2 transfer line--**make sure you attach to the correct line!** To

fill the instrument, simply open the transfer valve and transfer until liquid comes out the vent line. IRIM may be filled by simply pouring the LN_2 into the flasks through a funnel.

Safety Considerations

Because of its temperature and latent heat, LN_2 can cause severe frostbite when it contacts the skin for more than a second or so. In addition, cold transfer lines can cause intantaneous frostbite, so wear gloves when handling any cold metallic lines. Isolated drops of cryogen will generally create a vapor layer which protects the skin for a short time, but liquid driven by any pressure can instantly freeze the skin. Clothing can soak up the liquid and cause frostbite if it is held against the skin for more than a few seconds. In general, one should exercise care in working with LN_2, especially when filling storage or instrument dewars, where it is pressurized.

3. Liquid Helium

LHe is colorless, odorless, and cold. It has a specific gravity of 0.1 and an index of refraction (1.03) so close to that of air that it can be very difficult to detect visually in a dewar. Its temperature at ambient pressure is about 4.2 K. From the point of view of handling, its most critical property is the low latent heat of vaporization, which is only about 2.6 kJ/l. A heat input of only 1 watt will boil away 1.4 l of LHe in an hour. For this reason, the storage and instrument dewars, as well as the lines to transfer LHe from one to the other, must be carefully designed to minimize heat input from the outside world. All instruments using LHe also use LN_2 to minimize radiation heat load on the LHe and provide a reasonable time between refills. Storage dewars are specially designed with long, thin neck tubes and special radiation shields cooled by the LHe boiloff vapor for maximum hold time. The transfer lines have a vacuum jacket between the inner and outer tubes to insulate the liquid from the ambient temperature environment.

CRSP is the only IR instrument which uses LHe. For the initial fill with LHe, before the instrument is mounted on the telescope, a "U"-shaped transfer tube is used. When CRSP is on the telescope, access to the top of the dewar is impossible, and a special "L"-shaped fill line is mounted on the instrument. A second "L" tube with a flexible section is used to transfer LHe from the storage dewar. At the 4-m, because of size and weight considerations, it is necessary to use a more portable 10 l "intermediate" storage dewar to fill the instrument. Each of these procedures will be covered below.

Storage Dewars

A typical LHe storage dewar is illustrated in Figure 2. Both 30 l and 60 l dewars are used at KPNO; they are filled at the University of Arizona and transported up and down the mountain by truck. The principle of transferring LHe is similar to that used for LN_2; the transfer tube is inserted into the storage dewar to the bottom, and gas pressure forces the liquid through the tube into the instrument. However, because of the low latent heat, the actual process can be much more tricky.

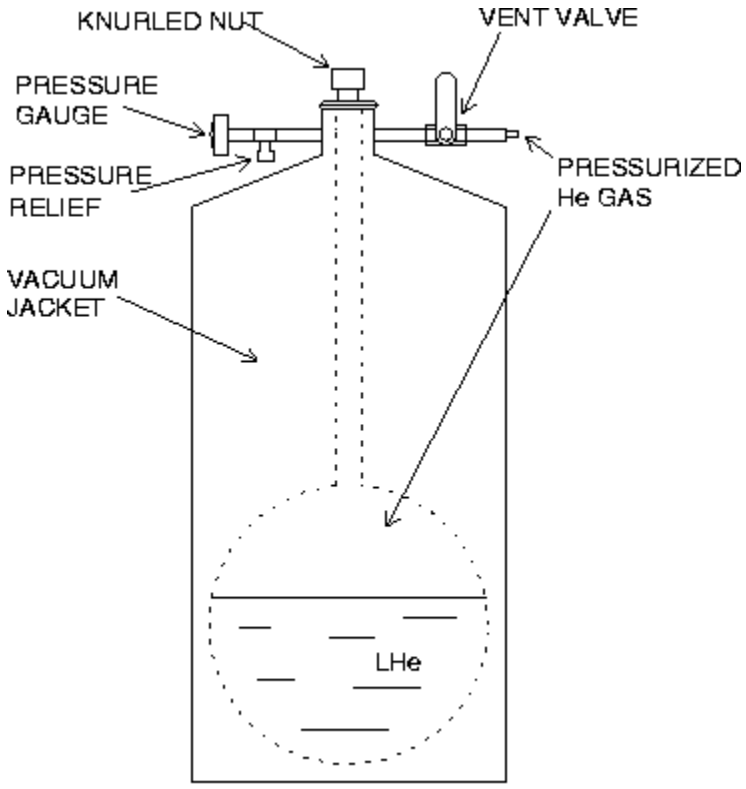

Figure 2

The storage dewars have two valves, one at the top, which must be opened to insert the transfer tube, the other on a vent line used for pressurizing the dewar during a transfer. Many dewars have a third valve terminating in a low-pressure relief port; several other pressure vents of different threshhold are scattered about the top of the dewar. These provide safety relief to avoid the buildup of excessive pressure in the dewar.

The most critical safety issue in dealing with LHe, both with storage and instrument dewars, is its temperature. It is so cold that it will **FREEZE ALL GASES** except He. This includes not only H_2O, but N_2 and O_2; all of these can freeze inside a LHe dewar, forming an "ice" plug which can potentially close up the neck and create a bomb. For this reason, the top and free vent valves on storage dewars must be kept closed, except when transferring LHe; the low-

pressure relief valve will maintain a small (1 psi) overpressure in the dewar to prevent air from entering the dewar and freezing. If an external source of gas is used to pressurize any LHe dewar, it is **essential** that only He gas be used! Any other gas will freeze inside the dewar and cause real problems. On the IR array instruments, both the fill and vent lines of the LHe fill fixture on the dewar are gently plugged with pipe cleaners; this results in a very small overpressure, which prevents the ambient atmosphere from being sucked in and frozen inside the lines.

Top Seal

All LHe storage dewars have a knurled nut with either a sheet rubber or O-ring seal on the top port. The purpose is to provide a leak-free seal around the transfer tube, so that internal gas pressure can be maintained to force the LHe through the transfer tube. If this seal leaks, the internal pressure will quickly drop and transferring will be difficult or impossible. Any evidence of leakage of this joint during transfer should be quickly investigated.

Pressure Line

When the transfer tube is inserted in the top port, it boils away LHe and creates gas pressure which begins to force liquid through the tube. Sometimes, this pressure is adequate to complete a transfer, but more frequently, it is necessary to maintain the pressure by external means. One method is to attach a source of pressurized He gas (must be He!) to the VENT port to maintain the pressure at about 1 - 1.5 psi.

Clacker

Since LHe is almost invisible, especially in a storage dewar, other techniques are necessary to measure the amount of liquid in the storage dewar, to ensure there is sufficient for a transfer and to anticipate the need for another storage dewar. This is done using a "clacker", essentially a long thin stainless steel tube with a closed resonator on the top. When the tube is inserted in LHe, the liquid will initially try to flow up the tube because the air inside cools and contracts. However, the LHe inside the tube will boil off and the vapor will push the liquid out of the bottom. This cycle will continue in a periodic fashion, resulting in an oscillation which is amplified by the resonator at the top of the clacker. Gaseous He at 4.2 K is only about 10 times less dense than the liquid, so the oscillations will continue if the tube is withdrawn from the liquid, but they will be at a higher frequency. This frequency discontinuity marks the surface of the liquid. To use the clacker, open the top valve of the dewar and slowly insert the clacker until it touches the

bottom of the dewar. Push the two black sliding washers against the top nut of the dewar. Then slowly raise the clacker until the resonant frequency of the clacker changes and push the bottom washer against the top nut. The separation of the two washers represents the depth of the liquid, which can be converted to liters using the calibration scale on the dewar. See Figure 3.

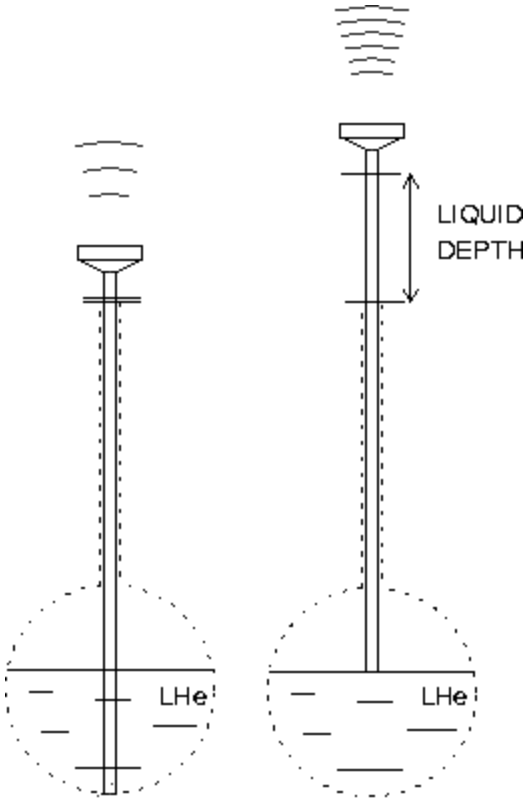

Figure 3

For unknown reasons, this technique is more difficult with the 10 l dewar used at the 4-m, although it can be done. It is virtually impossible to measure the liquid level in an instrument dewar when it is off the telescope, and it is impossible on the telescope, since the top of the LHe flask is not accessible.

HINT: If the oscillations of the clacker are difficult to hear, cover the top of the resonant chamber tightly with your hand and they can be easily felt.

Transferring

The principles and general techniques for transferring will be briefly covered here; checklists following cover specific situations. As mentioned above, there are two types of transfer tubes, a "U" tube for filling dewars when the top is accessible, and the "L" tube for refilling CRSP when it is mounted on the

telescope and the top is not accessible. General rules are:
1. Before the initial fill with LHe, any dewar must be precooled with LN_2, which is not only much cheaper than LHe, but has 60 times the latent heat. Failure to precool adequately will result in enormous waste of LHe. For CRSP, this is done by filling both the LN_2 and LHe flasks with LN_2, preferably the night before a run starts. The 10 l intermediate LHe storage dewar used at the 4-m should be filled with LN_2 at least one day before it is needed.
2. After precooling, it is necessary to remove **all** residual LN_2 from the flask before filling it with LHe. Failure to do so will freeze the LN_2, wasting LHe and possibly creating an "ice" plug during the transfer.
3. On initial fills, the height of the dewar to be filled must be adjusted so that the transfer tube will reach nearly to the bottom of its LHe flask when the other end is at the bottom of the storage dewar flask. This is necessary for efficient vapor cooling prior to collection of LHe in the flask.
4. When refilling a dewar which already has LHe in it, the transfer tube must be "precooled" by inserting it in the storage dewar (but not in the instrument dewar) until LHe comes out the end. If this is not done, warm He gas will be forced into the instrument dewar, boiling off all of the LHe remaining in it.
5. After using the "L" tubes to top off instrument dewars, store them with the valve OPEN. This prevents the resultant expansion as it warms up from cracking the internal welds on the valve seat.
6. If there is any doubt of the quantity of LHe in a storage dewar, MEASURE IT! Running out of LHe in a storage dewar during a transfer will blow He gas into the instrument dewar, boiling off the remaining LHe and causing an increased boiloff plume which can be mistaken for the completion of a successful fill. Measure the level of a storage dewar before and after transferring into the 10 l intermediate LHe dewar at the 4-m to make sure that a reasonable amount has been transferred.

Transfer Nuances

Transferring LHe is a combination of skill, art, and luck. Because the liquid does not appear or behave as LN_2 does; i.e., pouring out in a stream from a full dewar, it is necessary to use audio and visual cues to monitor progress. Manuals such as this and even hands-on instruction are not perfect guides; only with experience does one become proficient.

There are four basic "stages" during a transfer, which are described here by their audible and visual manifestations. Inductees are encouraged to be aware of these stages while transferring LHe or observing others doing so. Be aware that some locations, such as the Hindenburg Engine Room environment of the 4-m, will make some of the audible cues difficult to recognize.

"Chuffing" -- When the transfer tube is first inserted in the storage dewar, any LHe flowing through it is vaporized almost immediately, producing a pulsating flow of gas through the tube. As the tube cools down, the frequency of this pulsation will decrease, and one will eventually see a steady stream of dense white LHe about 10 cm long exiting from the tube.
"Cooling" -- This stage is most evident during the initial fill of a LHe flask or after connecting a precooled "L" tube to an IR array LHe fill tube. Liquid is flowing out of the tube, but is being vaporized almost immediately by the warmer surroundings (flask or fill tube). When using a "U" tube for initial fill, this stage is marked by a high-pressure "plume" exiting noisily from the flask neck.
"Condensation" -- When the flask has finally been cooled to LHe temperature, the liquid will begin collecting and filling up the flask. The boiloff will decrease dramatically, but will slowly build in intensity as the LHe fills up the flask, although not to the stage seen during cooling.
"Full" -- When the flask is full, LHe fill be forced out of the flask, although it will vaporize almost immediately in the air. When using a "U" tube, the boiloff plume will become a very dense white, and may pulsate with an audible "whoosh". When filling CRSP with an "L" tube, the plume from the vent line of the fill tube will likewise pulsate a dense white jet when the dewar is full. Maintaining an adequate pressure (at least 1 psi) in the storage dewar will not only facilitate the transfer, but will make the "full" characteristics much more definite.

(WARNING): If the storage dewar runs out of LHe during a transfer, it will blow gas into the instrument dewar and begin boiling off the LHe in the flask. This can cause a "burst" in the boiloff which can be mistaken for the "full" symptom. If any doubt exists, measure the storage dewar!

CHECKLISTS

INITIAL FILL OF CRSP ("U" TUBE)

* Make sure both LN_2 and LHe flasks are precooled adequately with LN_2.
* Blow out all LN_2 from LHe flask; check that it is dry. For the CRSP dewar, use the special blowout tube and dry N_2 gas from the plumbed lines.
* Position storage and instrument dewars at approximately the same height and at the proper separation for the "U" tube.
* Bleed down pressure in storage dewar using vent valve or top valve (but don't let rubber seal freeze!).

* Close vent valve and attach pressurized He gas line.
* Open top valve and slowly insert transfer tube in storage dewar. Pressure will build up and may vent through safety relief valves.
* As tube goes into storage dewar, guide exit end into instrument flask. It is not necessary to precool tube on an initial transfer.
* Continue to lower tube until it bottoms out in the storage dewar. It should also be well into the instrument flask. Raise the tube about 1 cm from the bottom of the storage dewar for better flow through the tube.
* Monitor the boiloff from the instrument dewar. One should go through the "chuffing", "cooldown", and "condensation" stages in a minute or so.
* If the pressure in the storage dewar drops below ~ 1 psi, open the vent valve and bleed in He gas until the pressure rises. Keep the pressure in the 1 - 1.5 psi range.
* Within 1 - 2 min of the "condensation" stage, the plume should indicate the "full" characteristics. Close the vent valve if it is open, and pull the transfer tube straight up out of the instrument and storage dewars. **Be careful not to bend the tube to the side as you do this!**
* Close the top valve on the storage dewar.
* The LHe boiloff will continue at a high level for some time as the detector cools down slowly. However, the experience with CRSP is that it should not be necessary to refill the instrument before installing on the telescope. The following checklist should be used only if it is necessary to do so.

TOPPING OFF CRSP WITH LIQUID HELIUM

* Position storage and instrument dewars as for initial fill.
* Vent down pressure in storage dewar, open top valve, and insert transfer tube
* Precool transfer tube through "chuffing" stage, with transfer tube rotated to the side of the instrument, so exit end vents into room. Make sure tube in storage dewar reaches to or near the bottom. Continue until steady stream of LHe exits from tube.
* Quickly but carefully raise transfer tube so exit end clears top of instrument, and insert into instrument flask.
* After an initial burst of boiloff, transfer should quickly settle into "condensation" stage as LHe is transferred.
* When the instrument dewar is full, remove the transfer tube and close the top and vent valves on the storage dewar, as in an initial fill.

FILLING AND TOPPING OFF 10 L INTERMEDIATE STORAGE DEWAR AT 4-M

Before initially filling, all of the LN_2 left over from precooling must be dumped out, preferably by inverting the dewar until all liquid is gone. A few points to be noted:
* The top flange assembly of the 10 l dewar should be removed before filling. On the initial fill, this will also be necessary to dump the LN_2.
* **THIS IS VERY IMPORTANT!! ONE MUST USE THE TRANSFER TUBE WITH BOTH LONG ENTRANCE AND EXIT TUBES. THE TUBE USED FOR INITIALLY FILLING CRSP WILL NOT REACH INTO THE 10 L DEWAR FLASK AND WILL NOT TRANSFER LHE INTO THAT DEWAR!**
* Because of the large neck diameter in the 10 l dewar, the exit gas plume will make almost no sound. However, when it is full, the plume will become very dense and white and will be unmistakable if a reasonable pressure (1.5 psi) is maintained in the large storage dewar during the fill.

TOPPING OFF CRSP ON THE 2.1-M TELESCOPE

When CRSP is on the telescope, one must refill using the special "L" tubes with the flexible section. If the instrument runs out of LHe, one may refill this way also, as long as the detector temperature is not too much above 77 K (`status` readout should be > 0.95) and there is liquid in the LN_2 flask. If the LN_2 flask is also dry, fill it through its fill tube and allow the detector temperature to fall to a sensor reading of ~ 0.95 before refilling the LHe flask. Otherwise, one will just waste LHe.

* Position observing floor so that top of storage dewar is about 6 inches below level of fill tube on instrument. With CRSP, it will be necessary to rotate the instrument so the fill tube is accessible.
* Remove caps and pipe cleaner filters from both fill and vent tubes.
* Make sure "L" tube has extender tube so it will reach bottom of storage dewar (about 12" extender for 60 l dewar; 3" for 10 l dewar).
* Open top valve on storage dewar, insert transfer tube slowly. Move dewar close to instrument when tube is in far enough to clear telescope.
* Open valve on transfer tube and let it precool, directing gas flow away from people or faces. When tube is cold, and white jet of liquid exits from end, close transfer tube valve.
* Maneuver storage dewar so "L" tube can be mated with fill tube on instrument. Insert "L" tube into fixture as far as it will go and snug down coupling nut. Raise/lower floor so that "L" tube is just above the bottom of the storage dewar.
* Open valve on transfer tube. One will initially get a blast of gas from the vent tube as warm He gas is blown into the instrument, but if reasonable (1 psi) pressure is maintained in the storage dewar, this will quickly settle down as

liquid begins to transfer.
* Maintain 1 psi or so on storage dewar, using He gas source. Plume from vent tube will be quite cold, and may cool end of tube so that atmospheric gas condenses to liquid on it. The fill should take 2 or 3 minutes. When the instrument flask is full, the exit plume will become much more dense white and will make a periodic "whoosh" sound.
* Close valve on transfer tube, unscrew coupling nut, and carefully move storage dewar away from instrument. When one has sufficient clearance, pull the transfer tube out of the storage dewar, and close the top valve of the storage dewar.
* Open the valve on the transfer tube and store it in a safe place.
* Replace pipe cleaner plugs on fill and vent tubes. These keep a small positive pressure in the instrument flask to prevent atmospheric gas from freezing in the tube ("ice" plug).
* If time permits, measure remaining LHe in storage dewar.

SPECIAL 4-M TECHNIQUES

Filling at the 4-m is done exactly the same way, but the limited space and need to use the 10 l storage dewar make it more complicated.

* The extender tube on the "L" tube should be removed for use with the 10 l storage dewar; a special 3" extender is used instead.
* Make sure there is adequate (> 3 l) LHe in 10 l dewar for a transfer.
* Carefully transport 10 l dewar down the stairs and set it on the special dolly just outside the cage door. Also bring down the long "javelin" tube and the tube from the pressurized He gas cylinder. The main valve on the He gas cylinder should be open and the regulator set to about 10 psi.
* Remove pipe cleaner plugs from instrument fill and vent tubes, and plug from top of 10 l dewar.
* Insert transfer tube in 10 l dewar, precool, close valve. Attach "javelin" tube to transfer tube, open valve, and precool until cold gas comes out of the "javelin". Close valve, mate "javelin" with instrument LHe fill line.
* Open transfer tube valve and transfer in usual way. The 10 l dewar may require continuous pressurization with He gas to keep the pressure at 1 - 1.5 psi; this is important for a timely transfer.
* When instrument flask is full, demate tubes, remove transfer tube from dewar, replace fill and vent line plugs, open valve on transfer tube before storage, as above. Clean up cass cage.

SPECIAL NOTE -- ICE PLUGS

In humid conditions, it is possible for an ice plug to form in the instrument fill line. Most often, these seem to occur in the small fill line which goes into the LHe flask neck. A reasonable fix is to blow He gas under low pressure from a He gas cylinder into the vent tube; this gas flows into the LHe flask around the small fill line, warming it up and eventually melting the "ice" plug. This technique works well only for condensed atmospheric gases, not for water ice plugs. Never try this trick with anything other than He gas, as it will simply add to the ice plug.

NOTE: The trick described above works well only if the LHe flask in the instrument is empty or almost so. If there is still significant LHe in the instrument, blowing warm He gas in the vent line will vaporize some of the LHe, causing a burst of *cold* gas to come back out the vent line. The ice plug will not be removed in this case. If an ice plug is encountered while attempting to fill, and the technique of blowing He gas in the vent does not remove it, the best approach is to continue observing until the `status` command on the instrument computer shows the instrument has run out of LHe. Attempting to blow out the ice plug with significant LHe in the instrument will eventually boil off the LHe, but at the cost of observing time. As long as one of the two lines (vent or fill) is open, and the boiloff from the LHe can escape, there is no danger in continuing to observe with one of the lines plugged.

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