LUX Xenon Sampling System Procedure

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1 Introduction

1.1 Purpose

The purpose of this document is to guide the user through the process of sampling xenon from the LUX circulation system and analyzing the xenon purity with the coldtrap/RGA method.

2 Prerequisites

2.1 Skills and Training

This work requires cryogenics training. HS5030-W ”Pressure and Cryogen Safety” This work will be performed by a Sampling System Expert, to be trained by Attila Dobi.

2.2 Permits and Authorizations

Work shall only be completed as authorized by the shift manager.

2.3 Equipment

- 4 L transfer Dewar with handle
- Cooler (for storing liquid nitrogen)
- Cryo-gloves
- Face shield
- Safety Glasses
- Lab-jack for supporting cooler
- Liquid nitrogen supply with delivery hose
- Portable O2 monitor

2.4 Hazard Mitigation

Hazard	Mitigation
High Pressure Gas	• All operators have completed HS5030-W, Pressure/Cryogen Safety. • Burst disk set at 41.1 psig (BDCT1) prevents dangerous overpressure in the coldtrap. • All components of the system have been pressure tested prior to operation Pressure Test Procedure • Only a fixed amount of xenon will ever be cryopumped into the coldtrap. At most a 0.5 L volume at 3 atm, the maximum pressure in the LUX xenon system, of xenon will be introduced into a 1.0L volume. Engineering controls are built in so that the maximum pressure in the coldtrap will be 1.5 atm, after warming the xenon ice. Since the LUX xenon system can not exceed 4 bar of pressure, without blowing a burst disk, the maximum amount of xenon that can be transferred to the sampling volume is 4 atm in 0.5 L. When expanded into the entire sampling system volume of 2.5 L the resulting pressure is 1.5 atm. In case of accidental overpressure a bust-disk set to 41.1 psig will relieve the pressure in the coldtrap plumbing.
Oxygen Deficiency Hazard (ODH)	• Oxygen monitors alert personnel to oxygen deficiencies • Inert gases used are only asphyxiants, not toxic. • Closed system reduces asphyxiation hazard; consult ODH analysis for details • Quantity of nitrogen gas and liquid-nitrogen is well below amount need to create oxygen deficiency hazard. Four Liters of Liquid nitrogen will be used to cool the coldtrap. 4 L of LN can expand suddenly to 2800 L of gaseous nitrogen at room temperature. This is less than 0.2% of the air volume of the Davis cavern. • ODH analysis completed and shown that ODH is zero.
Cryogen Safety	• All operators have completed HS5030-W, Pressure/Cryogen Safety. • Personal protective equipments(PPE) such as cryo-gloves, safety glasses, and face shield protect operators from exposure to cryogenic liquid. They will be located by the SRV. • The coldtrap consists of 316 S.S. (stainless steel) plumbing, with VCR and conflat connections, which have been pressure tested.
Administrative Locking	• For covering and locking valves in this procedure see operations procedure 36 Administrative Locking.

2.5 Lessons Learned

- RGA overpressure burnout in August 2013.

  Before the sampling algorithm had completed the user clicked a button on slow control to start a new sample. Specifically, the logic had gotten to the stage where SAM is waiting to confirm that the cold trap has warmed up and that the xenon is ready to be pumped away or recovered to the SRV. The sampling system Logic began the pre sampling process in parallel to the pump out process exposing the RGA temporarily to an atmosphere of xenon causing the filament and electron multiplier to burn out. The way the slow control backend is set up multiple instances of a C script can run in parallel when a front end command is sent. The problem was fixed by modifying the logic. All user inputs for the“Sampling System Master Control” are disabled until the analysis algorithm has completed and until all reported sampling errors are cleared by the user. As long as the user follows the procedures the code will do the rest.

- Hanging hose ejecting from sampling Dewar during LN fill.

  There have been two instances of the SRV vent line’s flex hose ejecting from the sampling system Dewar at the start of the LN fill. High pressure can build up in the LN fill line so when starting the fill there is a possibility that the hose will jolt initially. This has been address with CP13 version 6. Mitigated by removing the cover of the Dewar, and placing the Dewar directly under the flex hose (bend as little as possible). Also we can contain the flex hose to prevent it from swinging around. The correct response for the operator is to hit the ”Refill Stop” button, wait for the line to stop venting and place the hose back in the Dewar.

- SRV recovery procedure.

  It was pointed out that when recovering the sampled xenon to the SRV the high pressure lines should first be opened to the cold SRV prior to opening the vales to the low pressure side. No incidents ever occurred because the pressure in the lines are always checked prior to shorting the low and hight pressure plumbing , this is just good practice.

3 Filling the Sampling System's Dewar in the Lower Davis

Hazard Analysis:	A cryogen is used in this procedure. Wear PPE including cryo-gloves, safety goggles, and face shield when handling cold cryo-hose fittings and pouring liquid nitrogen. Avoid cuffs and wear proper shoes that cover the toes. Before filling the 4 L transfer Dewar assemble materials, Check that SRV vent line ready to deliver LN (Liquid Nitrogen), Sampling system is ready for LN. Notify others in the area of impending LN fill. Assure vent line is adequately contained by Dewar that hose whip will not kick the hose out of the Dewar. Don PPE: Cryo-gloves, safety glasses, face shield, oxygen monitor. Do not place the Dewar lid on Dewar, leave the Dewar open to allow pressure relief. Cuffs that could trap liquid should not be worn when working with LN. Before using an oxygen monitor, the operator should test if the device is operational. A simple test is to hold breath for several seconds, then slowly (>15 seconds) exhale near the sampling port. If monitor does not alarm and reads <19.5% do not use. Assure others (non-operators) are out of the area. The SRV LN Panel is about 2 m from SRV Vent Line and 4 L Dewar. Observe filling of 4 L Dewar from a distance at least 3' away. Listen for alarms and check personal and fixed oxygen monitors. If unexpected event occurs during filling or oxygen levels drop to <19.5%: Stop Fill by pushing "Stop Fill" button on the SRV LN Panel and leave the area (it is sufficient to take the stairs up to the upper davis). While filling the 4 L transfer Dewar there is a cryogen hazards to the users and others in the lower Davis, near the SRV. LN Splashes,a spill, or overflow could cause the floor to get slippery and cause oxygen deficiency. Check that the area in lower Davis is clear before transporting the 4 L Dewar to the sampling system. Before pouring LN, check floor and area around the cold trap Dewar for equipment that might be adversely affected by an LN spill. Pour slowly at start, especially if Dewar is warm.
Operation Risk:	When starting the fill of the sampling system's Dewar there is a chance that the hanging hose of the SRV vent line could be ejected from the Dewar, due to elevated pressure in the LN fill line. If this occurs stop the flow of LN by pressing the "Refill STOP" on the SRV LN Panel. See Figure 6 for a photo of the SRV LN BOX. The SRV vent line is near an oxygen monitor by the SRV and a LN spill during the filling of the sampling system Dewar may set it off. If the oxygen alarm is set off evacuate the area. Before beginning a LN fill check that the LN percentages of both the SRV and TS are greater than 52%, displayed on the SRV LN system panel. This is done in order to ensure that the SRV vent line will be free for the next 5 minutes. If either of them are reading less than 52% then wait until the automated LN system refills them. The coldtrap is a cryopump vessel which could potentially accumulate an amount of xenon which could overpressure when the xenon ice warms up. A burst disk set to 41.1 psig will relieve a overpressure in the coldtrap system plumbing.

This section describes the process of filling the 4 L transfer dewar form the SRV vent line and then transferring its contents to the Sampling System's cold trap dewar. Note, the Dewar is to be replaced every six months.

1. Before beginning check the usage data on the sampling system's Dewar. If the last replacement was over six months ago then replace the Dewar and label the new starting date.

2. On the LN system panels check that the LN percentages of both the SRV and TS are greater than 52%. This is done in order to ensure that the SRV vent line will be free for the next 5 minutes. If either of them are reading less than 52% then wait until the automated LN system refills them.

3. Push the button labeled “Refill SmpSys” on the SRV LN Panel. This will time out the SRV vent for 600 seconds. (Note: You can either use the touch screen interface or the physical button on the LN box).

4. Don Cryogen PPE: Cryo-gloves, safety glasses, face shield. Take the clip tested, functioning oxygen monitor (stored in the LUX office) close to your breathing zone.

5. Place the 4L Dewar into the 95 L S.S. pot located at the SRV vent line.

6. Adjust the vent line such that the 4 L Dewar is directly underneath the SRV vent line. Do not place the lid on the sampling system’s Dewar, leave it open.

7. Push the button labeled “Refill SmpSys” again. If the line is warm then at first only nitrogen gas will vent from the line.

8. If the SRV vent hose is ejected from the sampling system Dewar due to an overpressure in the line press the “Stop Fill” button.” Wait for the line to stop venting and return to Step 6.

9. After 5-10 minutes, depending on the initial line temperature, the flow of LN through the SRV vent line will begin at a rate of about 3 l/min. See Figure 6 for a photo of the SRV LN BOX.

10. When the sampling system’s Dewar is nearly full (about 2 minutes), stop the fill by pushing the “Refill STOP” on the SRV LN Panel. Once the “Stop Fill” button is pressed LN will continue to flow for about 30 seconds, wait until the flow stops. See Figure 6 for a photo of the SRV LN BOX.

11. There is a 2 minute timer on the Sampling System LN fill that will shut off the flow of LN, the timer begins when LN line temperature drops below -180 C. If you still need to top off then restart the fill by pressing the button labeled “Refill SmpSys”again (press twice). And then stop the fill by by pushing the “Refill STOP”. Remember, once the “Stop Fill” button is pressed LN will continue to flow for about 30 seconds.

12. If the LN fill fails to stop, or in the event of an emergency hit the RED “Emergency Stop” button on the LN panel. Then see LN System Procedure

13. Check that the floor of the lower Davis is clear of obstacles or workers. Lift the Dewar by handle and carry over to sampling system.

14. After a sample has been drawn, pour the LN from the 4 L Dewar into the cold trap Dewar. Before pouring LN, check floor and area around the cold trap Dewar for equipment that might be adversely affected by an LN spill. Pour slowly at start, especially if Dewar is warm.

15. Completion: Return 4 L Dewar to storage near the SRV vent line and log activity in the LUG.

4 Using the Automated Sampling System

Hazard Analysis: Cryogen and pressure hazards mitigated as noted in Section 2.4. A cryogen is used in this procedure. Wear PPE including cryo-gloves, safety goggles, and face shield when handling cold cryo-hose fittings and pouring liquid nitrogen. Avoid cuffs and wear proper shoes that cover the toes. Use a portable O2 monitor during LN transfer to ensure the O2 concentration is above 19.5%.

Operation Risk: The coldtrap is a cryopump vessel which could potentially accumulate an amount of xenon which could overpressure when the xenon ice warms up. A burst disk set to 41.1 psig will relieve a overpressure in the coldtrap system plumbing.

This section describes the process of sampling and analyzing xenon from the LUX circulation xenon system with the sampling system. Because the sampling procedure is largely the same for each of the locations, we will henceforth refer to the valves in each sampling location as VC&VB (valve on the circulation side) and VA (the valve on the sampling system side). Additionally, we will refer to the pressure transducer nearest the sampling port as PT-A. The valves and pressure transducer corresponding to each sampling location are summarized in Table 1.

This section is to be followed regardless of which port was selected. This procedure is for sampling xenon from the LUX gas system, the SRV, the Xe storage bottles, and for calibrating the sampling system. A 0.5 L sampling volume will be filled with xenon from the selected port and for calibrating from the internal calibration bottle. The valves and pressure transducer corresponding to each sampling location are summarized in Table 1, along with whether additional steps are required to collect the sample. See Figure 1 and Figure 2 for diagrams of the coldtrap plumbing and sampling port locations. Once PreSample has been initiated by the user, the sampling system logic will perform a brief internal pump-out prior to attempting an automated sample draw. After this, the user will make sure a sample has been properly collected and then begin the analysis. When the analysis is completed, the xenon ice in the coldtrap will warm and vaporize; the user can choose to vent this xenon or to recover it to the SRV. The analysis will be performed automatically, purity values will appear in the slow control database, and the user will need to record these and several other quantities in the LUG.

Sample Location	Pneumatics	Section	VA	VB	VC	Pressure to Watch
Getter Input	Yes	n/a	CV37	CV34	CV35	PT-C15
Getter Output	Yes	n/a	CV76	CV74	n/a	PT-C20
Detector Return	Yes	n/a	CV11	CV8	n/a	PT-C1
PMT Purge Line	Yes	n/a	CV9	CV7	n/a	PT-D41, PT-D4
Recirc Pump Inlet	No	4.1	CV60	CV61	n/a	PT-C15
To SRV	No	4.4	CV90	CV89	n/a	PT-S10
Storage Bottles	No	4.3	CV90	CV89	n/a	PT-S10
Calibration Bottle	No	4.2	SAM_V14	SAM_V13	n/a	n/a

Table 1: Sample ports with their corresponding valves and pressure gauge to watch, along with whether pneumatically controlled VA's have been installed. Additionally, the section number that provides additional instructions for collecting a sample from each port has been indicated in the 'Section' column. Refer to this table for valves VA, VB and VC as they depend on the location you will be collecting a sample from.

1. Check the pressure of instrumentation nitrogen. PT-GC10 should be more than 70 psig and PT-GC9 should read more than 200 psig. If not than the instrumentation nitrogen supply needs to be replaced.

2. Refer to Table 1 for valves VA, VB, VC and the pressure gauge to monitor as they will depend on the location you will be collecting a sample from.

3. Monitor and ensure the stability of the pressure gauge of interest (see Table 1). The pressure should be stable within 1 psig for one minute while the system is in a steady state. If not, contact the director of operations.

4. If the desired port has pneumatics installed (as noted in Table 1) confirm that VB and VC are locked open. If the selected port does not have pneumatics installed, confirm that VA, VB, and VC are locked closed. If VA, VB, or VC is in an unexpected state, stop and contact the director of operations.

5. Get liquid nitrogen (LN), but do not freeze the cold trap "U".

   a. Locate the sampling system's portable dewar

   b. Don proper PPE. Safety glasses, face shield, cryo gloves. Also, wear a portable O2 monitor.

   c. Fill the dewar from the SRV vent line. Go to Section 3 and follow the instructions.

6. Look in slow control, under "Text".

   a. The state of both "SAM Analysis Status" and "SAM Wait Status" should be "Idle". If not then the sampling system is not ready for PreSample; stop and consult section 5.

   b. The state of "SAM Error Status" should be "None". If "Error" is displayed see Section 6.

7. Go to the LUX slow control page, select 'Control' in the top menu LUX Slow Control. Then select 'Sampling' and hit the pencil button.

8. In the 'Sampling Port Select' box select the desired sampling port. The sampling will not start if you don't do this. Press change. For help see figure 3.

9. Double check that the correct port is displayed in the 'Sampling Port Select' sensor. If the wrong port is selected, valves will open to the main circulation path in unprepared locations.

10. Make sure that the number displayed in 'Sampling Pressure Minimum' is the desired sample pressure in torr. 700 is the most typical value, but for higher sensitivity a pressure up to 1600 torr can be selected.

11. In the 'Sampling System Master Control' box select 'Pre Sample' and then hit the 'Change' button. This will automatically prepare the system for analysis. While the pre-sample program is running the SAM Analysis Status box will display "PreSample" and the "SAM Wait Status" will display "Wait", they can be found under the "Text" tab. Do not change anything on the control page at this time, it could result in an error. For help see figure 3.

12. After the button is pressed wait approximately 10 minutes and refresh the page. When the SAM analysis status changes to 'Waiting', and the Wait status changes to 'RaiseLN' the sampling system is ready for the cold trap to be frozen. If the "Sampling System Master Control" current value changes to 'Error' then stop and go to Section 6.

13. Go to the LUX slow control page, select "Text" in the top menu LUX Slow Control. Then select 'Sampling' and hit the 'pencil' button.

14. The analysis status current value should be "Waiting" and the value of "SAM Wait Status" should be "RaiseLN", otherwise consult section 5. If the value of"Sampling System Status" is "Error" then stop and go to Section 6. For help see Figure 3.

15. Raise the cooler under the “U” of the coldtrap via a lab-jack until the bottom of the cooler touches the bottom of the “U”.

16. Fill the cooler underneath the cold trap’s “U” to the minimum fill marking with LN from the sampling system’s dewar. See figure 5.

17. In approximately 1 minute, the SAM logic will detect that the cold trap has been frozen and will display “PreSample Complete” in the analysis status box.

18. If the Wait Status displays:

    a. “Begin Analysis”, the user is free to continue to step 19.

    b. “Draw Sample Now”, no sample was collected during “PreSample”. Before continuing to step 19,the user must manually collect a sample according to section:

    - 4.1 if the user selected ‘CV60’ as sampling port in step 8
    - 4.2 if user selected ‘Cal’ as the sampling port in step 8
    - 4.3 if user selected ‘XeBottle’ as sampling port in step 8
    - 4.4 if user selected ‘SRV’ as sampling port in step 8

19. Start a LUG entry. This entry should contain:

    - The date and time of the sample
    - The port used for sampling
    - The pressure of PT-SAM2 after the sample was taken
    - The purpose of the sample
    - Any unusual detector conditions that may effect the purity

20. Go to the LUX slow control page, select ‘Control’ in the top menu LUX Slow Control. Then select ‘Sampling’ and hit the pencil button.

21. Before the analysis has begun check that the LN level is above the “Min LN” line, if not then add more LN.

22. In the ‘Sampling System Master Control’ box select:

    - “Calibrate” if user selected ‘Cal’ as sampling port. This will calibrate SAM using the xenon draw from the calibration bottle and then vent the used xenon.
    - Otherwise, the user may choose either “Analyze and Dump” or “Analyze and Recover”. “Analyze and Dump” will pump out the xenon sample after the measurement. “Analyze and Recover” will prompt the user when he/she can recover the xenon to the SRV.

23. While the analysis program is running. The “SAM Analysis Status” box will display “Analyzing” or “Calibrating” and the “SAM Wait Status” will display “Wait”. Do not change anything on the control page at this time, it could result in an error.

24. The user is now free to leave the system at this point if necessary, as long as they finish the rest of the steps in this section the next day.

25. The analysis completes in about 30 minutes, at which point the analysis status will display ”Waiting”, and the wait status will display “DropLN” until the cold-trap has reached room temperature.

26. At this time, the user can either lower the lab-jack supporting the LN or allow the LN to evaporate (the latter usually takes about 5 hours).

27. If the user chose "Analyze and Dump" or "Calibrate", once the cold-trap is warm the xenon will be pumped out automatically and the sampling system will prep for the next measurement.

28. If the user chose "Analyze and Recover" then they should lower the LN and check back in 30 minutes to recover the xenon, or return the next day. Once the LN evaporates SAM will display "Analysis Complete" in the analysis status and "Prepare for Recovery" in the wait status and will wait until the user begins recovery of the xenon to the SRV.

29. At this point, if the user wishes to recover the xenon to the SRV then go to section:
    - 4.6 if the sample was taken from the storage bottles.
    - 4.5 otherwise.

30. If the user does not wish to recover the xenon, select "Pump Out" in "Sampling System Master Control" and hit change. This will evacuate the remaining xenon remaining in the sampling system in preparation for the next sample. The value of "Sampling System Status" will change to "Pumping Out" while the remaining xenon vents, and then to "Idle" once the process is complete.

31. The user must wait until both the "SAM Analysis Status" and "SAM Wait Status" change to idle before collecting another sample.

32. After the analysis is complete the purity results will be written to the Slow Control data base.
    - If a calibration was performed, copy and paste values returned for Cal_N2, Cal_O2, Cal_He, Cal_Ar, Cal_Kr, Cal_Kr86, Cal_CH4 into the LUG entry that was started.
    - Otherwise, copy and paste the purity values returned for N2, O2, He, Ar, Kr, Kr86, CH4 into the LUG entry that was started. If the sample was taken from the storage bottles, also update these values in the Xe-inventory google-doc.

4.1 Manually collecting a Xenon Sample from Circulation System

1. Look in slow control, under "Text".

   a. The state of "SAM Analysis Status" should be "PreSample Complete", and "SAM Wait Status" should be "Draw Sample Now". If not then the sampling system is not ready to draw a sample; stop and consult section 5.

   b. The state of "SAM Error Status" should be "None". If "Error" is displayed see Section 6.

2. Monitor and ensure the stability of the pressure gauge of interest (see Table 1). The pressure should be stable within 1 psig for one minute while the system is in a steady state. If not, contact the director of operations.

3. Confirm that VA, VB, and VC are locked . If VA, VB, or VC is open, stop and contact the director of operations.

4. Open VC and VB. Then unlock and open VA to fill the 0.5 L sample volume with xenon from the LUX system. Crack VA open a bit until PT-SAM2 reaches 700 Torr. Drawing 700 Torr is sufficient for purity analysis. Figure 4 shows which pressure gauge to watch, it is visible to the user as he/she opens the sampling ports.

5. Close the sampling valves used (VA, VB and VC) to prevent leakage of xenon from the LUX system. Place an administrative lock on VA and tag it.

6. Go to the LUX slow control page, select ‘Control’ in the top menu LUX Slow Control. Then select ‘Sampling’ and hit the pencil button.

7. In the ‘Sampling System Master Control’ box select “Ready to Analyze” and then hit the ‘Change’ button. For help see Figure 3. Note: The SAM logic will not allow analysis to continue until this step has been completed.

4.2 Collecting a Xenon Sample from the Calibration-Xenon Bottle

1. Look in slow control, under “Text”.

   a. The state of “SAM Analysis Status” should be “PreSample Complete”, and “SAM Wait Status” should be “Draw Sample Now”. If not then the sampling system is not ready to draw a sample; stop and consult section 5.

   b. The state of “SAM Error Status” should be “None”. If “Error” is displayed see Section 6.

2. Minimize the regulator of the calibration bottle, SAM-R1, by twisting the handle counter clockwise until it stops.

3. Open the valve on the calibration bottle. Open SAM-V7 and SAM-V8 then increase the regulator SAM-R1(by twisting the knob clockwise) to fill the 0.5 L sample volume with 700 Torr of calibration xenon. Use PT-SAM2 to monitor the pressure at the output of the regulator. Figure 4 shows the location of PT-SAM2’s display.

4. Close the valve on the calibration bottle. Close SAM-V13 and SAM-14 and minimize SAM-R1(by twisting the handle counter clockwise until it stops).

5. Go to the LUX slow control page, select ‘Control’ in the top menu LUX Slow Control. Then select ‘Sampling’ and hit the pencil button.

6. In the ‘Sampling System Master Control’ box select “Ready to Analyze” and then hit the ‘Change’ button. For help see Figure 3. Note: The SAM logic will not allow analysis to continue until this step has been completed.

7. After the calibration is complete the results will be written to the Slow Control data base. Add the purity values returned for Cal_N2, Cal_O2, Cal_He, Cal_Ar, Cal_Kr, Cal_Kr86, Cal_CH4 into the LUG entry that was started.

4.3 Collecting a Xenon Sample from the Xenon Storage Bottles

This procedure is for collecting a xenon sample from the LUX xenon storage bottles. A 0.5 L sampling volume will be filled with xenon from the LUX circulation system. There are two bottle farms each containing four xenon storage bottles which can be sampled. The valves and pressure transducer corresponding to each xenon storage bottle are summarized in Table 2. See Figures 1, Figure 2 for diagrams of the coldtrap plumbing and sampling port locations. If sampling xenon from the storage bottles get clearance from a gas system expert.

1. Close all valves on the storage panel. SV1, SV2, SV3, SV6, SV16, SV18, SV15, SV25, SV30, SV31, SV9, SV33, SV32, SV49, SV50 (should be closed anyhow), SV12 and that Regulator SR1 is minimize.

Target cylinders	SVA	SVB	SVC	Pressure Gauge D
SB-1	SBV1	SBV11	SV15	PT-SB01
SB-2	SBV2	SBV12	SV15	PT-SB01
SB-3	SBV3	SBV13	SV15	PT-SB01
SB-4	SBV4	SBV14	SV15	PT-SB01
SB-5	SBV5	SBV15	SV30	PT-SB02
SB-6	SBV6	SBV16	SV30	PT-SB02
SB-7	SBV7	SBV17	SV30	PT-SB02
SB-8	SBV8	SBV18	SV30	PT-SB02

Table 2: Storage bottle and panel valves used for sampling xenon bottles and the pressure gauge to watch.

2. Ensure that all xenon storage bottles are closed. SB01, SB02, SB03, SB04, SB05, SB06, SB07, SB08. And that their corresponding VCR hand vales are closed SBV11, SBV12, SBV13, SBV14, SBV15, SBV16, SBV17, SBV18.
3. Ensure that the following valves near the compressor are closed: SV10, SV11, SV37, SV39, SV34, SV43, SV44, SV45. Minimize regulator SR2 by turning the the knob counter clockwise, stop once you encounter resistance, do not force.
4. Note: the values of SVA,SVB,SVC can be found in 2.
5. If PT-SB01 or PT-SB02 read more than 10 PSIA AND the xenon in the lines have been confirmed 'clean' within the past 30 days, then cryopump the remaining xenon from the storage panel to SRV (potentially at high pressure) by following sub steps 14.a through 14.e, else skip to 15. This is done to ensure that the xenon from the previous xenon bottle that was sampled is not mixed with the next bottle to be sampled. Again, before cryopumping the xenon to the SRV ensure that there was no air contamination indicated by any previous sample from the bottle farm, to do so check the LUG entires for 'Coldtrap'. (If the user wishes to only sample the xenon from the HP lines and not the xenon storage bottles then proceed from step 25, ignoring VA,VB and watching pressures PT-SB01 and PT-SB02 as Gauge D).

   14.a Ensure that the pressure in the SRV xenon space [PT-S10] is less than 0 psig . Also ensure that SRV LN Space Temperature [TSRV02] is reading below 165K, this will ensure that the SRV is ready for cryopumping xenon. Note: PT-S10 reads in psig, and TSRV02 reads in K.

   14.b Talk to a gas system expert and the shift manager to make sure nothing besides standard xenon circulation is happening at the time. There should be no SRV recovery from the circulation system, no ACRS alarm condition, and no compressing should be happening.

   14.c Open (in the following order): SV2, SV9, SV10, SV15 and SVC (SVC may also be SV15). Cryopump into the SRV until Pressure Gauge D and PT-S10 (on the SRV) flatten out below 5 PSIA. The flattening of the pressure signal vs. time indicates the flow induced by cryo pumping has stopped. Then, empty the line to the sampling system by ensuring CV80, CV42 and MFC8 are closed, then open SV33, SV32, SV44, SV45, SV11. Cryopump into the SRV Pressure Gauge D flattens out below 5 PSIA.

   14.d Close valves SVC, SV15, SV9, SV10, SV2 and SV32, SV33, SV11, SV45, SV44 (in that order).

   14.e Monitor pressure on Gauge D, PT-S15 and PI-S25 to confirm that you vacuumed the storage panel. Look for the pressures to be stable over a few minutes. Record the level these pressure gauges read out. Estimate the uncertainty of that reading. Remember HP gauge to 4000 psi, can't read well vacuum below 5 PSIA).

6. Double check that SV15, SV16, SV30, SV31, SV18 are closed. Double check that all eight xenon bottles in the bottle farm are closed shut.

7. Attach the turbo pumping cart via SV19 as illustrated in Figure 7 by following steps 16.a to 16.k, or skip ahead to step 17 if the turbo pumping cart is already attached via SV19.

    16.a Attach the pumping cart at SV-19. Ensure SV18 and SV19 closed. See Figure 7.

    16.b Close vales PCV1, PCV2, PCV3, PCV4 on the pumping cart.

    16.c Remove air using SP1 opening PCV3 until pressure drops to mbar level (1e-3 Torr).

    16.d Close PCV3, open PCV2.

    16.e Start TP1.

    16.f Open PCV1.

    16.g Pump until 10-5torr (PT-PC1 min pressure reading)

    16.h Start leak-checker, with PCV4 closed.

    16.i Close PCV1.

    16.j Open PCV4, Helium leak check the plumbing to SV-18.

    16.k Close PCV4, stop leak checker.

8. Ensure the turbo pumping cart is set up as illustrated in Figure 7 (The following steps use valve labels as indicated on the figure).

9. On the turbo pumping cart ensure that valves PCV4, PCV3 are closed.

10. Start up SP1 (the scroll pump on the turbo pumping cart attached to SV-19). If both the turbo and scroll pump are running then spin down the turbo pump, it will take about 10 minutes, this is to prevent any damage from pumping out the xenon.

11. Open SV19, SV18, SV15, SVC and SVB (Do Not Opened The Storage Bottle Valve!!!) . This will begin to evacuate the remaining xenon in the high pressure lines using only the scroll pump.

12. Once the pressure by the scroll pump is less than 1 Torr. Start the turbo pump, let it spin up. After the turbo has spun up let it pump on the lines for more than five minutes.

13. Close SVC, SV15, SV18 and SV19 (in that order). Place an administrative control lock or tag on SV18 and SV19. [At this point the turbo pumping cart is isolated and can be shut down if the user wishes by closing all hand vales on the turbo cart then spinning down the turbo pump, it will take about 10 minutes, then shutting off the scroll pump].

14. Then open SVA (the xenon storage bottle to be sampled), wait for the pressure in the lines to equalize. (Note: SVB, the corresponding VCR hand valve to the bottle being sampled, should already be opened).

15. Close SVA (the xenon storage bottle that was sampled), also close SVB (its corresponding VCR hand valve). Monitor the pressure in the storage panel on Gauge D, this will be the supply pressure to the input of regulator SR2 in the following steps.

16. Open SVC.

17. Open SV10 and SV44. Monitor the pressure on Gauge D.

18. Ensure that SR2 (the regulator at the compressor bypass) is minimized then open SV45. This will allow xenon from the high pressure side to flow through the regulator into the low pressure side.

19. Open up the regulator SR2 (by turning the knob clockwise) until the output pressure on PI-S23 reads just above 0 PSIG (or just above 1 ATM). It is ok to go up to 10 PSIG. If the pressure of PI-S23 10 PSIG then crank back one full turn (counter clockwise) on the regulator SR2.

20. Open valve SV11, this will fill the lines up to the sampling port CV89 with xenon from the output of the regulator SR2.

21. Look in the LUX slow control, under "Text" LUX Slow Control Text.

    a. The state of "SAM Analysis Status" should be "PreSample Complete", and "SAM Wait Status" should be "Draw Sample Now". If not then the sampling system is not ready to draw a sample; stop and consult section 5.

    b. The state of "SAM Error Status" should be "None". If "Error" is displayed see Section 6.

22. Open valve CV89 (behind the circulation panel by the SAES Getter).

23. Go to the LUX slow control page, select 'Control' in the top menu LUX Slow Control. Then select 'Sampling' and hit the pencil button.

24. In the 'Sampling System Master Control' box select "Ready to Analyze" and then hit the 'Change' button. For help see Figure 3. This will open the valves within the sampling to fill the 0.5l bottle to the desired pressure.

25. Return to the slow control 'Text' tab. While 'SAM analysis Status' reads 'PreSample', and 'SAM Wait Status' reads 'Wait', do nothing to the system.

26. After about a minute, refresh the page. When 'SAM analysis Status' reads 'PreSample Complete', and 'SAM Wait Status' reads 'Begin Analysis', continue to the next step. If at any point 'SAM Error Status' reads anything other than 'None', stop and consult section 6.

27. Close valve CV89 to prevent leakage of xenon from the LUX system. Place an administrative lock on CV89 and tag it.

28. Close SV10, SV11, SV44, SV45 and minimize SR2 (by turning the knob counter clockwise until you encounter resistance, do not force)

29. Close SVC.

4.4 Collecting a Xenon Sample from the SRV (when warm)

This procedure is for collecting a xenon sample from the LUX SRV. A 0.5 L sampling volume will be filled with xenon from the SRV. When sampling from the SRV get clearance from an SRV and gas system expert.

1. Ensure that the SRV is warm (no xenon ice) and ready for sampling. Check that the temperature of the LN space, TSRV02 is greater than 240 K and that the pressure inside the xenon space, PT-S10, is between 0 and 1000 PSIG. (This is to ensure that the xenon has fully vaporized and there is no longer residual ice).

2. Close all valves on the storage panel. SV1, SV2, SV3, SV6, SV16, SV18, SV19, SV15, SV25, SV30, SV31, SV9, SV33, SV32, SV49, SV50 (should be closed anyhow), SV12 and that Regulator SR1 is minimized.

3. Ensure that the following valves on the SRV are close, if not close them. SRVV1, SRVV2, SRVV3.

4. Ensure that the following valves near the compressor are closed : SV10, SV11, SV37, SV39, SV34, SV43, SV44, SV45. Minimize regulator SR2 by turning the the knob counter clockwise, stop once you encounter resistance, do not force.

5. Monitor the pressure in the SRV xenon space, PT-S10, while sampling. If the reading shows signs of continuous decline to atmospheric pressure it is an indication of a burst disk failure.

6. Open SRVV2, SV2, SV9

7. Open SV10 and SV44.

8. Ensure that SR2 (the regulator at the compressor bypass) is minimized then open SV45. This will allow xenon from the high pressure side to flow through the regulator into the low pressure side.

9. Open up the regulator SR2 (by turning the knob clockwise) until the output pressure on PI-S23 reads just above 0 PSIG (or just above 1 ATM). It is ok to go up to 10 PSIG. If the pressure of PI-S23 10 PSIG then crank back one full turn (counter clockwise) on the regulator SR2.

10. Open valve SV11, this will fill the lines up to the sampling port CV89 with xenon from the output of the regulator SR2.

11. Look in the LUX slow control, under "Text" LUX Slow Control Text.

    a. The state of "SAM Analysis Status" should be "PreSample Complete", and "SAM Wait Status" should be "Draw Sample Now". If not then the sampling system is not ready to draw a sample; stop and consult section 5.

    b. The state of "SAM Error Status" should be "None". If "Error" is displayed see Section 6.

12. Open valve CV89 (behind the circulation panel by the SAES Getter).

13. Go to the LUX slow control page, select 'Control' in the top menu LUX Slow Control. Then select 'Sampling' and hit the pencil button.

14. In the 'Sampling System Master Control' box select "Ready to Analyze" and then hit the 'Change' button. For help see Figure 3. This will open the valves within the sampling to fill the 0.5l bottle to the desired pressure.

15. Return to the slow control 'Text' tab. While 'SAM analysis Status' reads 'PreSample', and 'SAM Wait Status' reads 'Wait', do nothing to the system.

16. After about a minute, refresh the page. When 'SAM analysis Status' reads 'PreSample Complete', and 'SAM Wait Status' reads 'Begin Analysis', continue to the next step. If at any point 'SAM Error Status' reads anything other than 'None', stop and consult section 6.

17. Close valve CV89 to prevent leakage of xenon from the LUX system. Place an administrative lock on CV89 and tag it.

18. Close SV10, SV11, SV44, SV45 and minimize SR2 (by turning the knob counter clockwise until you encounter resistance, do not force)

19. Close SV2, SV9 and SRVV2 (unless SRVV2 is intended to be in a locked open state, ask the current Detector Operator Manager).

4.5 Recovering Sampled Xenon to the SRV

Hazard Analysis: Cryogen and pressure hazards mitigated as noted in Section 2.4

1. This section should only be used when the value of "Sampling System Status", in slow control, is "Ready for SRV Recovery." For help see Figure 3.
2. If the user wishes to cancel the SRV recovery and wants to pump out the xenon instead then skip ahead to step 17.
3. Ensure that the pressure in the SRV xenon space [PT-S10] is less than 0 psig . Also ensure that SRV LN Space Temperature [TSRV02] is reading below 165K, this will ensure that the SRV is ready for cryopumping xenon. Note: PT-S10 reads in psig, and TSRV02 reads in K.
4. Talk to a gas system expert and the shift manager to make sure nothing besides standard xenon circulation is happening at the time. There should be no SRV recovery from the circulation system, no ACRS alarm condition, and no compressing should be happening.
5. Ensure that CV11, CV37, CV61, CV76, CV80, CV9 and CV42 are closed.
6. Ensure that SV1, SV10, SV11, SV30, SV25, SV3, SV49, SV15, SV33, SRVV1, and SRVV3 are closed.
7. Open SRVV2 (SRVV2 is locked open and is the path into the SRV). Then open SV2, SV9.
8. Wait until there is no high pressure in the line by checking that the SRV xenon space pressure PT-S10 has leveled off at less than 0 psig.
9. Open SV33 and then SV32, this will connect the high pressure side of the plumbing to the low pressure side.
10. Look in the LUX slow control, under "Text" LUX Slow Control Text.

    a. The state of "SAM Analysis Status" should be "Analysis Complete", and "SAM Wait Status" should be "Prepare for Recovery". If not then the sampling system is not ready to draw a sample; stop and consult section 5.

    b. The state of "SAM Error Status" should be "None". If "Error" is displayed see Section 6.
11. Go to the LUX slow control page, select 'Control' in the top menu LUX Slow Control. Then select 'Sampling' and hit the pencil button.
12. In the 'Sampling System Master Control' box select "SRV Recovery" and then hit the 'Change' button. For help see Figure 3. This will open the valves within the sampling to allow the xenon to be recovered to the SRV.
13. Return to the slow control 'Text' tab. While 'SAM analysis Status' reads 'SRV Recovery', and 'SAM Wait Status' reads 'Wait', do nothing to the system.
14. After about a minute, refresh the page. When 'SAM analysis Status' reads 'Waiting', and 'SAM Wait Status' reads 'Open CV89', continue to the next step. The user now has 15 minutes to complete the recovery. If after 15 minutes PT_SAM2 still reads >20 torr, the SAM logic will return an error.

15. Open CV89. This will allow the xenon remaining in the sampling system to be cryopumped into the SRV.
16. Once the SAM CM gauge reads $<$ 20 torr, the SAM logic will close the sampling system valves, 'SAM Analysis Status' will read 'Idle', and 'SAM Wait Status' will read 'Begin Pumpout'. It is now safe to continue to the next step.
17. Close SV32, SV33, SV9, SV2, and CV89.
18. In "Sampling System Master Control" select "Pump Out" and hit change. This will evacuate the remaining xenon remaining in the sampling system. The the system will automatically prep for the next sample.
19. The value of "Sampling System Status" will change to "Pumping Out" while the remaining xenon vents, and then to "Idle" once the process is complete.

4.6 Recovering Sampled Xenon to the SRV when Sampling From the Xenon Storage Bottles

Hazard Analysis:	Cryogen and pressure hazards mitigated as noted in Section 2.4

1. This section should only be used when the value of "Sampling System Status", in slow control, is "Ready for SRV Recovery" AND when sampling xenon from the bottle farm. For help see Figure 3.
2. Ensure that the pressure in the SRV xenon space [PT-S10] is less than 0 psig . Also ensure that SRV LN Space Temperature [TSRV02] is reading below 165K, this will ensure that the SRV is ready for cryopumping xenon. Note: PT-S10 reads in psig, and TSRV02 reads in K.
3. Talk to a gas system expert and the shift manager to make sure nothing besides standard xenon circulation is happening at the time. There should be no SRV recovery from the circulation system, no ACRS alarm condition, and no compressing should be happening.
4. Ensure that CV11, CV37, CV61, CV76, CV80, CV9 and CV42 are closed.
5. Ensure that SV1, SV10, SV11, SV30, SV25, SV3, SV49, SV15, SV33, SV44, SV37, SV34, SRVV1, and SRVV3 are closed.
6. Open SRVV2 (SRVV2 is locked open and is the path into the SRV). Then open SV2, SV9, SV10, SV15 and SV30.
7. Wait until there is no high pressure in the line by checking the SRV xenon space pressure PT-S10, PT-SB01 and PT-SB02. Wait for the readings to level off below 5 PSIA to ensure there is no high pressure remaining in the line.
8. Open SV33, SV44 and then SV32, SV45 and SV11, this will connect the high pressure side of the plumbing to the low pressure side.
9. Look in the LUX slow control, under "Text" LUX Slow Control Text.

   a. The state of "SAM Analysis Status" should be "Analysis Complete", and "SAM Wait Status" should be "Prepare for Recovery". If not then the sampling system is not ready to draw a sample; stop and consult section 5.

b. The state of "SAM Error Status" should be "None". If "Error" is displayed see Section 6.

10. Go to the LUX slow control page, select 'Control' in the top menu LUX Slow Control. Then select 'Sampling' and hit the pencil button.
11. In the 'Sampling System Master Control' box select "SRV Recovery" and then hit the 'Change' button. For help see Figure 3. This will open the valves within the sampling to allow the xenon to be recovered to the SRV.
12. Return to the slow control 'Text' tab. While 'SAM analysis Status' reads 'SRV Recovery', and 'SAM Wait Status' reads 'Wait', do nothing to the system.
13. After about a minute, refresh the page. When 'SAM analysis Status' reads 'Waiting', and 'SAM Wait Status' reads 'Open CV89', continue to the next step. The user now has 15 minutes to complete the recovery. If after 15 minutes PT_SAM2 still reads >20 torr, the SAM logic will return an error.
14. Open CV89. This will allow the xenon remaining in the sampling system to be cryopumped into the SRV.
15. Once the SAM CM gauge reads <20 torr, the SAM logic will close the sampling system valves, 'SAM Analysis Status' will read 'Idle', and 'SAM Wait Status' will read 'Begin Pumpout'. It is now safe to continue to the next step.
16. Close CV89, SV11, SV32, SV33, SV45, SV44, SV10, SV15, SV30, SV9, SV2.
17. In "Sampling System Master Control" select "Pump Out" and hit change. This will evacuate the remaining xenon remaining in the sampling system in preparation for the next sample.
18. The value of "Sampling System Status" will change to "Pumping Out" while the remaining xenon vents, and then to "Idle" once the process is complete.

5 Understanding SAM Status Readouts

In addition to the error status (see section 6) there are two status readouts in the slow control, "Text" tab as shown in figure 3. "SAM Analysis Status" indicates what the SAM logic is doing, and "SAM Wait Status" gives instructions to the user. The possible states of "SAM Analysis Status" are: 0) Idle. 1) PreSample. 2) PreSample Complete. 3) Analyzing. 4) Calibrating. 5) Waiting. 6) SRV Recovery. 7) Pumpout. 8) Error. 9) Analysis Complete. The possible states of "SAM Wait Status" are: 0) Idle. 1) Wait. 2) Open CV89. 3) Begin Pumpout. 4) Prepare for Recovery. 5) Draw Sample Now. 6) Begin Analysis. 7) Raise LN. 8) Drop LN. This section is meant to provide an overview of the different states that these status displays can indicate. In this section the pair of status readouts will be indicated as "Analysis:Wait". If none of the following status pairs are displayed, immediately contact the system owner.

5.1 Idle:Idle

In this readout state the SAM logic is doing nothing, and the user has not instructions to be completed. The system is ready to begin pre-sample, pump-out, or SRV recovery.

5.2 Presample:Wait

In this state, the user should not do anything to the system. SAM logic will conduct a brief pump out, and attempt to draw a sample from the indicated port.

5.3 Analyzing:Wait

In this state, the user should not do anything to the system. SAM logic will perform an analysis of the drawn Sample.

5.4 Calibrating:Wait

In this state, the user should not do anything to the system. SAM logic will perform a calibration.

5.5 Pumpout:Wait

In this state, the user should not do anything to the system. SAM logic will pump any remaining gas in the system to air.

5.6 SRV Recovery:Wait

In this state, the user should not do anything to the system. If pressure is higher than 20 torr, SAM logic will open valves for SRV recovery.

5.7 PreSample Complete:Draw Sample Now

Pre-sample has completed successfully, but no sample was drawn. User should manually draw sample and prepare for analysis according to section **??**.

5.8 PreSample Complete:Begin Analysis

Pre-sample has completed successfully and system is ready for analysis. User should initiate analysis according to section **??**.

5.9 Analysis Complete:Prepare for Recovery

Analysis has completed successfully. User should prepare SRV plumbing for recovery according to section 4.5.

5.10 Idle:Begin Pumpout

SRV recovery has been completed successfully, user should now initiate pump-out by selecting "Pumpout" in the "Sampling System Master Control" sensor in the slow control "control" tab.

5.11 Waiting:RaiseLN

User must freeze cold trap before logic will continue.

5.12 Waiting:DropLN

SAM logic will not proceed until clod trap is above 260 Kelvin.

5.13 Waiting:OpenCV89

System has been prepared for SRV recovery. The user now has 15 minutes to recover xenon according to 4.5.

6 Debugging Sampling System Errors

This section is meant to guide the user in the event that the "SAM Analysis Status" displays "Error." The following error conditions are possible and can be debugged. 1) Xenon is too dirty. 2) Input pressure did not decline. 3) Valve Failure. 4) Low Sample Pressure. Do not start debugging while the status of ""SAM Run Status"", in slow control, reads "Wait". It is important to let the code finish before changing values on the Control page. Once the status of ""SAM Run Status"" reads "Idle" then it is okay to proceed. If ""SAM Run Status"" does not change to "Idle" within 30 minutes after an error is displayed then contract the system owner (Attila Dobi).

6.1 Poor Vacuum

This message is displayed when the value of vacuum gauge PT-SAM1 or the RGA partial pressure of N2, O2 is to high to begin sampling. These parameters indicate that the sampling system plumbing has not yet been sufficiently pumped out.

To clear the error follow these steps:

1. In "Sampling System Master Control" select "Idle" and hit the "change" button.
2. Ensure that PT-SAM2 reads less than 5 Torr (the sampling volume is in vacuum). If not then contact the system owner (Attila Dobi).
3. In slow control turn off "SAM Vacuum Gauge 2" [PT-SAM3].
4. Open SAM-V1 and SAM-V2. If "SAM Turbo 2" is not on, then turn it on in slow control and wait 2 minutes. Then turn on "SAM Vacuum Gauge 2" [PT-SAM3].
5. Once "SAM Vauum Gauge 2" [PT-SAM3] reads less than 1e-6 Torr. Open SAM-V3.
6. Wait until PT-SAM1 reads less than 1e-6 Torr. Then resume section 4.1.

6.2 Xenon is too dirty

If this message is displayed then the sampled xenon contains to much of an impurity for the analysis to continue. To find out which species caused the overpressure check plots of all SAM_RGA partial pressures from the time the analysis was begun until the time of the Error condition.

To clear the error follow these steps:

1. Remove the LN from the cold trap's U, by lowering the cooler with the lab jack.
2. Wait until SAM-TC1 and SAM-TC2 read more than 265 K. This is sufficient temperature for all the xenon to have vaporized.
3. In "Sampling System Master Control" select "Pump Out" and hit the "change" button.
4. The sampled xenon will be evacuated and the sampling system will prep for the next sample.
5. Once the xenon has pumped away the "Sampling System Status" will display "Idle".

6.3 No Pressure Drop

If this message is displayed during "Analyze" then the sampling valves VA, VB and VC (to the circulation panel) might have been left open by the operator. The system will stop the sampling process to prevent too much xenon from being drawn out of the circulation panels. This error might also be displayed if pneumatic pressure was lost during the analysis process. The user should do the following:

1. Confirm that all VA, VB and VC noted in Table 1 are closed.
2. Check that there is between 60-100 psig being supplied by the instrumentation nitrogen feed. The pressure is read out on sensor PT-GC10.
3. Once these have been checked the user can re-try the analysis.
4. In "Sampling System Master Control" select "Analyze&Dump" or "Analyze&Recover" and hit the "change" button. The user can chose to pump out the xenon after analysis or recover it to the SRV.
5. The user should continue at Section 4.3

If this error is displayed during "SRV Recovery", then either the user did not open CV89 within 15 minutes, or the path to the SRV is not clear. If the user simply did not open CV89, go the 'Control' page in slow control and select 'Idle' in the master control box. You may now re-start the recovery process according to the appropriate section (4.5 or 4.6).

If the user opened CV89 and this error was still displayed, select 'Idle' in the sampling system master control, and confirm that the SRV is cold and the path is clear according to the appropriate section (4.5 or 4.6). If the valves were opened correctly and the SRV is cold, stop and contact the director of operations.

6.4 Valve Failure

If this message is displayed then the sampling valves have failed to open, potential due to loss of pneumatic pressure.The user should do the following:

1. Check that there is between 80-100 psig being supplied by the instrumentation nitrogen feed. The pressure is read out on sensor PT-GC10, and the nitrogen supply bottle is PT-GC9.
2. Once this has been checked the user can re-try the analysis.
3. In "Sampling System Master Control" select "Analyze&Dump" or "Analyze&Recover" and hit the "change" button. The user can chose to pump out the xenon after analysis or recover it to the SRV.
4. The user should continue at Section 4.3

6.5 Low Sample Pressure

If this message is displayed then the initial pressure of the xenon sample is insufficient for analysis. The user should do the following:

1. There needs to be at least 400 Torr of pressure read by PT-SAM2.
2. Go to section 4.2, this will guide the user to drawing the xenon sample. Ensure that PT-SAM2 reaches 400 Torr.
3. Once this has been checked the user can re-try the analysis.
4. In "Sampling System Master Control" select "Analyze&Dump" or "Analyze&Recover" and hit the "change" button. The user can chose to pump out the xenon after analysis or recover it to the SRV.
5. The user should continue at Section 4.3

6.6 Low LN

If this message is displayed when there is insufficient LN to continue.

1. Follow the steps in section 3 to get more LN. And fill the cooler underneath the cold trap's "U" with LN.
2. Wait 1 minute after adding more LN.
3. Under Sampling System Master Control, Select 'Idle' then hit Change. This is necessary to clear the Sampling System Error message.
4. Under 'Sampling Port Select', Select the current sampling location and hit 'Change'.
5. Under Sampling System Master Control, Select 'PreSample' then hit 'Change'. The analysis can not be restarted with out doing the PreSample step again, there is no ill effect in re-running 'PreSample' once the sample has already been collected.
6. Restart the purity analysis or calibration process. Section 4.1 and 4.2.

6.7 PumpOutErr

If this message is displayed during the pump out function:

1. Check that there is between 80-100 psig being supplied by the instrumentation nitrogen feed. The pressure is read out on sensor PT-GC10, and the nitrogen supply bottle is PT-GC9.
2. Ensure that the cooler containing LN has been lowered from the U of the cold trap. And that SAM-TC1 and SAM-TC2 read more thank 265 K.
3. If the status of "SAM Run Status" reads "Idle" then go to the Control page under "Sampling" and in "SAM Master Control" select "PumpOut" and hit change. This will restart the pump out process.
4. If the problem persists, or if the value of "SAM Run Status" remains at "Wait" for more than 5 minutes, then contact the system owner (Attila Dobi)

If this message during 'PreSample', stop and contact the owner of the system.

6.8 NetErr

If this message is displayed when a network time out occurred, or if a value state or an instrument control command failed.

1. Check that there is between 80-100 psig being supplied by the instrumentation nitrogen feed. The pressure is read out on sensor PT-GC10, and the nitrogen supply bottle is PT-GC9.
2. Check that all ethernet and power cables on SAM are plugged in and that the Sampling System instrument values are updating in slow control.
3. Contact the system owner (Attila Dobi)

A Sampling System Logic

This section explains the decision tree that is made when the following is selected "Idle", "Pre Sample", "Analyze&Dump", "Analyze&Recover", "Calibrate", "PumpOut" and "Error". The code is contained in the SC_Backend/slow_control_code/LUX_SAM/SAM.c

Note: At each step the code will check the time stamp of the value from the MySQL data base. If it is less than 120 seconds then there is a network connection error. SAM will go to its Error condition and display NetErr.

A.1 Sampling System Control: Error

The 'Error' status is displayed if one of the parameters required to continue along the logic tree failed. All valves will been shut by SAM.c

1. Close all SAM valves.
2. Set all sampling system update period values to 60 seconds.
3. Display the appropriate error in "Sampling System Master Error" text box.
4. Display "Error" in "Sampling System Status" text box.

A.2 Sampling System Control: Idle

When this value is selected the sampling system logic does nothing.

A.3 Sampling System Control: PreSample

1. NewSetValue=1;
2. Check if port is selected and SAM_P_Min is between 100 and 2000. If not then print Error: no port selected.
3. Check RGA filament is on. If not turn it on.
4. Check N2PP,O2PP and PT-SAM1 $<$ 1e-7 and timestamp is $<$ 5min. If not then Error-poor vacuum.
5. Close all valves. Open SAM V7. Check status. If valve status not confirmed then Error-valve failure.
6. Check SAM CM gauge reads $<$10 torr. If not Error: pumpout error.
7. Turn off CCG 2 to protect it and make sure Turbo 2 is spun up.
8. Open SAM V1 and V2 to conduct brief pumpout.
9. sleep 60 seconds for pump-out.
10. Turn on CCG2 and wait for it to read $<$ 5e-6 torr. While doing this check that CM gauge remains $<$ 5torr. If not Error: pumpout error.
11. If CCG2 reads $>$ 5e-6 torr after 10 min, Error: pump out error.
12. Close V7 and open V3, then sleep 60 seconds while pressure levels off.
13. Check N2PP,O2PP and PT-SAM1 $<$ 1e-7 and timestamp is $<$ 5min. If not then Error-poor vacuum.

14. Close all SAM valves.
15. Choose which valve if any to open to draw sample (call this the sample-valve).
16. Open V7.
17. If sample port allows for automatic sampling, cycle open/closed sample-valve until SAM CM gauge > SAM_P_Min, up to maximum 6 tries.
18. Close all SAM valves.
19. Display “RaiseLN” in SAM_wait until SAM TC1 and TC2 read < 80 Kelvin.
20. If OK then display “Presample Complete” in Analysis_status.
21. If sample was drawn, display “Begin Analysis” in SAM_wait, otherwise display “Draw Sample Now”.

A.4 Sampling System Control: Analyze&Dump/Analyze&Recover/Calibrate

Note: the option of “Calibrate” is identical to “Analyze&Dump”, except purity values will not be calculated and written to the slow control table.

1. Analyze and dump the sample when new_set_val == 2. Analyze and wait for the user to recover the sample to the SRV when new_set_val == 3. Run Calibration when new_set_val==4.
2. Disply “RaiseLN” in SAM_wait until SAM TC1 and TC2 read < 80 Kelvin.
3. Open SAM V3 and V7.
4. Check TP1 current >0.2 Amp and <1.0 Amp //Turbo pump on?
5. Check RGA on
6. Check N2&O2&PT-SAM1 <1e-7 //no air leak, plumbing is sufficiently clean. If not then Error-poor vacuum.
7. Check P3>400 Torr. // Sufficient pressure for a xenon sample. If not then Error-low sample pressure
8. Assign a dummy variable to the initial pressure, check that after sampling the value has decreased
9. Check V1,V2,V4,V5,V6 are closed & V3 open. If not then stop! Error-valve failure.
10. Check TC1&TC2 < 85 K //make sure the cold trap is immersed in LN. If not then Error-low LN.
11. Open V4 // to form ice
12. Check V4 is open? If not then Error-valve failure.
13. Check XePP, N2PP, O2PP and PT-SAM1 over pressure condition every 1 min. If overpressure then close V4 and display Error-Dirty Xe.
14. wait 5 min
15. Close V4
16. Ensure V4 is closed. If not then Error-valve failure.
17. wait 5 min

18. Check Xe PP before moving on
19. Check that V4, V5, V6, V1, V2 are still closed! & V3 is open. If not then Error-valve.
20. Open V5 // for first measurement
21. Check V5 is open? If not then Error-valve failure.
22. wait 3 min
23. Check XePP, N2PP, O2PP and PT-SAM1 every 1 min. If overpressure then close V4 and display Error-Dirty Xe.
24. Close V5
25. Ensure V5 is closed. If not then Error-valve failure.
26. wait 5 min, In the last 3 min define RGA backgrounds
27. Check that the pressure remaining in the sampling system is less than it was before flowing. If not then shut all valves! Error-input pressure did not decline.
28. Check TC gauge < 85 K
29. Open V6 // for high flow measurement
30. Check V6 is open? If not then Error-valve failure.
31. wait 5 min. Average the values of N2, O2, He, Ar, Kr, CH4 and Flow for the first 3 minutes // will be used to calculate purity
32. Check XePP, N2PP, O2PP, and PT-SAM1 every 1 min. If overpressure then close V4 and display Error-Dirty Xe.
33. Close V6
34. Ensure V6 is closed. If not then Error-valve failure.
35. wait 5 min, In the last 3 min define new backgrounds
36. Close V3.
37. Check V3 closed? If not then Error-valve failure.
38. Measurement is done
39. Run Function to write purity values to a table. Either a Calibration(new_set_val==4) or Sample Analysis(new_set_val==2——3). // First calculate the background subtracted leak rate normalized values then divide by the latest calibration.
40. Begin Clean Up.
41. Check TC1 & TC2 > 260 K //LN has evaporated? If not then wait. The value of "Sampling System Status" will change to "DropLN" and will remain there until the cold trap has sufficiently warmed.
42. Check V1, V2, V3, V4, V5, V6 are closed. If not then close.
43. Open V4, V5, V6 and Check status. If not then Error-valve failure.

44. Check PT-SAM2 Pressure >100 Torr. If not then wait.
45. At this point the logic will only continue if either “Analyze&Dump” or “Calibrate” was chosen as the initial condition. If “Analyze&Recover” was chosen then SAM will display “Ready to Recover to the SRV” once the system is ready for manual SRV recovery.
46. Check that SAM Turbo Pump 2 is off (if not, turn off and wait 10 min)
47. Check V3 is closed
48. Open V1 and V2, Check status // This will begin to evacuate the coldtrap and sampling volume
49. Wait until PT-SAM2 is < 5 Torr
50. Turn on SAM Turbo Pump 2
51. wait 5 min, then turn on PT-SAM3 (vacuum gauge of TP2) (Keep repeating until the CCG turns on)
52. wait until PT-SAM3 < 1e-6 Torr then Open V3 (check V3) // This will expose the RGA to all of the plumbing
53. Close V2 (and check) //This will isolate TP2 from the sampling system. If not then Error-valve failure.
54. Turn off TP2 and check.
55. clean up complete (The sampling system should be being pumped to vacuum by TP1)

A.5 Sampling System Control: Pump Out

1. NewSetValue=5;
2. Check TC1 & TC2 > 260 K //LN has evaporated? If not then wait. The value of “Sampling System Status” will change to “DropLN” and will remain there until the cold trap has sufficiently warmed.
3. Check all SAM valves are closed. If not then close.
4. Open V1, V4, V5, V6, V7 and Check status. If not then Error-valve failure.
5. Check that SAM Turbo Pump 2 is off (if not, turn off and wait 10 min)
6. Check V3 is closed
7. Open V2, Check status // This will begin to evacuate the coldtrap and sampling volume
8. Wait until PT-SAM2 is < 5 Torr
9. Turn on SAM Turbo Pump 2
10. wait 5 min, then turn on PT-SAM3 (CCG of TP2) (Keep repeating until the CCG turns on)
11. wait until PT-SAM3 < 1e-6 Torr then close V7 and open V3 (check V7 and V3) // This will expose the RGA to all of the plumbing
12. clean up complete (The sampling system should be being pumped to vacuum by TP1)

A.6 Sampling System Control: Recover

1. NewSetVal=6;
2. Check TC1 > 270 K //LN has evaporated? If not then wait. The value of "Sampling System Status" will change to "DropLN" and will remain there until the cold trap has sufficiently warmed.
3. Check that there is sufficient pressure to recover (> 20 torr). If not, do nothing.
4. Close all SAM valves.
5. Open V1, V4, V5, V6, V7, & V9
6. Display "Open CV89" until PT_SAM2 reads < 20 torr for up to 15 minutes. If pressure does not reach ¡20 torr in this time, Error: No Pressure Drop.
7. Close all SAM vales
8. If Okay, display "Begin Pumpout" in SAM_wait and "Idle" in Analysis_status.

A.7 Sampling System Control: Ready to Analyze

Note: This option is used to begin an analysis without going through "Presample", or if SAM was unable to automatically draw a sample.

1. NewSetVal=7;
2. Check if port is selected and SAM_P_Min is between 100 and 2000. If not then print Error: no port selected.
3. If sample port is SRV or xenon bottles, cycle open/closed sample-valve until SAM CM gauge > SAM_P_Min, up to maximum 6 tries.
4. Close all SAM valves.
5. Display "Presample Complete" in Analysis_status.
6. Display "Begin Analysis" in SAM_wait.

B Collecting a Xenon Sample From the LUX System with a 0.5 L Sampling Bottle

This procedure is for sampling xenon from the LUX xenon system. A sample bottle is attached to a pump-out port of the xenon system, a slug of air will be pumped out via a turbo pumping cart, and then the sample bottle is filled with xenon from the system, and removed. Because the sampling procedure is exactly the same for each of the six locations, we will henceforth refer to the valves in each sampling location as VB (the valve closest to the sampling port) and VA (the valve immediately after VB). Additionally, we will refer to the pressure transducer nearest the sampling port as PT-A. The valves and pressure transducer corresponding to each sampling location are summarized in Table 1.

Note: Refer to Table 1 for valves VA, VB and VC as they depend on the location you will be collecting a sample from.

1. Find a green all-metal valve (AMV). There is a dedicated valve (SS-4UW-V51) for the Turbo-Pump cart. Find a 1/4" VCR bellows. Also find a 1/4" all-male VCR Tee and 1/4" gaskets. Prepare a portable pump cart.

2. Monitor and ensure the stability of the pressure gauge of interest (see Table 1). Ensure that the pressure is stable to within 1 psig for one minute, if not contact the shift maneger.

3. Confirm that the sampling valves of interest (VA, VB and VC) are closed.

4. Remove the lock and cap from VB. Note: Make sure the sampling valve, or at least the hose connecting to it, is securely restrained. If it is not, you may inadvertently loosen a VCR connection and open a major leak directly to the xenon system.

5. Set up the sampling plumbing according to Figure 8 and Figure 9.

   1. Attach the 1/4" VCR bellows to the sampling valve
   2. Attach the VCR Tee to VB.
   3. Attach the AMV to one end of the Tee.
   4. Open the AMV.
   5. Attach the 0.5 L sample-bottle to the other end of the Tee.
   6. Attach the pump station to the free end of the AMV. Note: Strain relieve any hoses you use so you avoid torquing any of the VCR connections.

6. Confirm VA, VB and VC are closed.

7. With the scroll-pump on the pumping cart, pump up to the sampling valve and the sample bottle.

8. Open the valve on the sample bottle (BV) to pump out the bottle.

9. After the pressure on PT-PC1 reaches 1e-1 Torr open VB and pump it with the scroll-pump until the PT-PC1 is below 1e-1 Torr (to pump out the space between VA, VB and VC).

10. Ensure that PT-PC1 is less than 1e-1 Torr then start the turbo-pump.

11. Once the pressure gauge on PT-PC1 reaches 1e-5Torr(it's minimum value), helium leak check the new connections using the RGA on the turbo-cart.

12. Turn off the RGA's filament once the leak checking is complete.

13. Pump on the plumbing for 1 hour. PT-PC1 only reads down to 1e-5Torr, so the ultimate pressure reached will not be known.

14. When done pumping, close the AMV. This will isolate the turbo from the sample volume.

15. Continue to monitor the pressure in the region to be sampled (PT-C15 if sampling the getter input, PT-C20 if sampling the getter output, PT-C1 if sampling the detector return line, PTD41 if sampling the PMT purge line). Insure that the pressure is stable to within 1 psig.

16. Record the pressure, before sampling, from the pressure gauge in the region which was sampled. PT-C15 if sampling the getter input, PT-C20 if sampling the getter output, PT-C1 if sampling the detector return line, PTD41 if sampling the PMT purge line.

17. Open VA(see Table 1) to fill the 0.5 L sample bottle with xenon from the LUX system. After 5 seconds the bottle should be full and at system pressure. The sample bottle volume is small enough so that taking a sample should not impact the system pressure. If desired, crack VA open a bit until PT-SAM2 reaches 700 Torr. Drawing 700 Torr if sufficient for purity analysis.

18. Close VA, VB and VC.

19. Close, cover and tag VA
20. Record the pressure, after sampling, from the pressure gauge in the region which was sampled. PT-C15 if sampling the getter input, PT-C20 if sampling the getter output, PT-C1 if sampling the detector return line, PTD41 if sampling the PMT purge line.
21. Close the sample-bottle's valve (BV).
22. The next step will vent the Tee, so it is crucial that the sampling valve, the sample bottle, and the AMV are closed.
23. Disconnect the sample bottle from the Tee.
24. Remove the sampling manifold from the sampling valve.
25. Cap VB and label that air is behind the cap.
26. Label the sampling bottle with the date, pressure and sample location.

C How to Analyze the Data

C.1 Overview

The principle of the RGA/coldtrap method is simple. The partial pressures of O2, N2, Ar, and Kr observed by the RGA are proportional to two things: the leak rate into the cold trap, and the concentration of the impurity species in the xenon. Therefore we can measure the partial pressure, account for the leak rate, and infer the impurity concentration. The proportionality constant can be measured using the calibration xenon bottle, which is known to contain 1 ppm of O2. (The O2 concentration in the calibration bottle is known because we prepared the gas using a known volume and pressure of O2 and a known amount of xenon.)

Several other factors can also affect the partial pressure reading on the RGA: the conductance of the plumbing between the leak valve and the RGA, the speed of the turbo pump, the response and gain of the RGA, and non-ideal effects such as RGA saturation. However these factors are all mitigated and accounted for as follows: The conductance and pumping speed are expected to be the same from measurement to measurement, and the RGA response and gain can be monitored using the calibration xenon. Saturation can be avoided by following the procedures carefully and by monitoring the total pressure seen by the RGA, as read by the PT- multi-purpose vacuum gauge.

If an identical and constant leak rate is used in every measurement, then the impurity partial pressure reading is directly proportional to the impurity concentration. At UMD we typically collect data in this mode. However, in the LUX coldtrap system, the pressure at the input to the leak valve decreases exponentially during the five-minute measurement period, because a finite amount of gas is contained in the sample bottle. This means that the leak rate and RGA partial pressure measurements also decrease exponentially, and we must account for this time-dependence in the data analysis.

C.2 Measuring the dynamic leak rate

We infer the leak rate by measuring the amount of gas remaining in the sample bottle as a function of time with PT-SAM2. The amount of gas is given by the pressure times the volume, and is measured in units of torr*liters. The leak rate is then the time derivative of this function, and is given in units of torr*liters/minute.

The leak rate which will be obtained in any given experiment is determined by two factors: the leak valve setting and the input pressure. By default, we always use a leak valve setting of 1 turn + 28 ticks. The input pressure may vary from measurement to measurement, depending on the pressure in the LUX xenon system.

Calibration data shows how the leak rate depends in the initial pressure. (Note that if a non-standard leak valve setting is used by accident, the data can still be used, as long as the Baratron data is recorded so that we can calculate the leak rate which was obtained.)

C.3 Accounting for the dynamic leak rate

To account for the changing leak rate, we divide the RGA partial-pressure data by the dynamic leak rate as a function of time. Unfortunately, the RGA measurement and the Baratron measurement are not synchronous, because the Baratron(PT-SAM2) is sampled by the LUX slow control system, while the RGA is not. This means that an exponential function should be fit to the Baratron data, and the derivative of this function can then be used to normalize the RGA data. Fortunately, the exponential form of the Baratron(PT-SAM2) data can, in most cases, be determined simply from the initial input pressure, because we have measured the dynamic leak rates for a variety of initial input pressures at the standard leak valve setting. (Note that in order to do the normalization properly, it is important that the two datasets have accurate time stamps which can be compared to each other).

The RGA partial pressure divided by the leak rate should be independent of time, and this ratio is proportional to the impurity concentration in the xenon. In practice, however, it takes two minutes for the partial pressure data to stabilize, after which a constant plateau value is reached. Therefore we use the plateau value to infer the impurity concentration.

Ideally the plateau value would be completely independent of the initial input pressure, once the leak rate normalization has been done. In practice, we find a small linear dependence of the plateau value on the initial input pressure. The reason for this remaining correlation is not known. We can either account for this dependence by comparing to the calibration data, or we can assign a modest systematic error to the final measurement.

C.4 Peak pressure method

A second, simpler technique can be used to quickly eyeball the purity measurement directly from the RGA data. In this method, the peak value of the RGA partial pressure data is used to infer the purity measurement. This method is probably accurate only to a factor of two or three, but it gives a reasonable estimate of the order-of-magnitude of the xenon purity.

D Figures

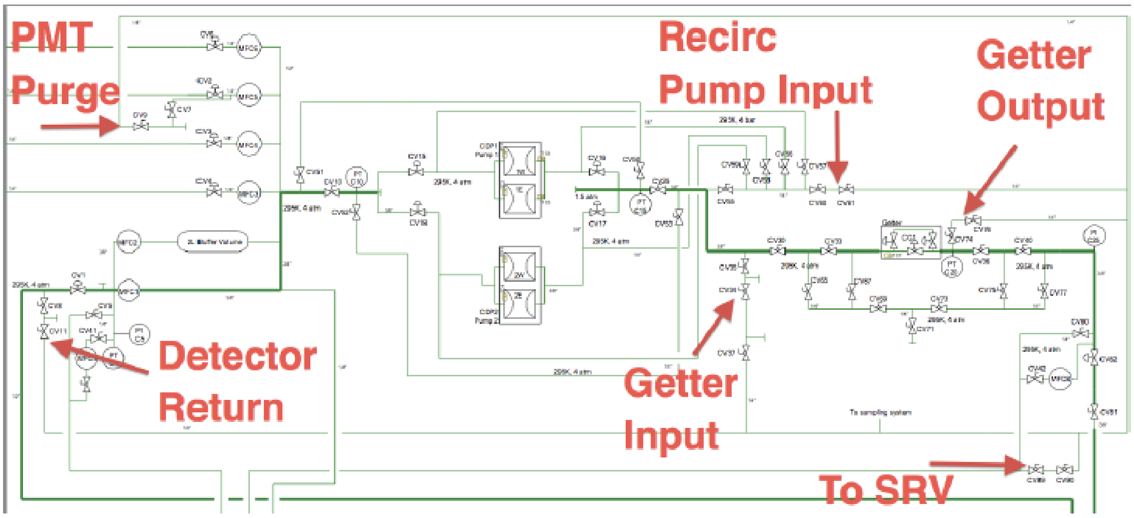

Figure 1: Sampling Locations

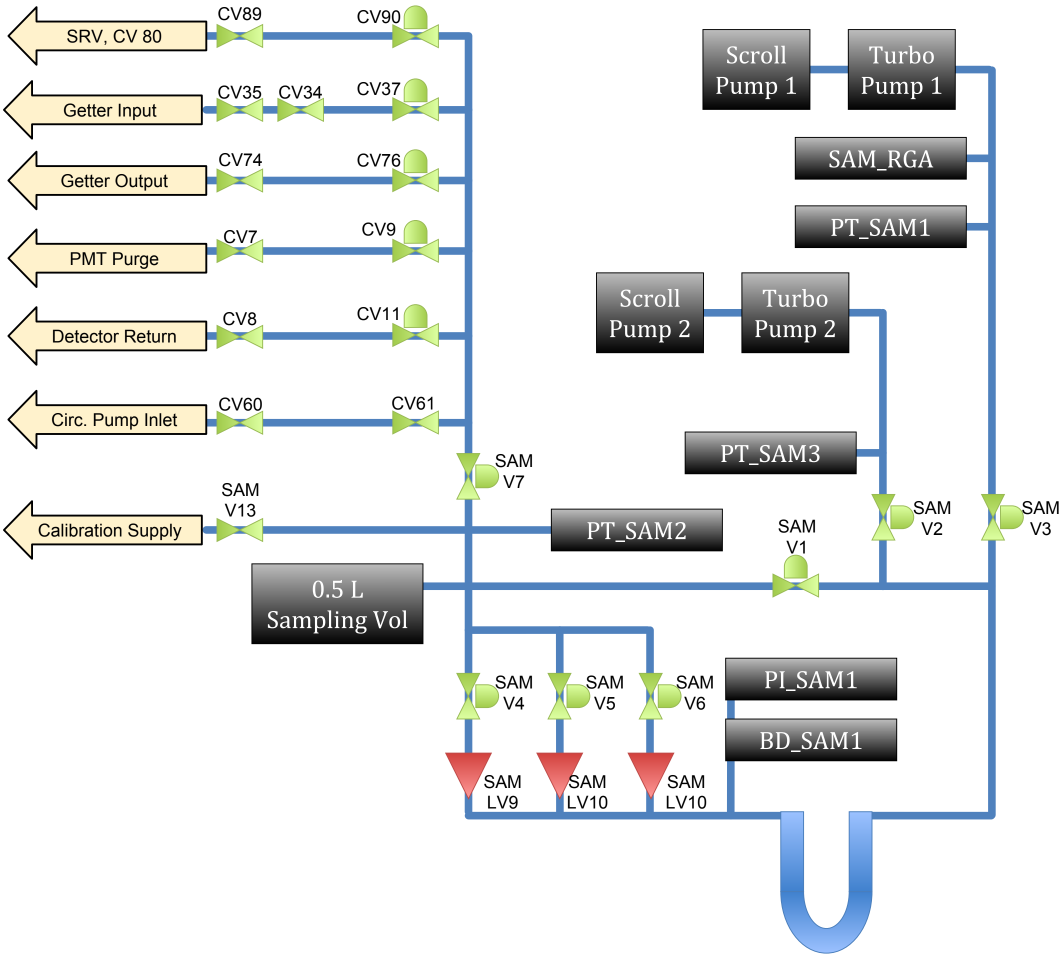

Figure 2: Diagram of the Coldtrap Sampling System

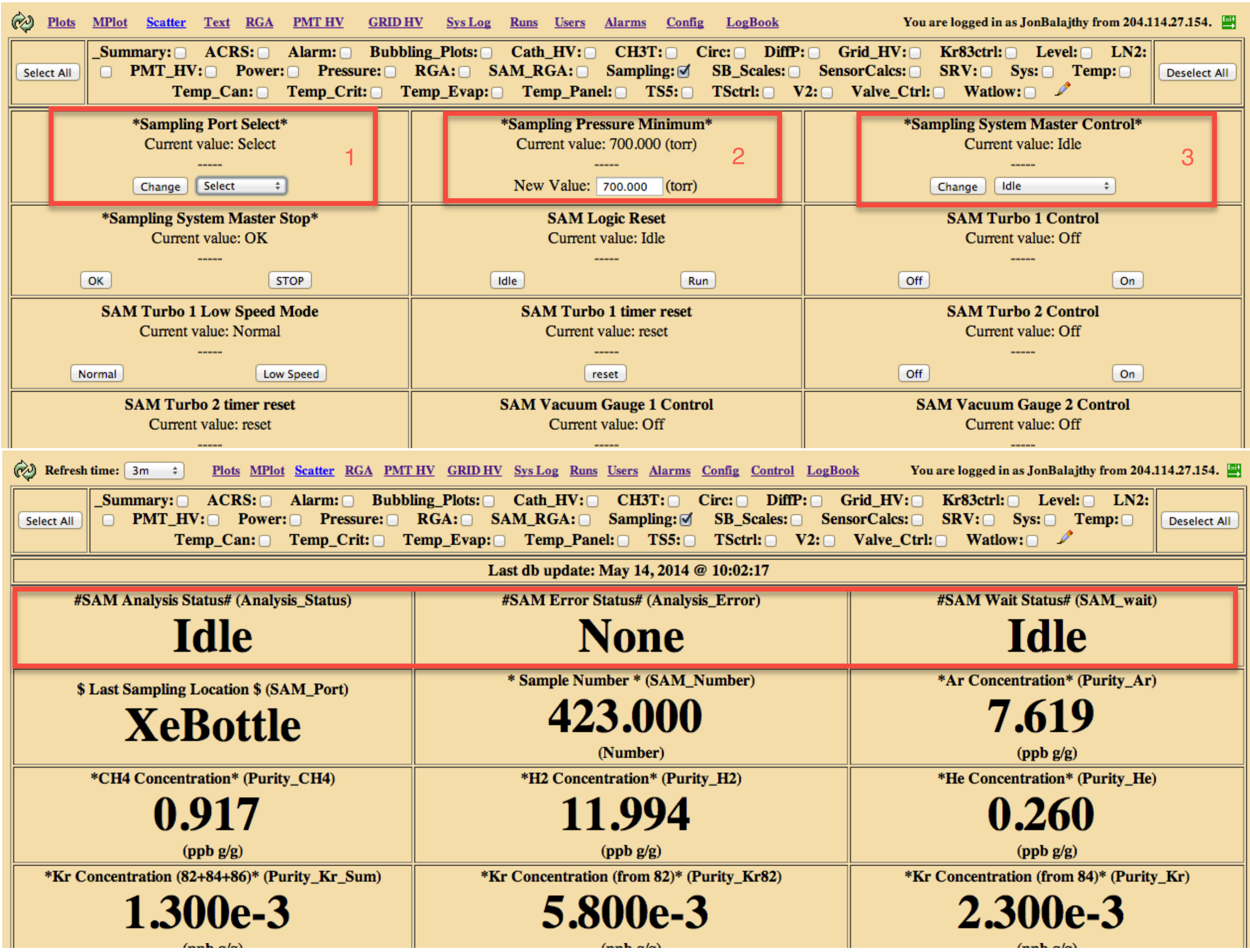

Figure 3: Top: The Sampling System Master Control box in LUX slow control. Bottom: The Sampling System status display in LUX slow control

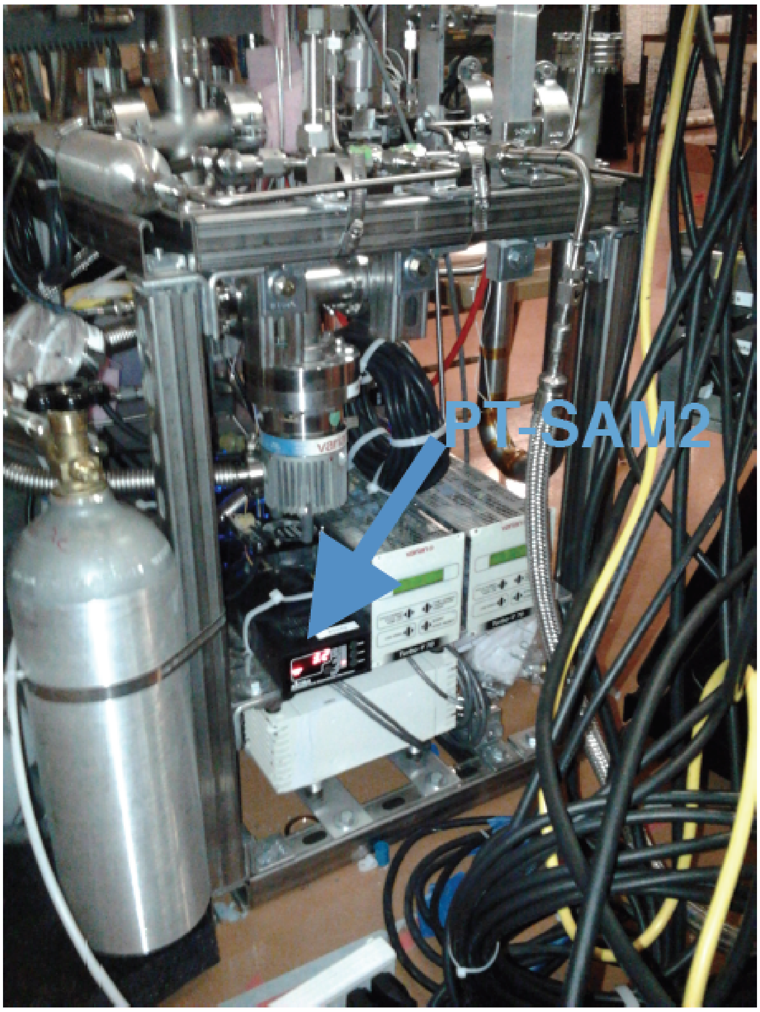

Figure 4: The view of the sampling system from behind the circulation panel, where the xenon samples will be drawn. The user should watch PT-SAM2 when drawing a xenon sample.

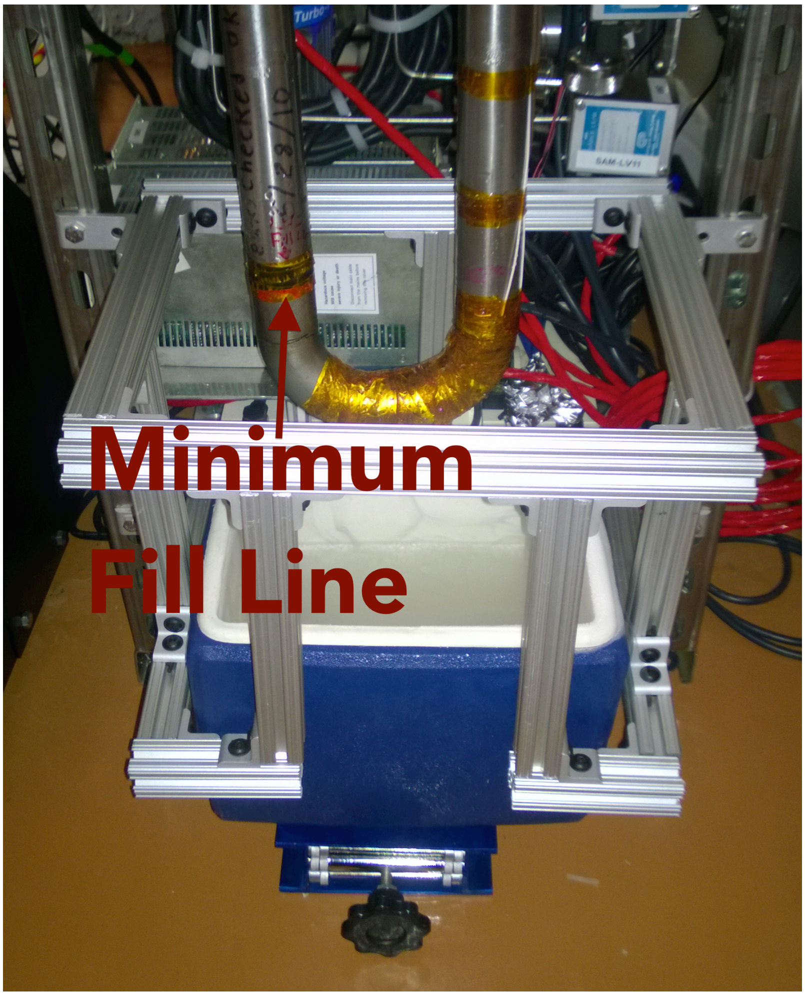

Figure 5: Minimum fill line on cold trap “U”

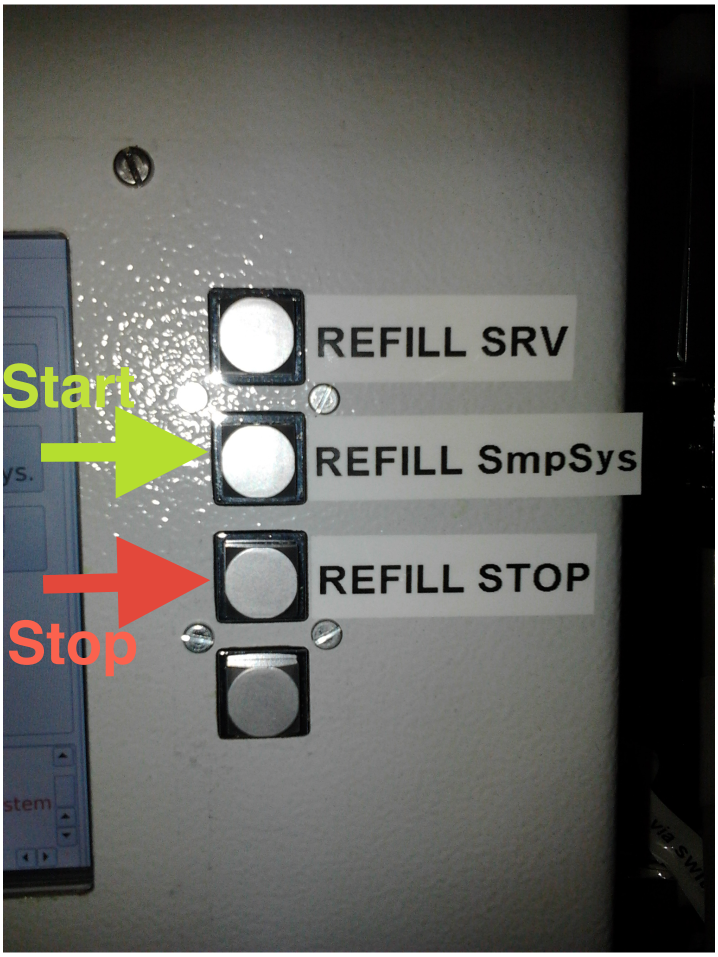

Figure 6: SRV LN system control box. To fill the 4 L transfer dewar push "Refill SmsSys" to begin the flow of LN through the SRV pre-cool line. Once the dewar is full hit the "Refill STOP" button.

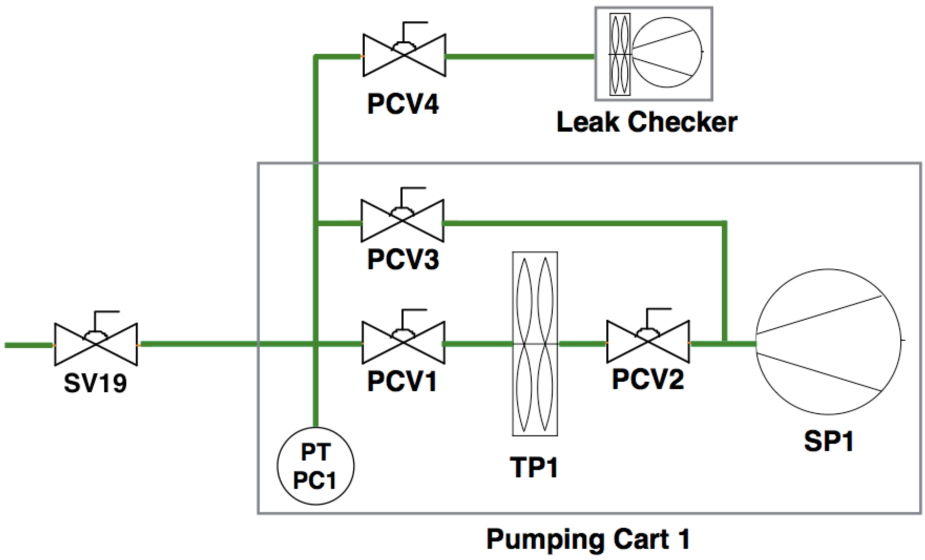

Figure 7: Diagram of the turbo pumping cart to be used when sampling LUX storage bottles in the bottle farm via SV19.

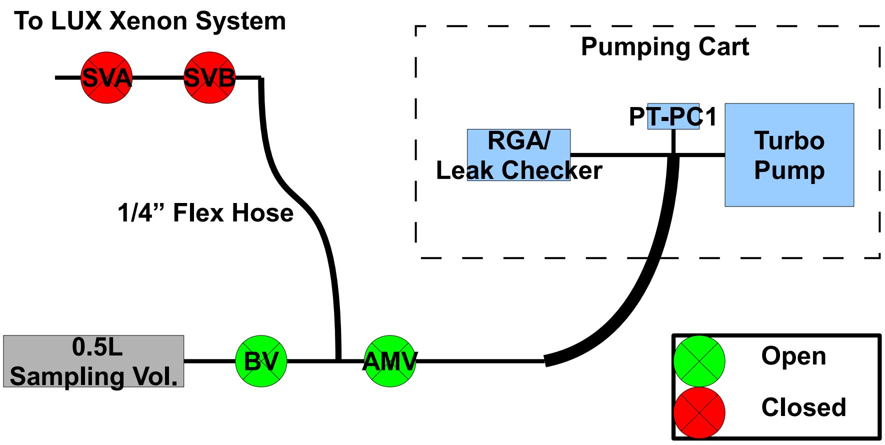

Figure 8: Illustrated procedure for attaching the sampling manifold to the LUX xenon system

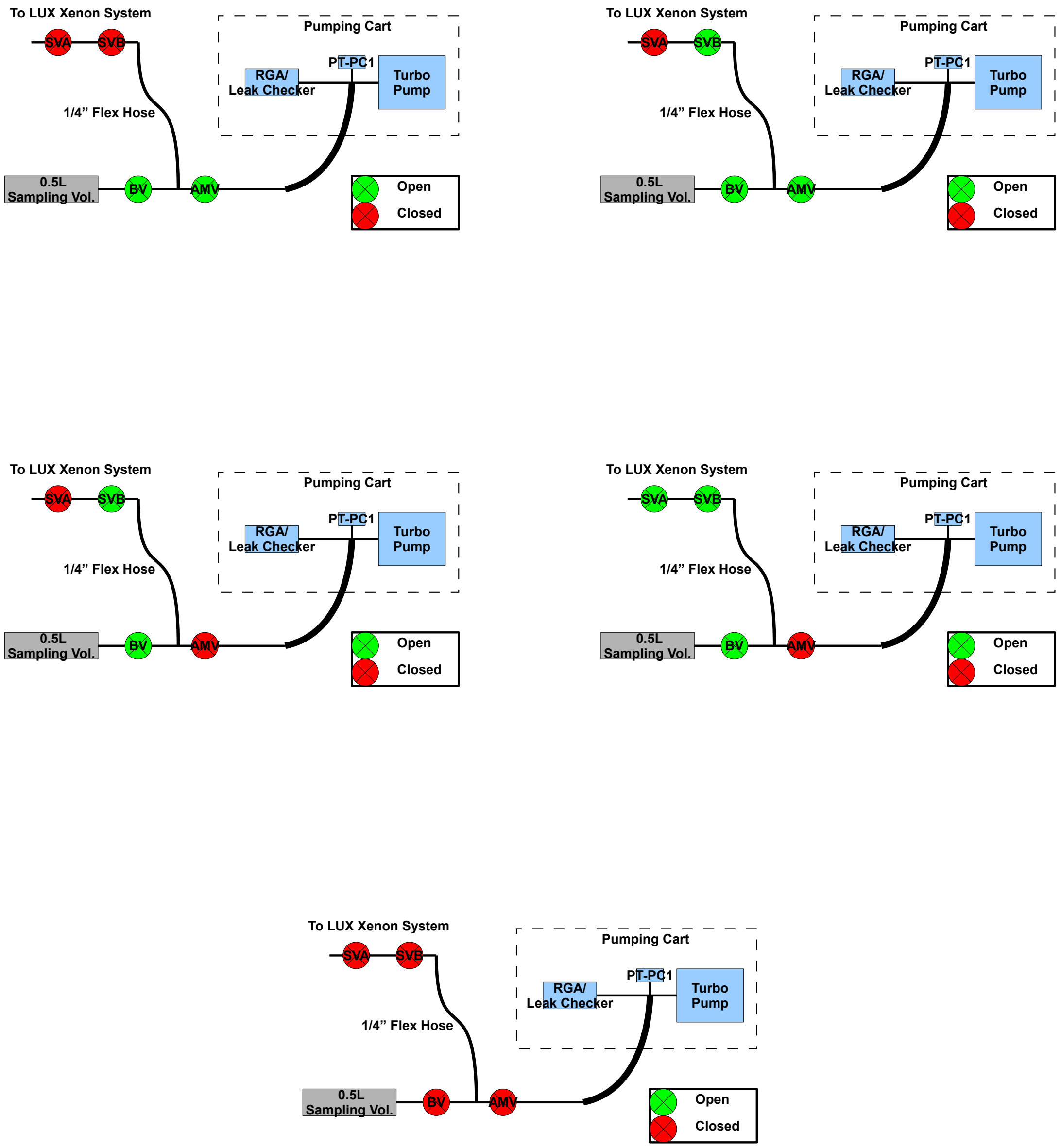

Figure 9: Illustrated procedure for filling the sample bottle. First(top left), the sampling plumbing is attached to VB and then pumped to vacuum with the scroll-pump on the pumping cart. Second(top right), once the pressure on PT-PC1 reaches less than 0.1Torr VB is opened. The plumbing up to VA is then pumped to vacuum with the turbo-pump for one hour. Third(middle left), after pumping to vacuum for one hour the turbo-pump cart is isolated by closing AMV. Fourth(middle right), VA is opened filling the 0.5 L sample bottle with xenon at system pressure. Fifth(bottom), the VA, VB and the sample-bottle's valve (BV) are closed.