The SOLID Heavy Gas Cerenkov C4F10 Gas System

Introduction

The Hall A SOLID Heavy Gas Cerenkov uses C4F10 as the radiator gas. The detector operates at 1.5 atm. pressure or about 7 psi. Each of the two detector volumes is approximately 10,000 liters in volume and will contain approximately 150 Kg of C4F10 gas.

Gas loss during system operation will be due to leaks only. This detector is referred to as a “Fill & Seal” detector. Ambient pressure changes are too small to have any effect on detector volume pressure of 1.5 atmosphere. It is critical that the detector volume and gas system be as leak tight as possible to minimize operational cost. The design of this system permits us to determine the gas leak rate over time with great accuracy.

The gas system design permits recovery of the gas from the detector volumes prior to maintenance. The C4F10 gas is transferred to a holding tank and stored for later distillation.

C4F10 gas has no industrial use and is considered an Ozone Depleting Chemical by the EPA. Currently, there is no stock of C4F10 gas available for purchase, the gas must be manufactured to order. The Oct 2018 price quote was $260 USD per Kg. Each of the two detector volumes will contain $40,000 cost of C4F10 gas. The high cost and long lead times, 6-12 months, to procure this gas must be considered during the early planning stages for an experiment.

Gas System Functions

The gas system performs three main functions

1) Gas volume Purge and Fill

2) Detector gas volume Recovery and Storage

3) Maintain Pressure of 1.5 atm in detector gas volume

Gas System Design Concepts

This gas system is designed for the detector radiator gas, C4F10, which has a density 10X that of air or N2. C4F10 density is 1/10th that of water. As a result of this density difference, C4F10 gas does not readily mix with air or N2. C4F10 displaces the air or N2 as it fills the volume. This process is most efficient at minimal pressure and gas flow velocity.

There are competing issues with the C4F10 fill. The minimal filling pressure achievable is slightly above atmospheric pressure due to the back pressure of the vent bubbler. The vent bubbler acts as a low pressure check valve and a visual indication of flow. The minimum flow rate achievable with the MFC is 100 sccm per minute, but at that rate, it would take nearly 70 days to fill the detector volume. Alternatively, a flow rate of 1000sccm will fill the detector in ~7 days.

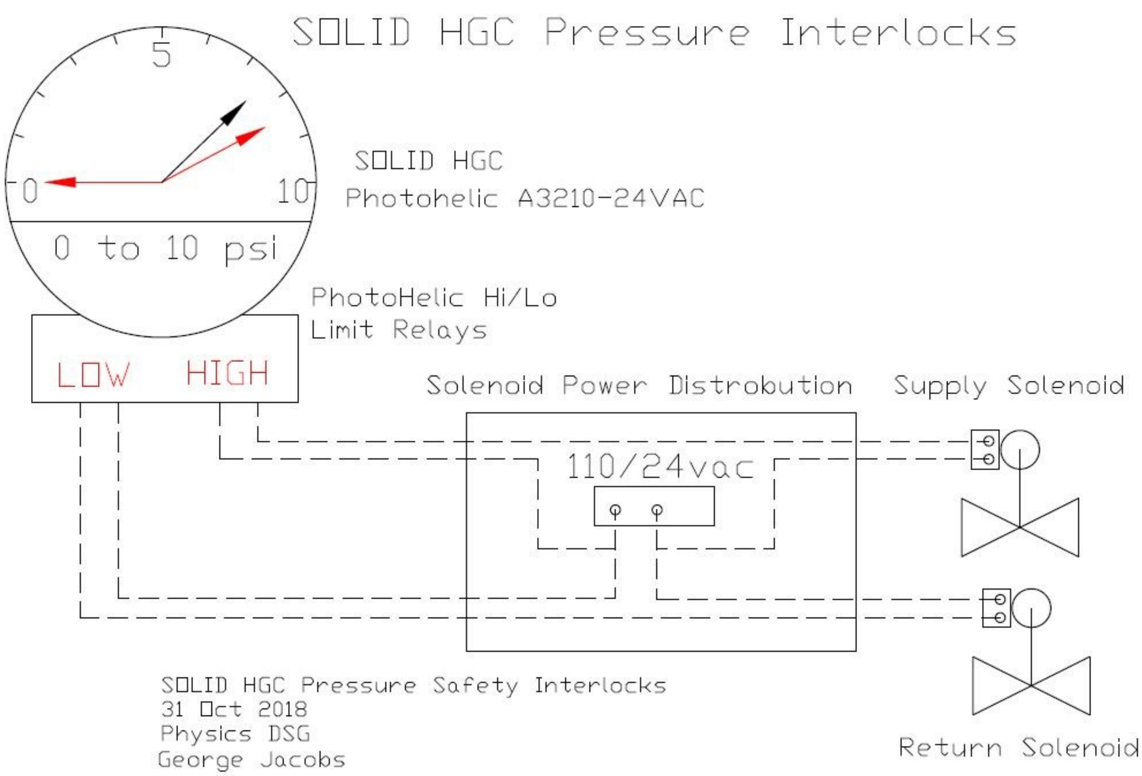
N2 displacement by C4F10 gas due to the 10X density difference is not 100% efficient. Diffusion is a factor. In order to maximize the separation of the C4F10 from the N2, a vertical separation column must be employed. There are 3 main factors in designing this column, height, path length, and the velocity of the gas flowing in the column. Gas velocity is minimized by using a larger diameter tube. The column height is the vertical distance between the detector outlet and the vent bubbler. The path length of the column can be increased, providing more time for the C4F10 gas to separate from the N2.

The detector operational pressure of 1.5 atm is high enough that even severe changes in atmospheric pressure, ~0.08 atm, have no effect on system operation. Temperature changes, however, may have a significantly effect on detector volume pressure depending on the magnitude of the change.

Gas System Operation – Under Pressure and Overpressure Safety Features

The detector gas volume must be protected from any overpressure or under pressure condition to prevent damage. Each detector volume is protected from an overpressure condition by a relief valve. This relief valve is adjustable and of the proportional type and will begin releasing gas at the setpoint of 12psi. This is the system passive overpressure pressure protection.

In addition to the relief valve, the system also uses an independent active overpressure and under pressure safety system. This system operates to prevent an overpressure or under pressure condition by isolating the source of the problem.



The pressure in each detector volume is monitored by a PHOTOHELIC pressure gauge with high and low limit pressure switches. When the detector pressure exceeds the high limit setpoint, a solenoid valve de-energizes and closes to isolate the gas supply from the detector. When the detector pressure reaches the low limit setpoint, a solenoid valve shuts to isolate the only source of under pressure, the recovery pump from the detector volume. The system safety isolation valves, SV01, SV02, SV03, and SV04, also fail shut on loss of power to isolate the detector volumes from the gas system.

Gas System Operation – Pressure Instrumentation

Signals	Type	Output	Range	Part number
PT1	Absolute	4-20ma	150 psig	Omega PX409-150GI
PT2	Absolute	4-20ma	15 psig	Omega PX409-015GI
PT3	Differential	0-10v	+/- 10 in wc	Ashcroft CX3F0110P1IWL
PT4	Absolute	4-20ma	15 psig	Omega PX409-015GI
PT5	Differential	0-10v	+/- 10 in wc	Ashcroft CX3F0110P1IWL

Gas System Operation – Pressure Control

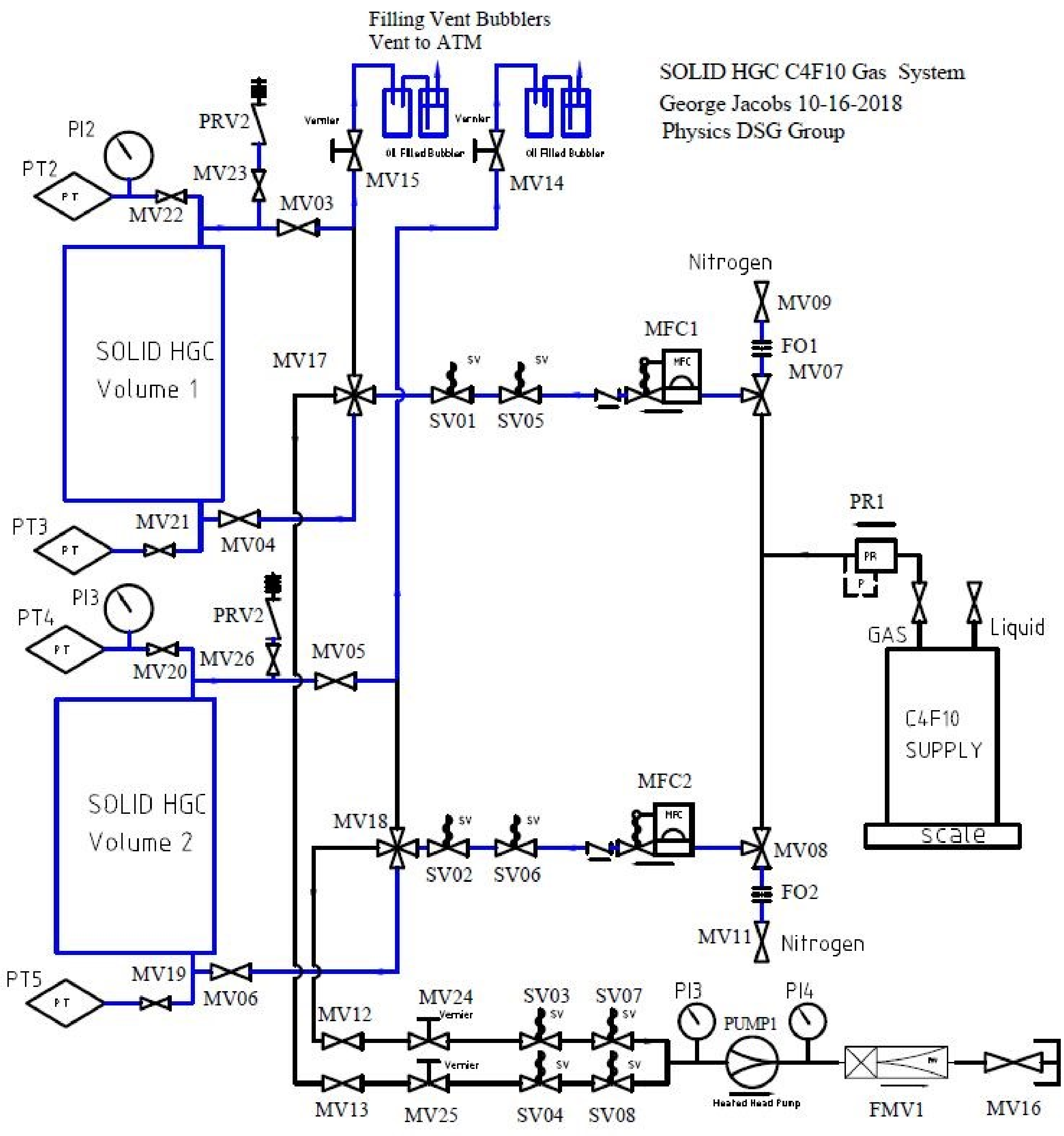
Detector volume pressure is monitored by absolute pressure transducers at the top connections. The outputs of these transducers are used by the cRIo controller to open or close pressure control solenoid valves, SV05, SV06, SV07, and SV08, according to the preprogrammed setpoints. Pressure is controlled within an operating band during fill and normal operation. Gas flow stops at the upper operating band limit and then turns on at the lower pressure limit. Gas will flow at the preprogrammed flow rate until the high pressure setpoint is reached. Once the high pressure setpoint is reached, the solenoid valve will shut, stopping gas flow.

Pressure control during recovery operation prevents system pressure from dropping below atmospheric pressure and triggering the under pressure safety interlock. This setpoint is only slightly higher than the pressure safety setpoint. Gas recovery operation is most efficient when there is minimal mixing of the N2 gas with the C4F10 gas being recovered. In order to minimize mixing, recovery operation is performed with minimal gas flow velocity and minimal pressure.

Pressure Control Mode	HIGH Setpoint	LOW Setpoint
Normal Operation	7.5 psi	7.2 psi
N2 Displacement	0.4 psi (20 torr)	0.2 psi (10 torr)
C4F10 pressurization	7.5 psi	7.2 psi
C4F10 Recovery	0.4 psi (20 torr)	0.2 psi (10 torr)

Gas System Operation – Step 1 – N2 Gas Purge

The first step is to purge the gas system and detector volumes with nitrogen to remove air and moisture. The nitrogen purge gas flows into the detector volume at the lower connection. Gas flow is controlled by a Mass Flow Controller, MFC, which is also used to track the total purge flow. Gas exits the detector volume from the top connection and vents to atmosphere via the oil filled vent bubblers.

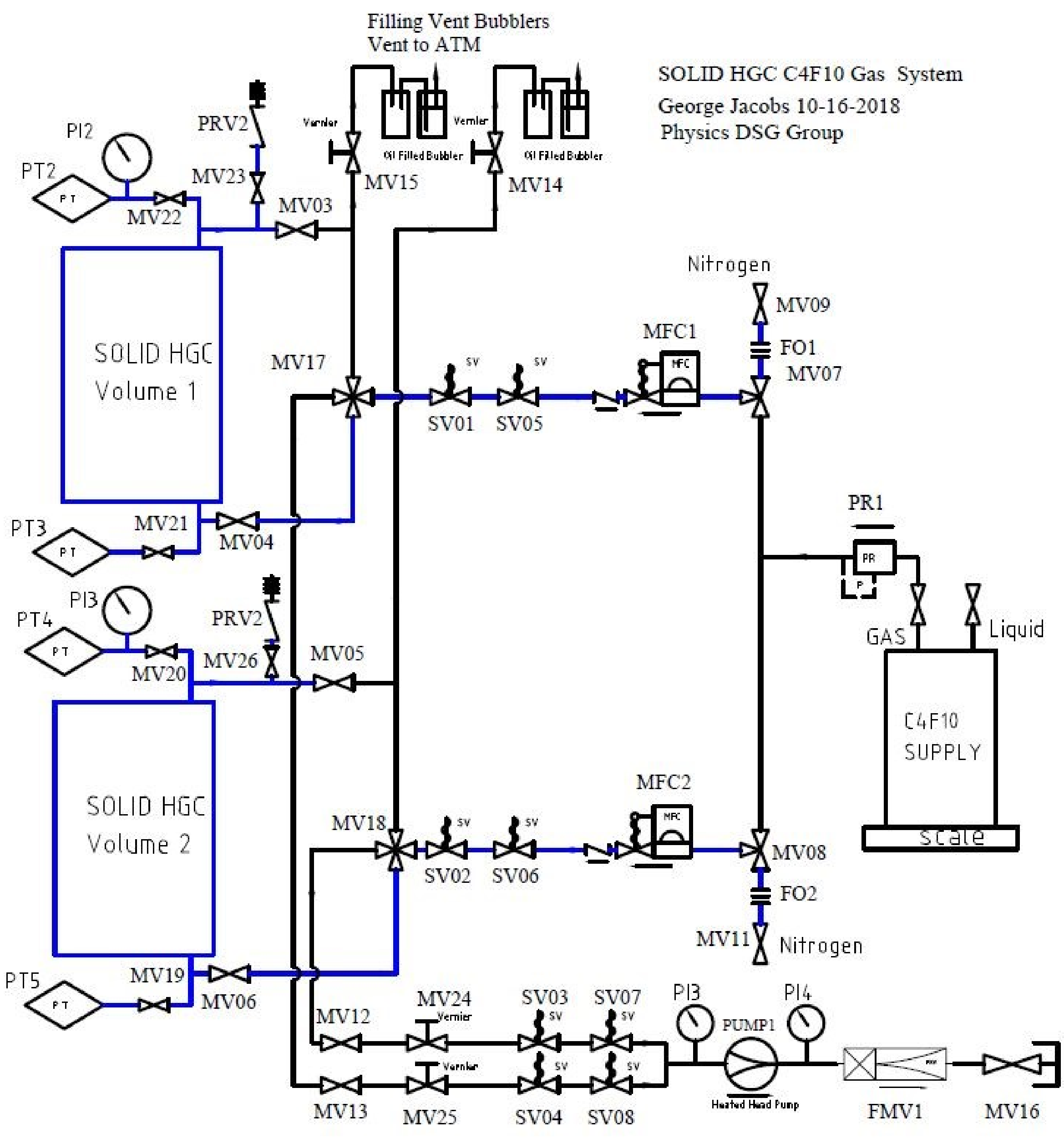


C4F10 Fill Process - Step 1 - Nitrogen Gas Purge

The blue lines in the above diagram represent the nitrogen flow paths.

Gas System Operation - Step 2 –Nitrogen Gas Leak Test

The second step is to pressurize the detector gas volume with nitrogen and determine the leak rate. The detector volume upper isolation valves are shut and the detector pressure is increased to 1.5 atm. Once this pressure is achieved, gas make up flow to maintain pressure will be recorded over time to determine the leak rate. The leak rate must be minimized in order to minimize C4F10 gas loss and operating cost.

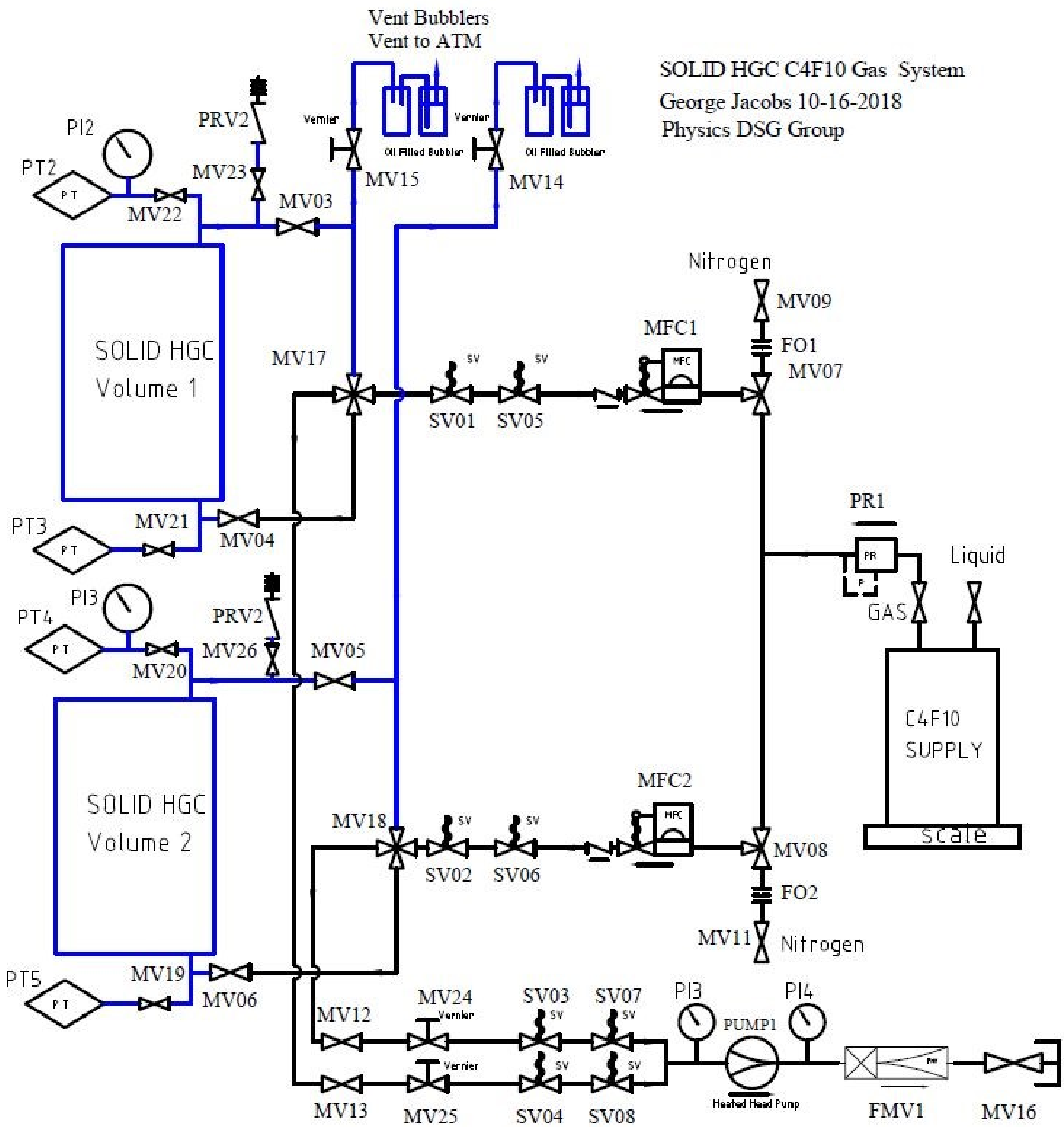


C4F10 Fill Process - Step 2 - Nitrogen Gas Leak Test

The blue lines in the above diagram represent the nitrogen flow paths.

Gas System Operation - Step 3 –Nitrogen Gas Depressurization

Once the detector leak test is complete, the detector volume must be depressurized in a controlled manner. MV14 and MV15 are flow control needle valves. These valves are shut prior to opening the detector volume upper isolation valves, MV03 and MV04. Then the needle valves are used to vent the detector volume in a controlled manner.

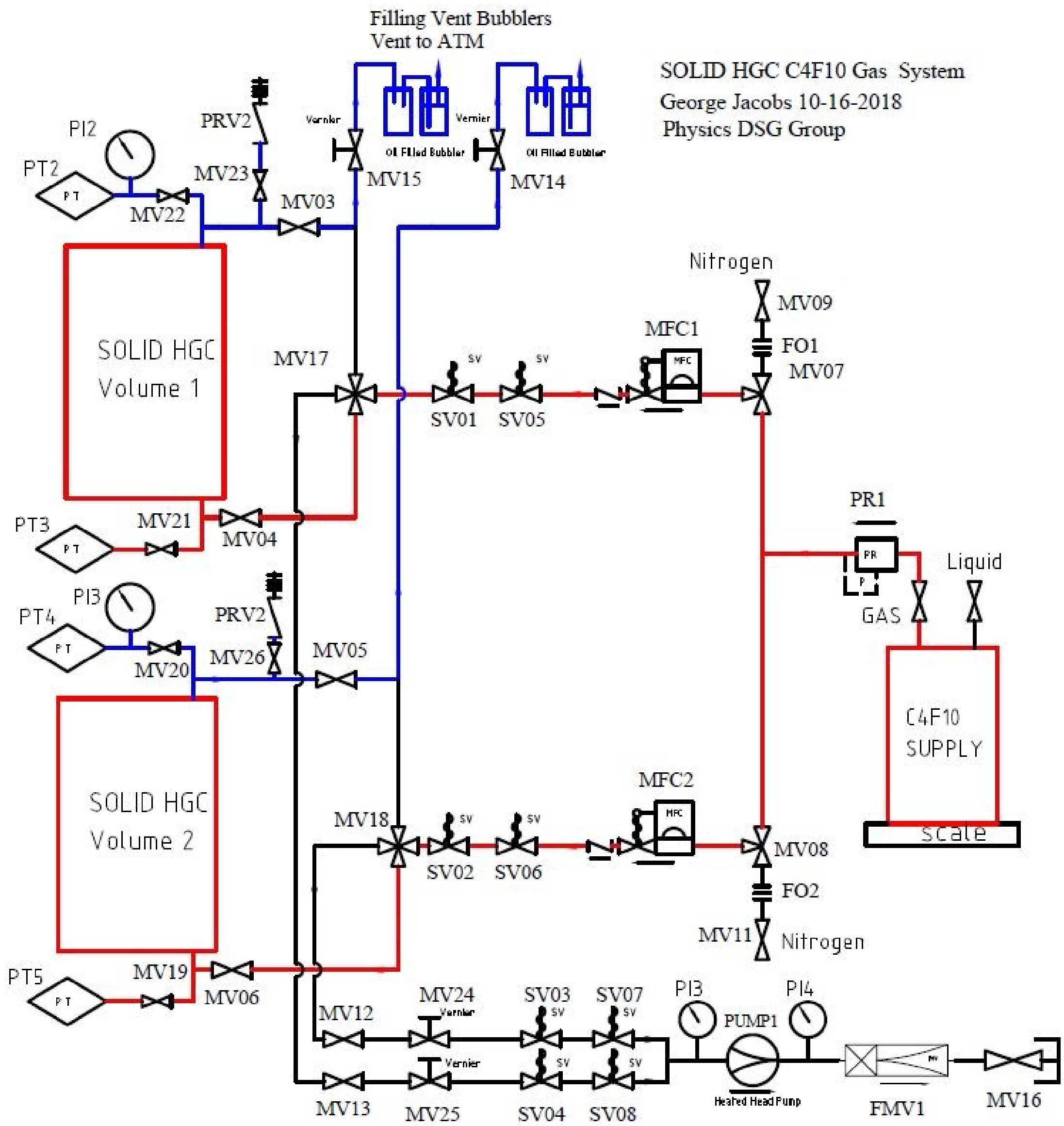


C4F10 Fill Process - Step 3 - Nitrogen Gas Depressurization

The blue lines in the above diagram represent the nitrogen flow paths.

Gas System Operation - Step 4 –Nitrogen Gas Displacement with C4F10

In order to fill the detector volume with C4F10, the nitrogen must be displaced. The most efficient way to complete this task is a slow fill at atmospheric pressure while permitting the remaining nitrogen to vent out via the oil filled bubblers. C4F10 gas flow is set to 1000sccm and controlled by the MFC. The detector will be full in ~ 7 days or ~167 hours. Detector volume fill level is monitored by a differential pressure transducer connected between the top and bottom of the volume. Once the differential pressure stops increasing, the detector is full.

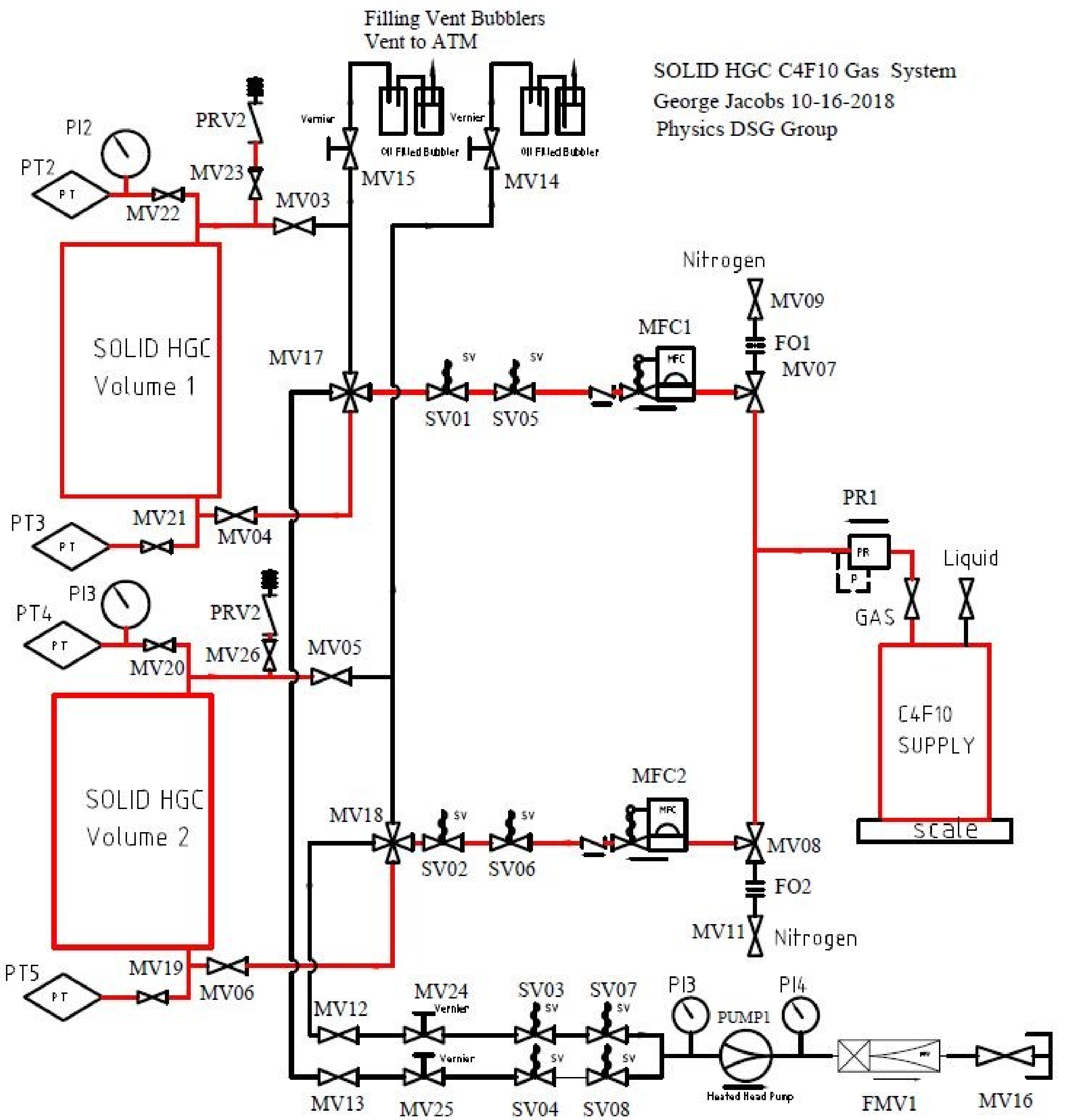


C4F10 Fill Process - Step 4 - Nitrogen Gas Displacement with C4F10

The red lines are C4F10 flow paths. The blue lines are nitrogen flow paths.

Gas System Operation - Step 5 - C4F10 Pressurization and Normal Operation

Once C4F10 gas has displaced the nitrogen in the detector volume, the upper isolation valves, MV03 and MV05, and the flow control valves, MV14 and MV15 are shut. Continued gas flow will now pressurize the detector volume. Once the detector pressure reaches the high limit, C4F10 gas flow will cease when the pressure control solenoid valve shuts. The gas flow setpoint should now be decreased to 150sccm.



C4F10 Fill Process - Step 5 - C4F10 Gas Pressurization and Normal Operation

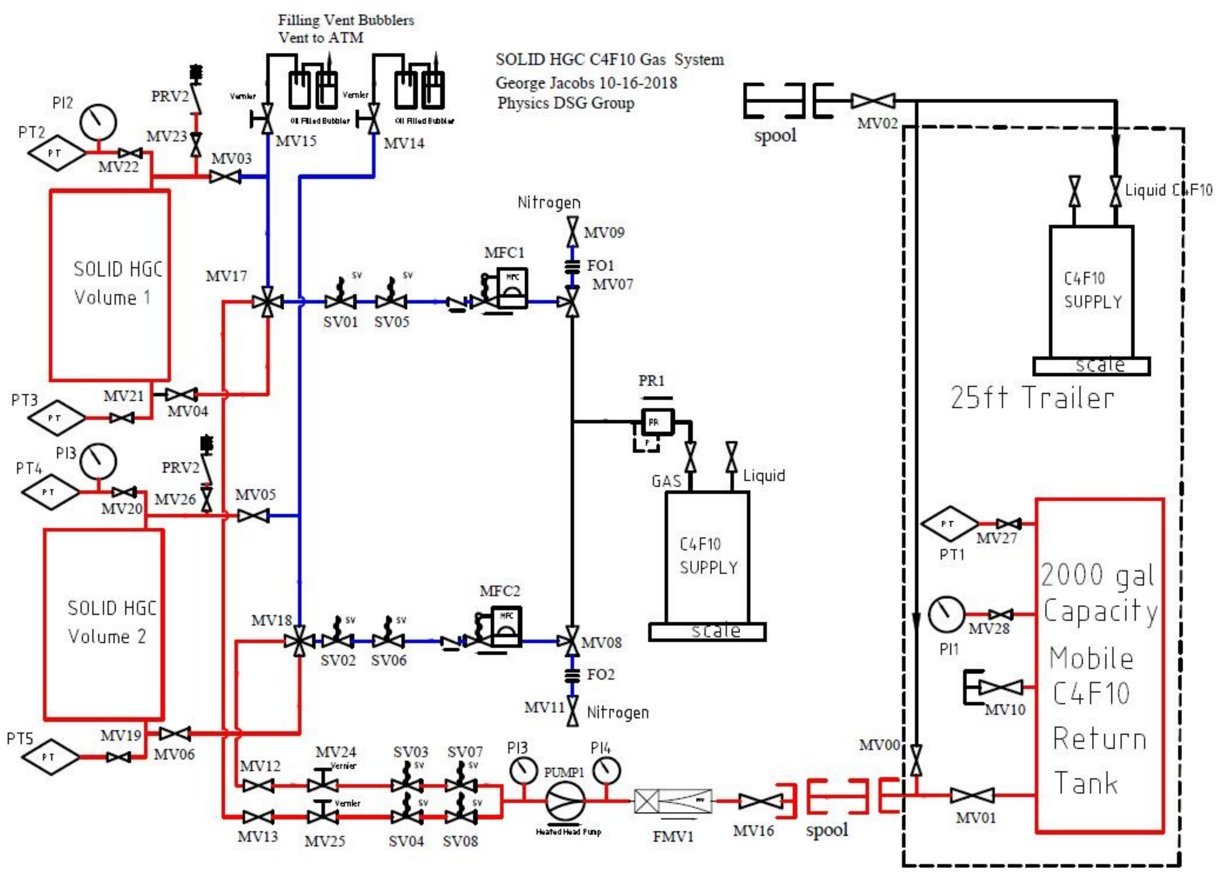
The red lines are C4F10 flow paths.

C4F10 Gas Recovery - Step 1 - Detector Volume Depressurization

The C4F10 gas in the detector volume should be recovered prior to opening the volume for maintenance. Each of the two detector volumes contains ~$40K of C4F10 gas. This gas must be transferred to a storage tank until it can be distilled using the Hall B C4F10 Distillation unit.

The 2000 gal storage tank and the piping from the tank back to MV12 and MV13 must first be pumped down, back filled with nitrogen gas, and then pumped down again to remove water vapor. Starting the recovery process with 30"Hg vacuum in the storage tank and return lines will increase tank recovery capacity and reduce distillation unit run times.

The Gas Selection valves, MV07 and MV08, are switched to the nitrogen position. The Flow Reversal Valves, MV17 and MV18 are used to redirect the supply nitrogen gas flow to the top of the detector volume so that the C4F10 will exit the detector via the lower connection.



C4F10 Gas Recovery Process - Step 1 - Detector Volume Depressurization

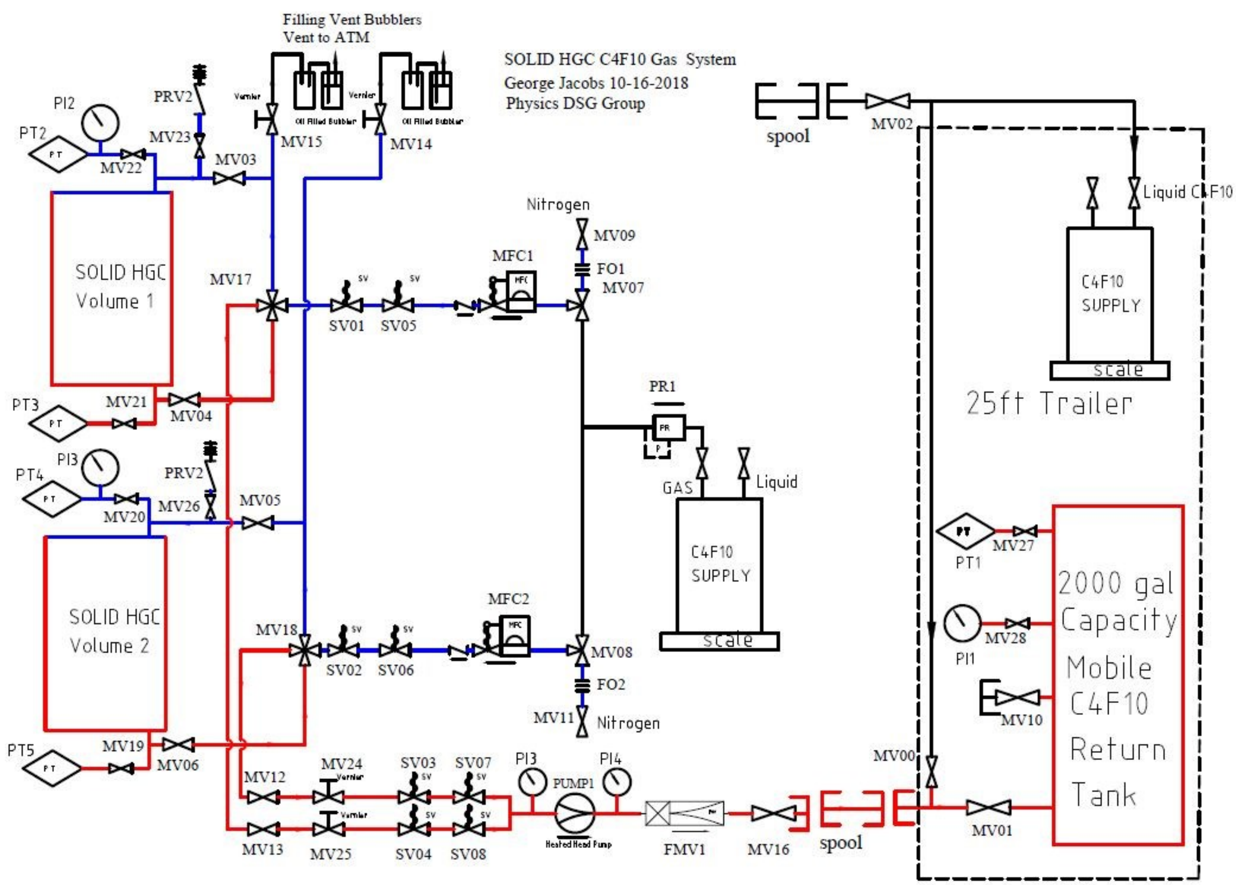
The red lines are C4F10 flow paths. The blue lines are nitrogen flow paths.

Once the storage tank and associated piping is pumped down, MV10, the pump down connection is shut, MV24 and MV25 are also shut. MV24 and MV25 are flow control needle valves. After the flow control valves are shut, MV12 and MV13 are opened. The pump is turned on. The flow control needle valves are slowly opened while monitoring the differential pressure across the pump. These flow control valves are used to limit flow in order to prevent pump overload.

The pressure control solenoid valves, SV07 and SV08, shut when the pressure drops to 10 torr. This prevents the detector volume from going sub atmospheric. The flow meter with valve, FMV1, with fully opened valve, provides visual indication of gas flow to the storage tank.

C4F10 Gas Recovery - Step 2 – C4F10 Gas Displacement by N2

This final step in the recovery process uses nitrogen gas to replace the C4F10 gas removed from the detector volume. New pressure control setpoints for the pressure control solenoid valves, SV05 and SV06, are required for this operation. These valves will now shut if the pressure in the detector volume reaches 50 torr. The MFCs are set for N2 gas and a flow setpoint of 25 slm.



C4F10 Gas Recovery Process - Step 2 - C4F10 Gas Displacement by N2

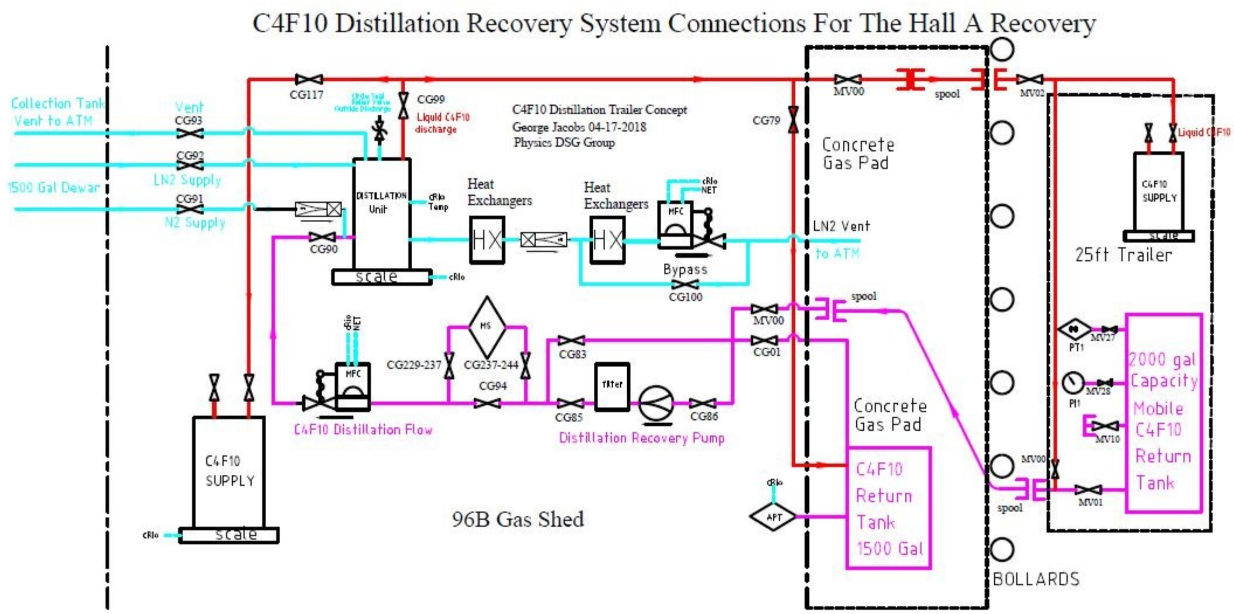
The red lines are C4F10 flow paths. The blue lines are nitrogen flow paths.

The gas flow indicated by the flow meter, FMV1, will start to decrease once most of the C4F10 has been transferred to the storage tank. As the C4F10 gas is displaced by the nitrogen, the differential pressure indicated by PT3 and PT5 will decrease. Once the differential pressure reads zero, the volume is empty.

Once all the C4F10 has been transferred to the storage tank, MV01 and MV16 are shut, the spool is removed. The lines and valves are capped to prevent gas loss and contamination. The gas can be stored in the tank until it can then be transported to the Hall B distillation unit to recover the gas for reuse.

Distillation of the recovered C4F10 gas

Distillation of the recovered gas requires the Hall B C4F10 Distillation System. The trailer with the 2000 gallon storage tank and a C4F10 supply tank is moved to bldg. 96B. Once there the spool lines are connected as shown in the below diagram.



The magenta lines are C4F10/N2/Air mixture flow paths. The red lines are C4F10 flow paths. The cyan lines are distillation unit nitrogen flow paths.

Once the spool lines are attached, they must be pumped down to remove air and water vapor. A pump down line is provided between the storage tank piping and the supply tank piping for that purpose. Great care should be taken to eliminate any leaks prior to beginning the distillation process.

Once the storage tank is empty, the liquid C4F10 can be transferred from the distillation unit internal tank to the supply tank. The liquid transfer to the supply tank will leave the piping full of C4F10 gas. In order to minimize gas loss, the vacuum in the storage tank can be used to recover most of the gas remaining in the lines prior to disconnecting them. After this is complete, the lines can be disconnected and the ends capped.

The recovered C4F10 is now stored in the supply tank in liquid form and at saturation pressure. This tank can now be moved to Hall A to refill the detector gas volumes when needed.