

Fall 2024 Technical Report

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Cornell Rocketry Team

Hybrid Fill Station

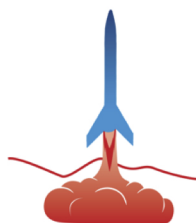
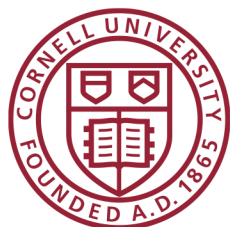
Propulsion

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SPACEPORT AMERICA®
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Nomenclature

CV - Check valve

RV - Relief valve

SV - Solenoid valve

MV - Manual valve

PF - Particulate filter

PT - Pressure transducer

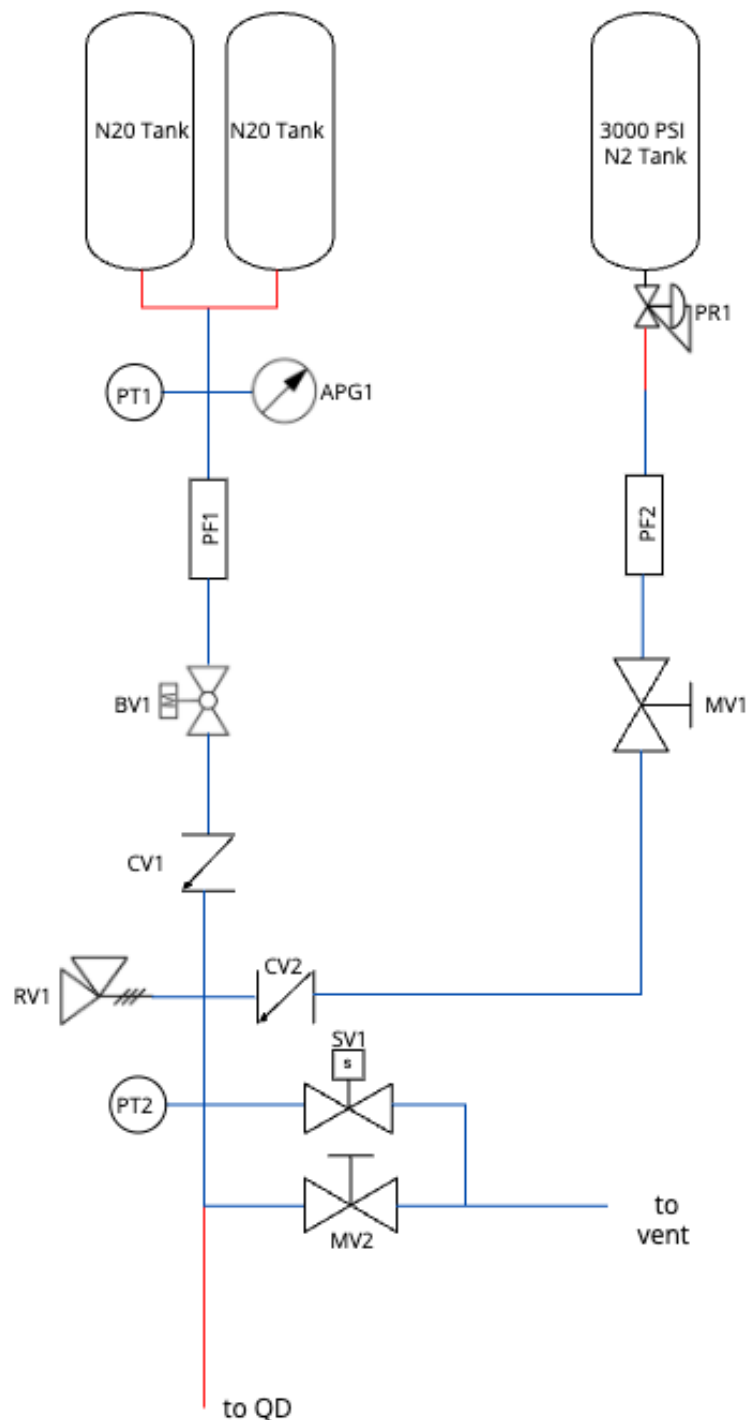
APG - Analog pressure gauge

RTD - Resistance temperature detector

QD - Quick disconnect

P&ID - Piping & Instrumentation Diagram

1 System Overview



Piping Key.

- 1/4" Flex Hose
- 1/4" 304 SS Tube

Passive System Components

- CV1 - N2O Check Valve
- CV2 - N2 Purge Check Valve
- RV1 - Pressure Relief Valve
- PR1 - N2 Purge Pressure Regulator
- PF1 - N2O Particulate Filter
- PF2 - N2 Particulate Filter
- MV1 - N2 Purge Manual Valve
- MV2 - QD Vent Manual Valve
- APG1 - Analog N2O Pressure Gauge

Electronic Valves

- BV1 - N2O Fill Ball Valve
- SV1 - QD Vent Solenoid Valve

Sensors

- PT1 - N2O Pressure Transducer
- PT2 - QD Pressure Transducer

Figure 1: Fill Station P&ID

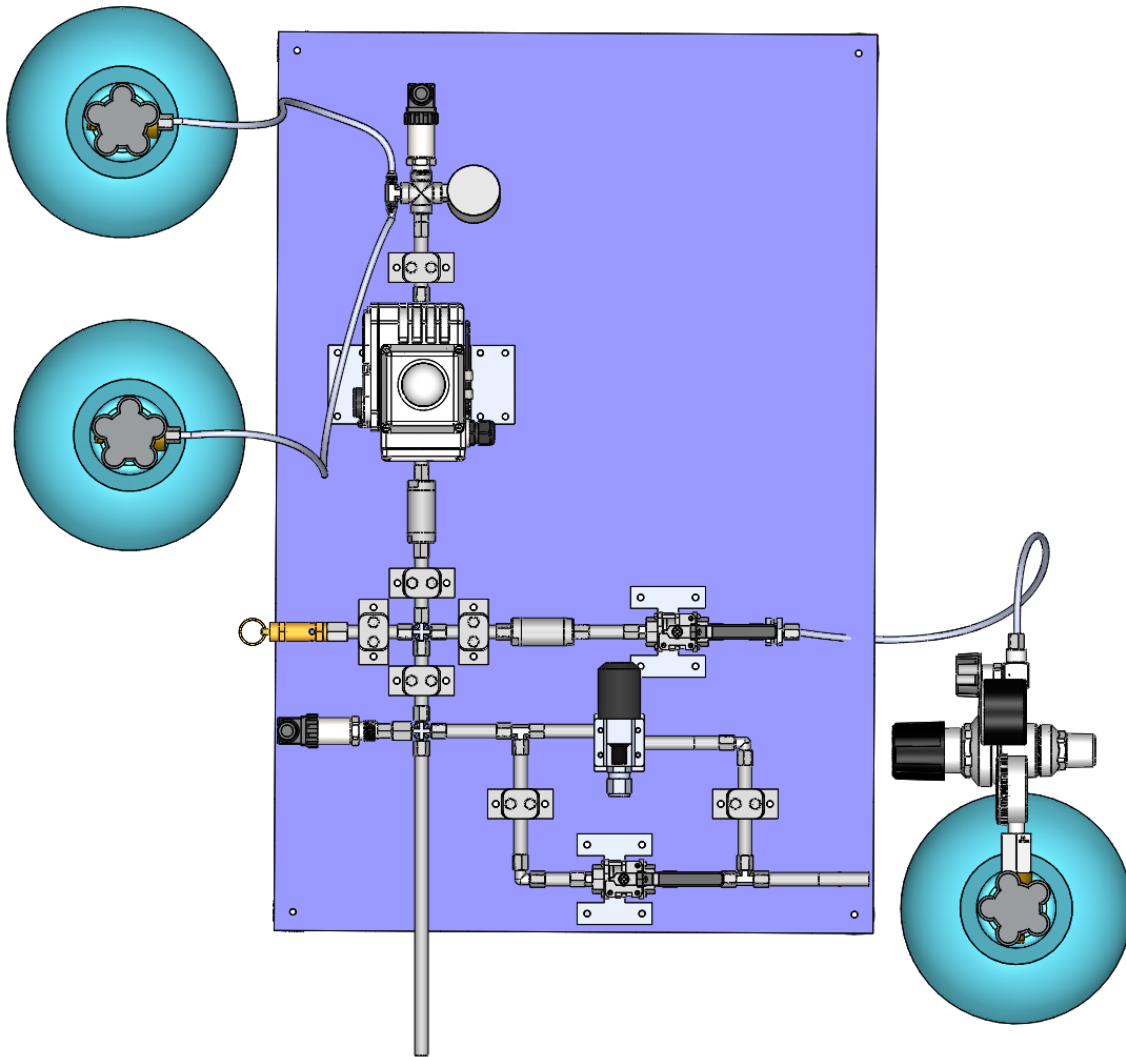


Figure 2: Fill Station CAD Top View

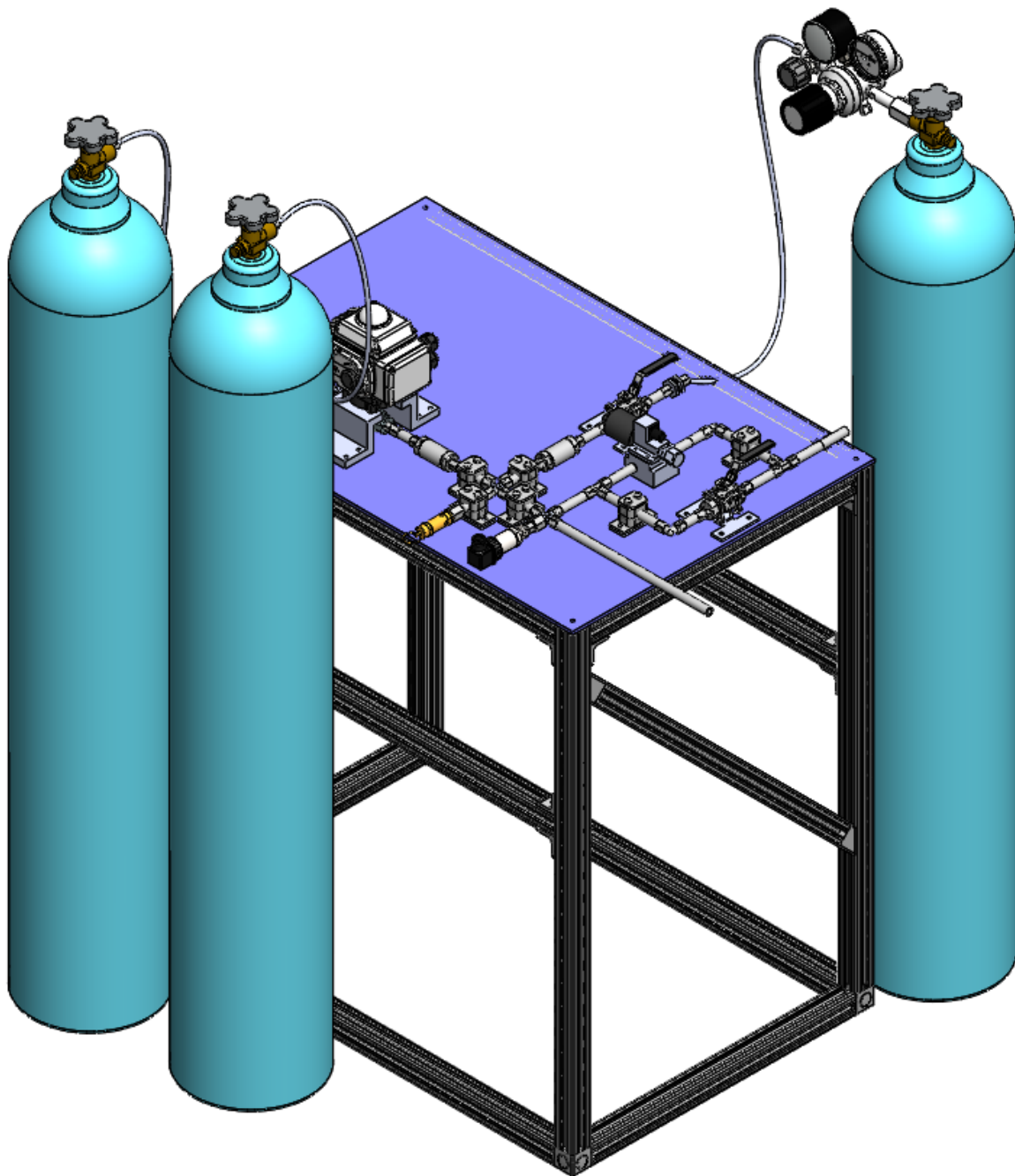


Figure 3: Fill Station CAD Side View

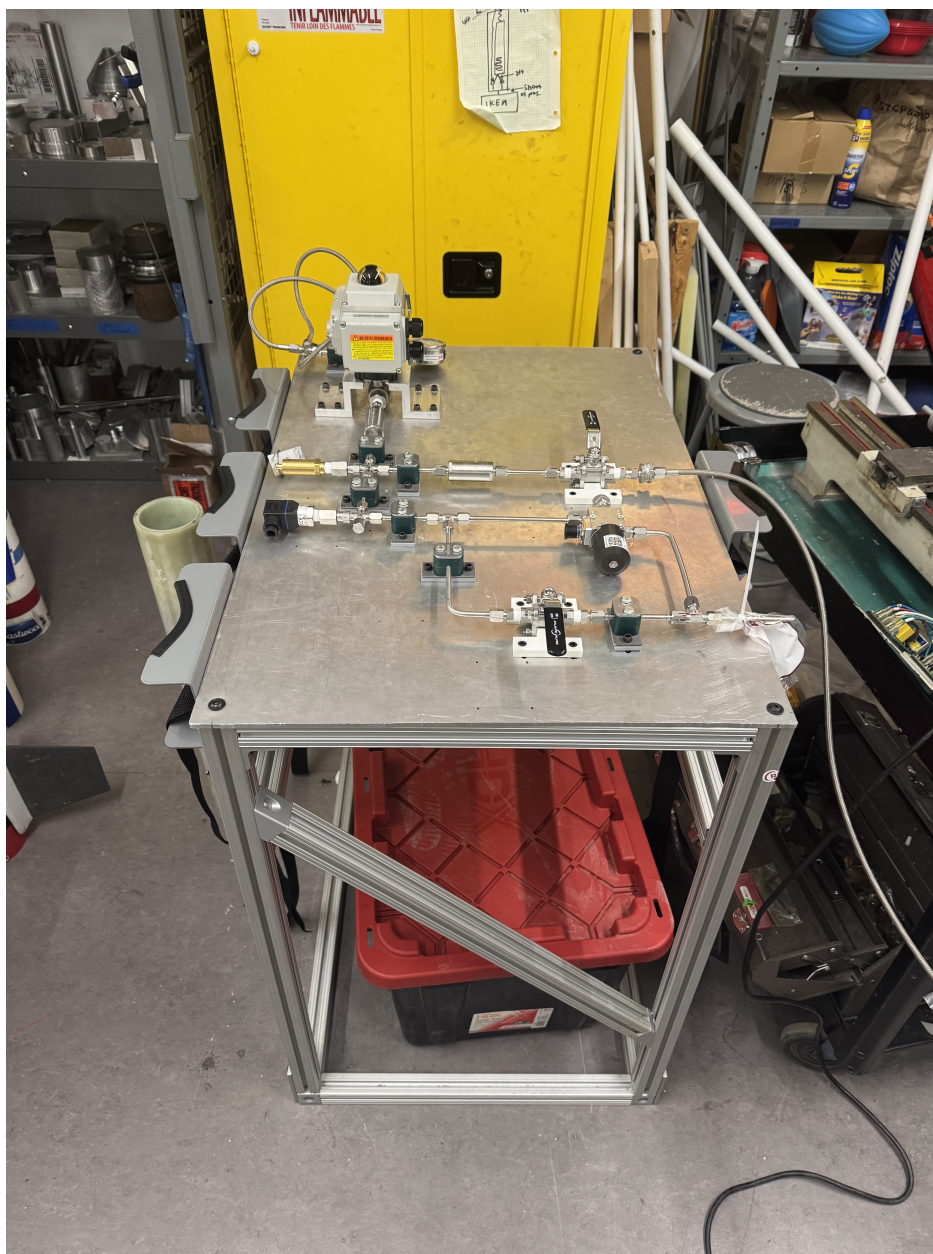


Figure 4: Fill Station Assembly: Front View

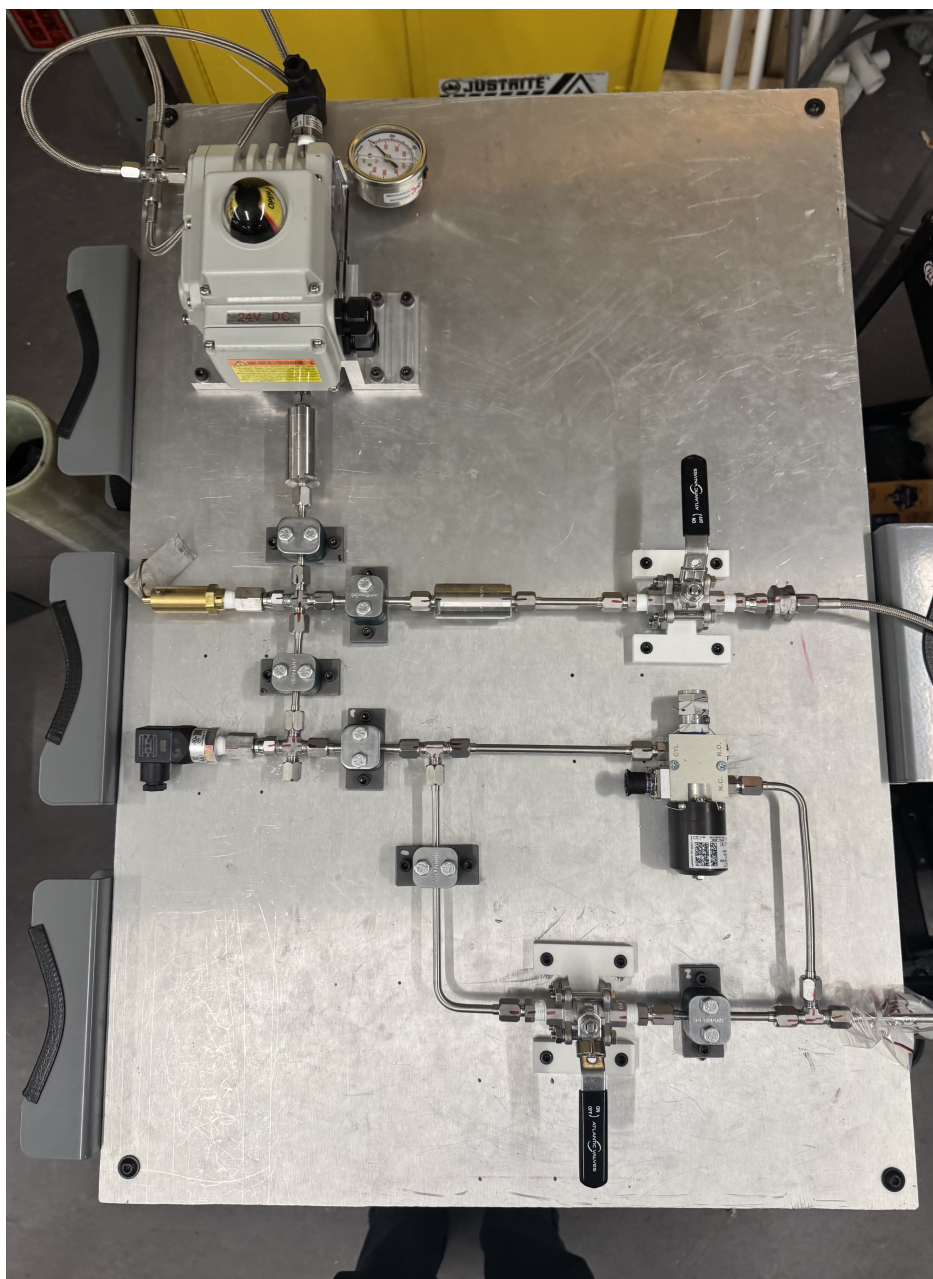


Figure 5: Fill Station Assembly: Top View

1.1 System Purpose

- The purpose of the fill station is to fill the run tank with N₂O via the quick disconnect when the launch vehicle is on the pad.

1.2 System Function

- Safely fill run tank while on the pad.
- Vent the quick disconnect to ensure safe retraction.
- Purge the run tank and QD line.

1.3 Requirements

1. System must be remotely operated, when personnel are at least 150ft away from the fill station.
2. System must be human-portable over a distance of at least 100m.
3. The system must allow CONOPS to ensure that the fill-to-fire time is < 30 min.
4. The system must house the electronics responsible for:
 - Ground station communication
 - Engine ignition
 - MAV actuation
 - QD retraction
 - Electrical umbilical communication
 - PT1 data sensing
 - PT2 data sensing
 - SV1 actuation
 - BV1 actuation

2 Subsystems

- The fill station is composed of 3 primary subsystems: Fill system, Purge System, and QD Vent System

2.1 Fill System

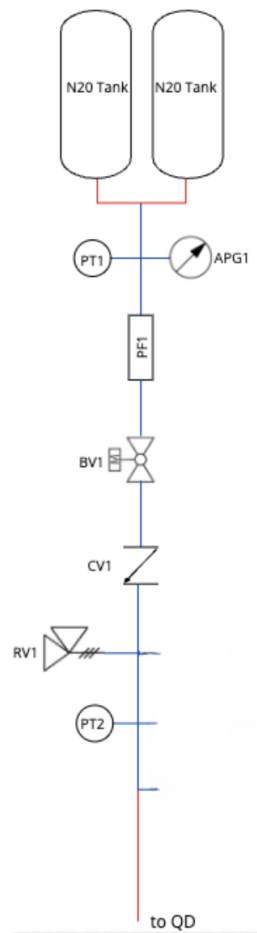


Figure 6: Fill System P&ID

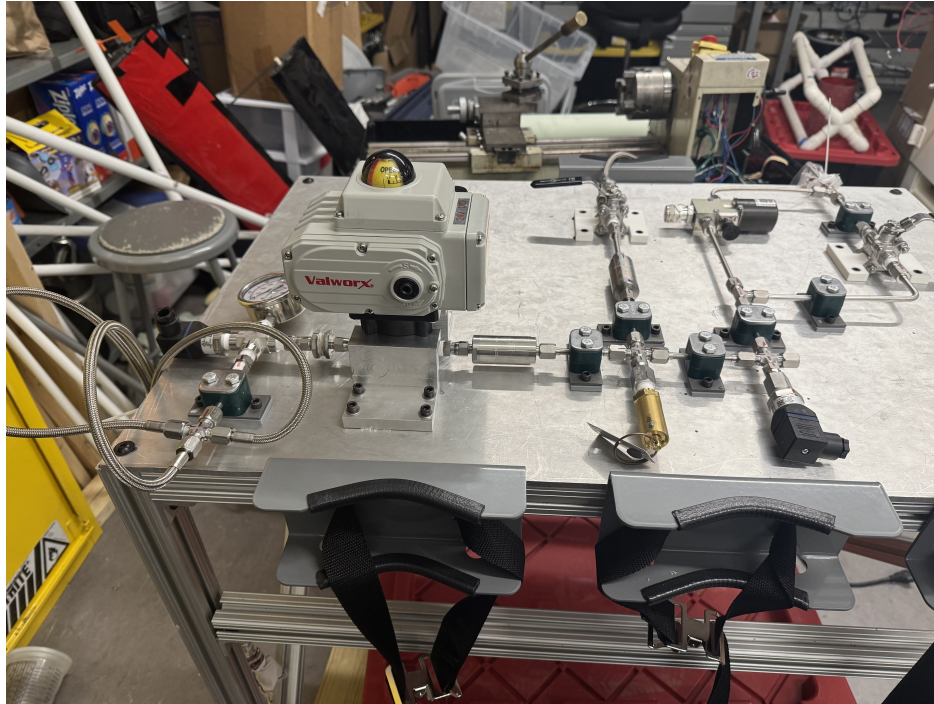


Figure 7: Fill System Assembly

2.1.1 System Function

1. Controls the flow of N₂O from gas cylinders to the run tank.
2. Measures N₂O supply pressure.

2.1.2 System Overview

1. N₂O supply tanks attach to fluid system with CGA-660 fittings through a -04 stainless steel flex hose.
2. Supply pressure is measured through PT1 and APG1.
3. Particulates are filtered out through PF1 and the flow of N₂O is controlled using a Valworx 565244E electric actuated ball valve (BV1).
4. N₂O flows through CV1 to prevent backflow.
5. N₂O flows through the QD fill line and into the run tank.

2.1.3 Design Choice Justification

- Kunkle Safety Valve Model 542 (RV1) was chosen due to its Viton seal, which is compatible with N₂O. RV1 is set at 1000psi to ensure N₂O does not exceed its critical pressure of 1050psi.
- Pressure transducer (PT1) was chosen to remotely monitor N₂O supply pressure.

- An analog pressure gauge (APG1) was chosen to aid in monitoring N2O supply pressure without PT1 data while out at the pad.
- Valworx 565244E electric actuated ball valve (BV1) was chosen to control the flow of N2O into the QD. Actuation time for a 90° rotation is 20 seconds, which is acceptable since fill CONOPS does not require a quick start/stop.
- Strataflo No.3395RB 303 Stainless Steel Check Valve with Viton Rubber Poppet (CV1) was chosen to prevent N2O backflow, which is especially necessary given the actuation time for BV1.
- Norman Filters Model 425AT-4TT with Sintered Filter Disk (PF1) was chosen to protect the fluid system and run tank from contamination that could lead to nitrous decomposition.
- -04 High-Pressure Braided Chemical Hoses were chosen to connect N2O supply cylinders to the fill station.
- 1/4" stainless steel tubing was chosen since a high N2O flow rate is not necessary.

2.2 Purge System

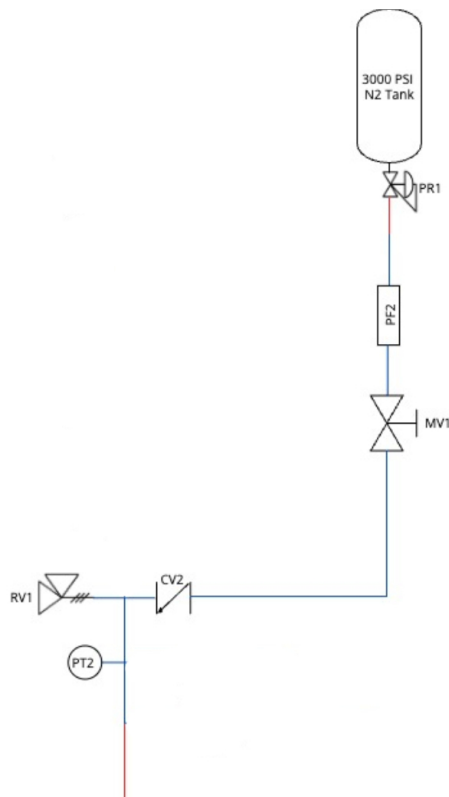


Figure 8: Purge System P&ID

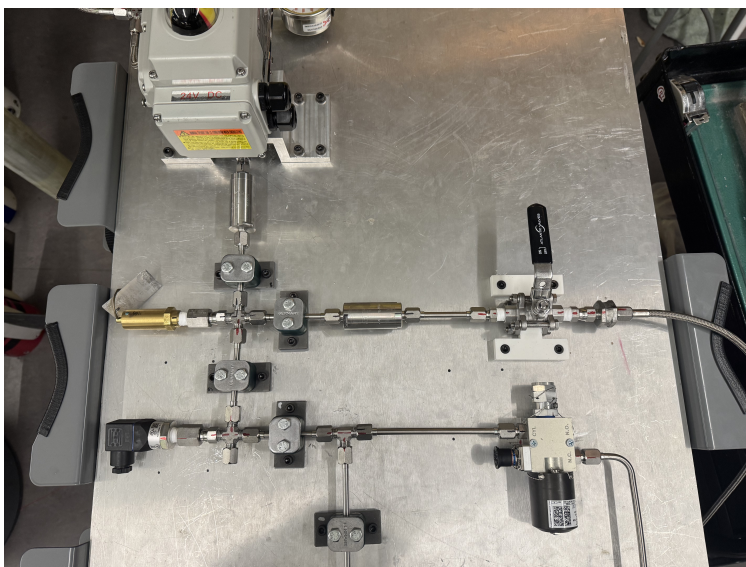


Figure 9: Purge System Assembly

2.2.1 System Function

1. Clear out moisture and any unwanted gases from QD line and run tank prior to fill CONOPS.

2.2.2 System Overview

1. N₂ flows through PR1 and is regulated down to ~ 200psi.
2. PR1 attaches to fluid system through a -04 stainless steel flex hose.
3. Particulates are filtered out through PF2.
4. The flow of N₂ into the QD and run tank is controlled using a manual ball valve MV1.
5. N₂ flows through CV1 to prevent backflow from the QD.
6. N₂ flows through the QD and into the run tank, where it will ultimately exit through the RTD vent (SV2).

2.2.3 Design Choice Justification

- Single stage Tank-Mount Pressure-Regulating Valve (PR1) was chosen due to its tank-mounting capabilities to simplify the fluid system and its analog pressure gauges which will aid in regulating the N₂ to the correct pressure without having to use pressure transducers. In addition, this pressure regulator was chosen due to its 1/4" Male AN outlet fitting, which can attach directly to the flex hose.

- A -04 High-Pressure Braided Chemical Hose was chosen to connect N2 supply cylinder to the fill station.
- Norman Filters Model 425AT-4TT was chosen to protect the fluid system and run tank from contamination.
- A manual ball valve (MV1) was chosen to control the purge process. This was done to reduce complexity, as a manual valve does not require any electrical integration. A manual ball valve will also allow personnel to purge the QD and run tank while out at the pad and confirm that a purge has been conducted successfully.
- Stainless Steel Check Valve (CV2) was chosen to prevent N2 backflow and to prevent the flow of N2O into the upstream purge lines.
- 1/4" stainless steel tubing is sufficient for the necessary N2 purge flow rate.

2.3 QD Vent System

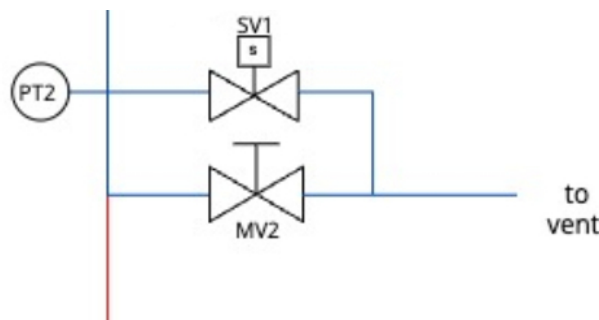


Figure 10: QD Vent System P&ID

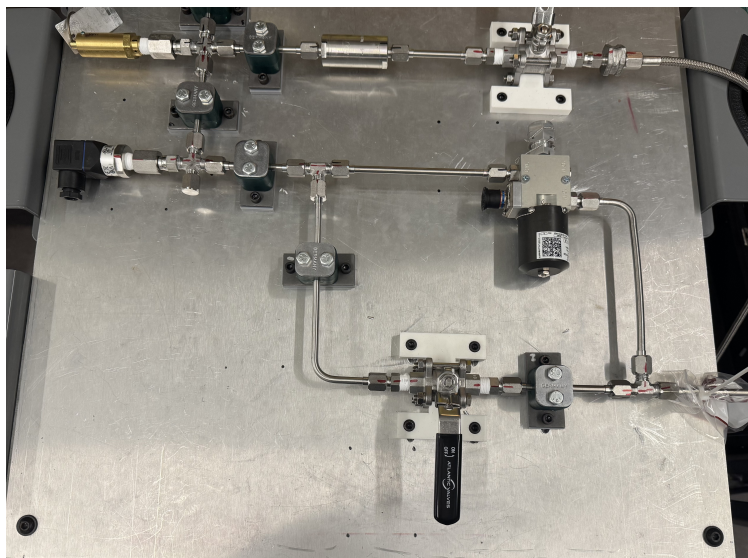


Figure 11: QD Vent System Assembly

2.3.1 System Function

1. Depressurize the QD line by venting excess N₂O to allow for safe retraction from the launch vehicle.
2. Monitor QD line pressure to confirm successful vent.
3. Provide the option to manually vent the QD in the event of an electrical failure.

2.3.2 System Overview

1. N₂O flows through QD during fill process until run tank is full, which will be indicated by the RTD sensor on the launch vehicle.

During nominal operations:

2. SV1 is opened, and the remaining N₂O left in the QD line flows out of the vent, effectively depressurizing the QD line.
3. Pressure drop in PT2 readings will indicate a successful vent and give the go-ahead for QD retraction.

In the case of SV1 failure:

2. MV2 is to be slowly opened remotely using a line.

2.3.3 Design Choice Justification

- Marotta Model MV74LT Solenoid Valve (SV1) was chosen because of its 3-way 2-position design that can be configured such that SV1 operates as a normally-closed valve, only venting the QD when actuated.
- A manual ball valve (MV2) was chosen to be configured in parallel with SV1 to allow for a safe QD vent even in the case of SV1 failure.
- Pressure transducer (PT2) was chosen to remotely monitor QD line pressure in order to confirm a successful vent before proceeding with QD retraction.
- 1/4" stainless steel tubing is sufficient for vent flow rate.

3 Testing

The fluid system will be tested as follows:

1. Leak test

- Pressurize the fluid system to a low pressure, use a bubble solution to check whether there are any leaks in the system.

2. Electrical and Software Full Integration Test

- Demonstrate the ability to actuate BV1, actuate SV1, and read PT data through the ground software architecture.
- Run through full fill-to-fire CONOPS utilizing ground software.

3. Vertical Coldflow Test

- Operate fill station in conjunction with the QD and a fully integrated booster section.
- Complete a full wet dress rehearsal, simulating launch utilizing ground software.

3.1 Vertical Coldflow/Fill-to-Fire CONOPS

- Safety Procedures

- All personnel except for the operator shall stand at a safe distance (>300ft) away from the fill station and run tank.
- Fill station should only be approached when run tank pressure is below 20 PSI, and when QD has been properly vented.
- In the case of an electronics failure on the run tank side, test stand may be approached after 45 minutes, or after the run tank has finished venting.

To Be Done Before Fill:

- ☐ Ensure vertical stand is fully assembled.
- ☐ Ensure booster section is fully assembled.
- ☐ Ensure AV Bay is fully assembled.
- ☐ Ensure Ground Station is assembled and connects successfully to the fill station.
- ☐ Ensure fill station is fully assembled and connected to QD.
- ☐ Ensure QD is aligned and connected to the rocket.

- ☐ Cover all fittings in sealing plastic baggies or rubber balloons.
- ☐ Arm the CFC.

Operations:

- ☐ Power electronics on and confirm via radio that:
 - ☐ All sensors are reading nominal values.
 - ☐ Values can be read through the Ground Station.
 - ☐ Voltage readings are within expected limits.
- ☐ Verify ground station is receiving sensor readings:
 - ☐ PT
 - ☐ PT2
 - ☐ LC1
 - ☐ RTD
 - ☐ PT3
 - ☐ PT4
- ☐ Actuate each individually and confirm functionality via radio:
 - ☐ MAV
 - ☐ SV1
 - ☐ QD
 - ☐ BV1
 - ☐ SV2

State Checks:

- ☐ Ensure the following states:
 - ☐ SV1 = Closed
 - ☐ BV1 = Closed
 - ☐ MV1 = Closed
 - ☐ MV2 = Closed
 - ☐ MAV = Closed
 - ☐ SV2 = Open
 - ☐ QD = Connected

Tank and Regulator Setup:

- ☐ Connect the three N₂O tanks to the Fill Station and torque to 25 ft-lb (CGA 660).
- ☐ Connect the pressure regulator to the N₂ tank and torque to 40 ft-lb (CGA 580).
- ☐ Ensure the pressure regulator is fully closed.
- ☐ Ensure all personnel except the operator are clear of the testing area.
- ☐ Don proper PPE:
 - ☐ Welding gloves
 - ☐ Eye protection
 - ☐ Face shield
 - ☐ Thick, long clothing
- ☐ Arm MAV (remove key).
- ☐ Slowly open the N₂ tank.
- ☐ Confirm adequate tank supply pressure through the inlet gauge (should read around 3000 psi).
- ☐ Slowly adjust the pressure regulator until the outlet gauge reads ~200 psi.
- ☐ Begin purge:
 - ☐ Crack open MV1.
 - ☐ Open MAV after 2 minutes (adjust duration depending on run tank conditions).
 - ☐ Close MV1.
 - ☐ Close N₂ tank.
- ☐ Install igniter.
- ☐ Confirm all valve states are locked.
- ☐ Confirm BV1 is fully closed.

Fill Operations:

- ☐ Slowly open the three N₂O tanks.
- ☐ Confirm adequate tank supply pressure through the pressure gauge.
- ☐ Retreat to a safe distance (>500 ft).
- ☐ Confirm PT1 reading matches the pressure gauge reading via radio.

- Confirm all systems are go for fill operations:
 - Open BV1 and confirm fill has started:
 - Camera pointing at BV1.
 - LC1 data begins increasing in magnitude.
 - PT4 shows a pressure increase.
 - Wait for the run tank to fill:
 - RTD data begins dropping rapidly.
 - Expected LC1 reading is reached.
 - Close SV2 and wait for PT1 and PT4 to equalize (~30 seconds).
 - Close BV1 and confirm fill has stopped:
 - Camera pointing at BV1.
 - LC1 reads constant.

Hold:

- During the hold:
 - Continuously monitor PT4 (Run Tank) pressure.
 - If pressure exceeds ~975 psi:
 - Open SV2 to vent until PT4 reads 950 psi.
 - Open BV1.
 - Close SV2.
 - Close BV1.
 - Repeat until the correct fill level and pressure (950 psi) are achieved.

Coldflow Operations: to begin once run tank is at correct fill level and pressure, and we are GO for coldflow

- Vent QD:
 - Open SV1.
 - Close SV1.
 - Confirm successful QD vent (PT2 should read atmospheric pressure).
 - Retract QD and confirm successful retraction via camera.
- T-00:00:30:
 - Arm igniter through software.
- T-00:00:03:

- ☐ Push button to ignite the igniter.
- ☐ Confirm ignition via camera view, resistor values, and/or current through igniter.
- ☐ T-00:00:00:
 - ☐ Open MAV to launch.
- ☐ T+00:00:15:
 - ☐ Close MAV.
 - ☐ Open SV2 after drogue and main deploy.

Recovery:

- ☐ Check SV2 status and PT4 readings.
- ☐ If SV2 = open and the run tank is not pressurized, the LV is safe to approach.
- ☐ Cover all exposed ports and the nozzle with plastic baggies.

Fill Station Breakdown:

- ☐ Operator approaches with proper PPE:
 - ☐ Face shield
 - ☐ Welding gloves
 - ☐ Long clothing
- ☐ Close all three N₂O tanks.
- ☐ Back the N₂ pressure regulator all the way off.
- ☐ Close the N₂ tank.
- ☐ Walk away (~30 ft).
- ☐ Open BV1 and SV1 and wait for N₂O flex hoses to vent.
- ☐ Close BV1.
- ☐ Re-approach the fill station.
- ☐ Open MV1 while keeping SV1 open and wait for the N₂ flex hose to vent.
- ☐ Close SV1.
- ☐ Confirm all fluid lines are depressurized.
- ☐ Detach N₂O flex hoses from cylinders and cover them with plastic baggies.
- ☐ Detach the N₂ pressure regulator and cover it with plastic baggies.
- ☐ Cover all ports with plastic baggies.

4 Supply Chain

4.1 Bill of Materials

Product	Link	Vendor	Quantity	Total Price
N2 Purge Pressure Regulator	Link	McMaster	1	\$221.56
N2O Pressure Transducer (1000psi)	Link	PressureWorx	2	\$134.55
4-way cross connector (N2O Side)	Link	Titan Fittings	1	\$54.87
4-way Cross Connector (JIC)	Link	Titan Fittings	2	\$182.04
Relief Valve (Model 30 Kunkle)	Link	M&M	1	\$210.46
Check Valve	Link	Strataflo	2	\$103.80
Analog Pressure Gauge	Link	Grainger	1	\$48.72
Manual Ball Valves	Link	Electric Solenoid Valves	2	\$36.04
N2O Ball Valve	Link	Valworx	1	\$571.20
Solenoid Valve		Marotta (MV4LT)	1	\$7000.00
Particulate Filters	Link	Norman Filters	2	\$548.00
3ft Flex Hoses	Link	McMaster	2	\$85.58
4ft Flex Hose	Link	McMaster	1	\$27.26
5ft Flex Hose	Link	McMaster	1	\$49.31
1/4" JIC Tube Nut	Link	Titan	35	\$101.15
1/4" JIC Tube Sleeve	Link	Titan	35	\$60.55
1/4" JIC Tee	Link	Titan	2	\$61.02
1/4" NPTM to JICM	Link	Titan	8	\$61.12
1/4" JICM to NPTF	Link	Titan	6	\$72.42
1/4" NPTM to JICF	Link	Titan	3	\$83.07
CGA 660 Nuts	Link	McMaster	3	\$17.70
CGA 660 Nipples	Link	McMaster	3	\$25.47
Routing Clamps	Link	McMaster	7	\$22.19
80/20 Corner Bracket	Link	McMaster	10	\$88.00
80/20 Diagonal Braces	Link	McMaster	4	\$48.68
80/20 Corner Block	Link	McMaster	4	\$38.60
4ft 80/20	Link	McMaster	2	\$64.26
5ft 80/20	Link	McMaster	1	\$43.06
6ft 80/20	Link	McMaster	5	\$232.50
80/20 Framing Bracket	Link	McMaster	4	\$53.36
1/4" Piping	Link	McMaster		\$40.00
24"x36" Aluminum Plate				\$100.00
M7 Bolts	Link	McMaster	1	\$9.02
Handles	Link	McMaster	4	\$18.76
Fill Flex Hose	Link	McMaster	1	\$80.62
Flourosilicone O-rings	Link	McMaster	1	\$10.58
Tank Holders	Link	McMaster	4	\$190.64
Total Cost				\$10,282.72

A Appendix

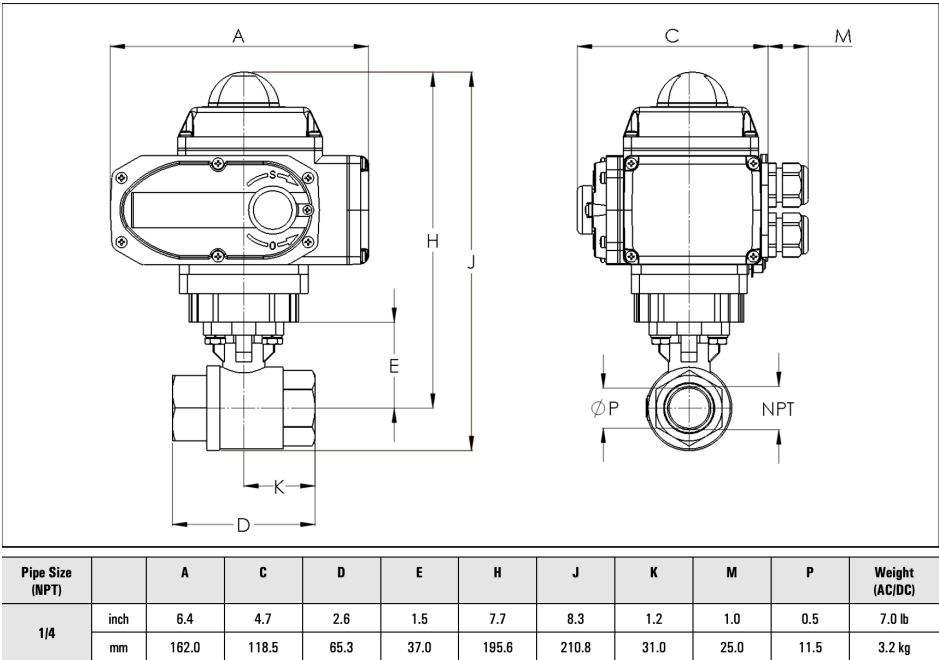


Figure 12: Valworx Ball Valve

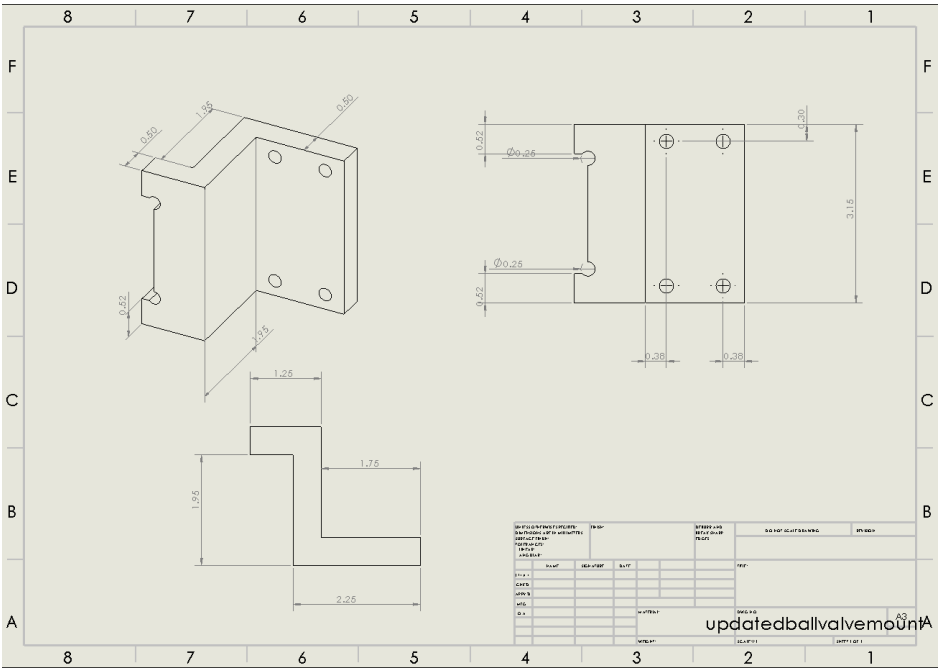


Figure 13: Ball Valve Mount Drawing

References

- [1] Arizona State University: Safetygram #31 - Cylinder Valve Outlet Connections
<https://safe.engineering.asu.edu/wp-content/uploads/2011/12/Cylinder-Valve-Outlet-Connections.pdf>
- [2] Viton Chemical Compatibility
<https://www.calpaclab.com/viton-chemical-compatibility-chart/>