Students for the Exploration and Development of Space
University of California, San Diego

Colossus
Liquid Rocket Engine Static Test Stand
Oxygen Compatibility Assessment Report

Submitted to:
NASA Marshall Space Flight Center
Program Office: Rocket Propulsion Testing

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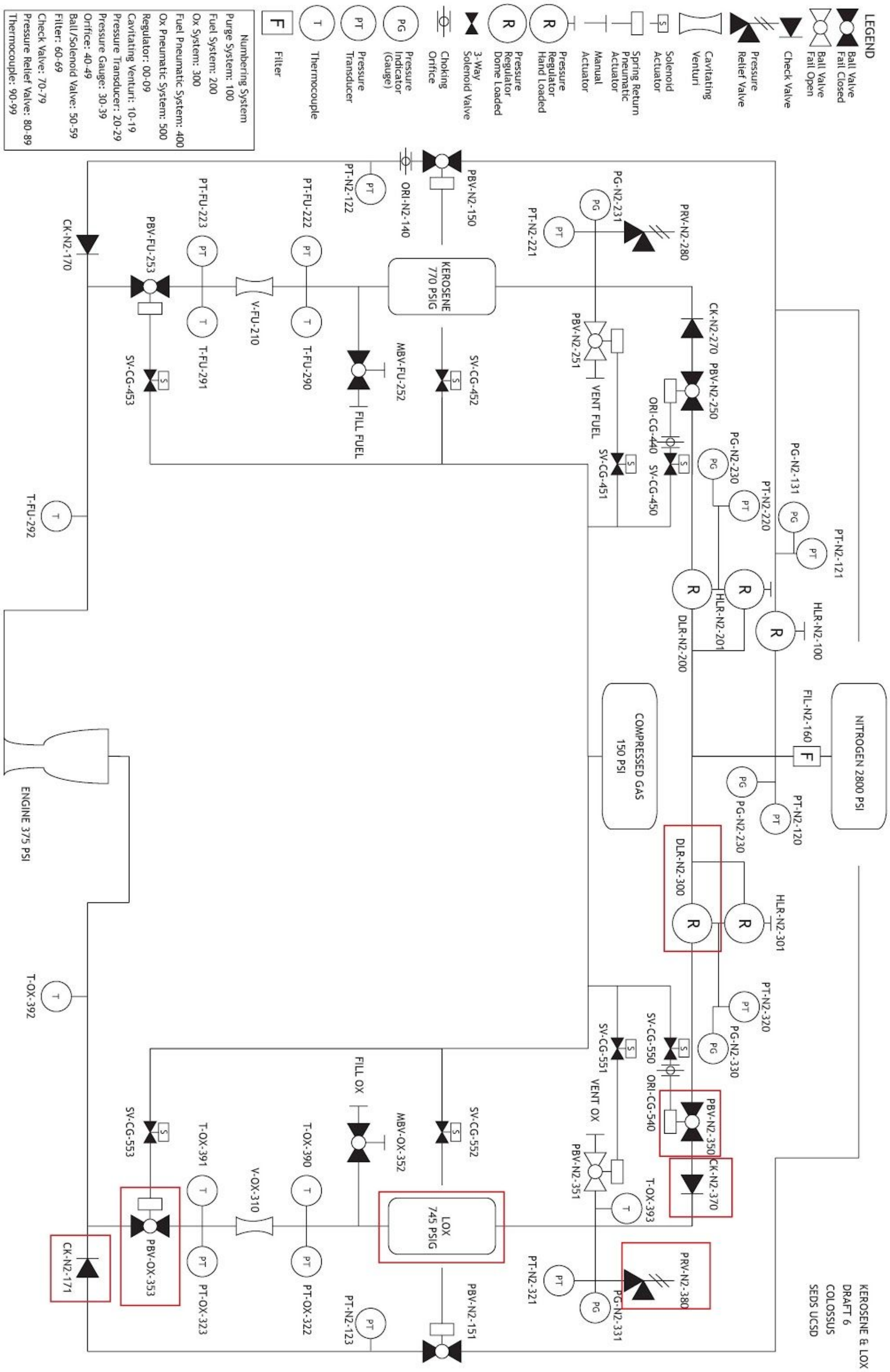
1. Introduction

The Colossus Static Fire System Project is established to create a long-lasting hot fire capability for the SEDS UCSD program. The project will create a doubly cryogenic bi-propellant liquid rocket engine test stand the team can reuse and could potentially loan to other student programs with similar testing requirements. Given the team's previous design of the LOx/RP-1 Vulcan-1 engine and future designs utilizing liquid oxygen as an oxidizer, it is imperative that the system and the team be equipped for handling liquid oxygen. This means creating designs that maximize safety and undergoing a review process to ensure it is liquid oxygen compatible. To this end, a select team of SEDS UCSD students received technical professional training in ASTM's Fire Hazards in Oxygen Systems by Joel Stoltzfus, WSTF (retired) at the Open Source Maker Lab in Carlsbad, CA on May 14-15, 2016. This team of individuals has now assessed the oxidizer lines and valves on the Colossus Static Fire System for liquid oxygen compatibility in accordance with the training received on May 14-15th to present to the NASA Rocket Propulsion Test Program (RPT) on July 11, 2016. The results of this analysis are presented herein.

2. Plumbing and Instrumentation Diagram

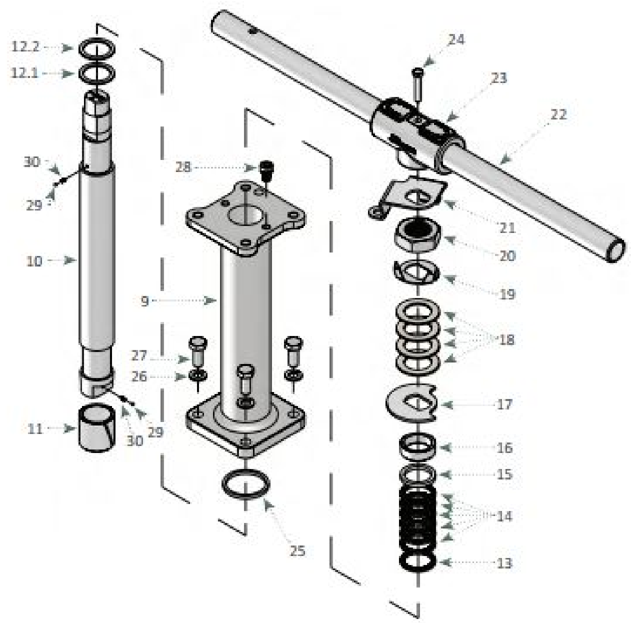


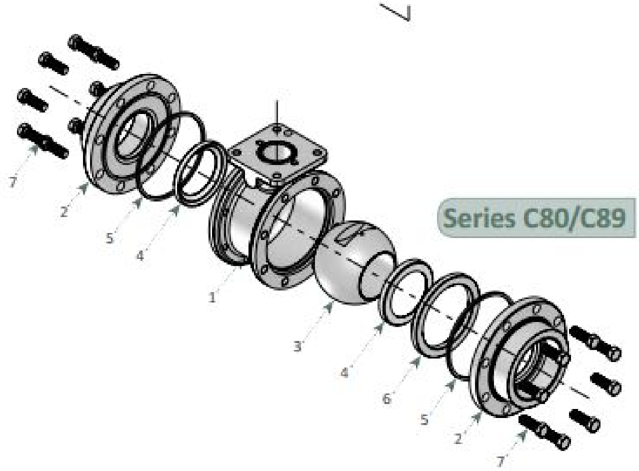
3. LOx Specific Risk Matrix

			Impact			
Probability		**Negligible**	**Minor**	**Moderate**	**Significant**	**Severe**
	Very Likely					
	Likely	Purge Check Valve Failure		Press Check Valve Failure		
	Possible		PRV Fire	Vent Valve Fire		
	Unlikely			Regulator Fire		
	Very Unlikely				Piping Fire	Main Valve Fire/Tank Fire

***The risk matrix focuses only on elements of Colossus that come into contact with LOx and/or GOx and therefore prove to be a significant risk factor.**

4. Main Ball Valve





Vendor: Sharpe
Part Number: ¾ Inch C89 Full Port Cryogenic Ball Valve
P&ID P/N: PBV-OX-353
Function Description:
The main ball valve serves as the main flow control mechanism from the oxidizer tank to the engine. It is responsible for controlling the sole source of oxidizer to the engine. This valve is in contact with LOx as soon as LOx filling begins. It remains in contact with LOx until the end of a test, when the entire system is depressurized and vented.
Oxygen Contact:

This valve is in contact with oxygen from the beginning of the LOx fill procedure to the end of the test. The downstream side of the valve will only be in contact with LOx during the hot fire sequence.

Material Assessment :

		Worst-Case Operating Conditions		Material Flammable?			
Compone nt	Materials	Pressure (psi)	Temperatu re (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body,	SS 316	1480	-361.82(L o),150(Hi)	200 psi	N/A	1888.15	Yes
Stem							
Stem Packing	PTFE	1480	-361.82(L o),150(Hi)	95-100%	813	1701.24	Yes
Seat	PCTFE (Kel-F)	1480	-361.82(L o),150(Hi)	N/A	N/A	N/A	Yes
Body Seal	Impregnate d Graphite	1480	-361.82(L o),150(Hi)	N/A	N/A	N/A	N/A

Ignition Mechanism Ratings**:**

Ignition Mechanism Ratings							Kindling Chain	Reaction Effect (A-D)
Particle Impact	Compression Heating	Friction/ Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
1	1	0	0	0	3	0	Yes	B

Ignition Mechanism Analysis:

Particle Impact: Particle velocity will not exceed 100 ft/s and there will be no impact since the particles run straight through the valve when open. As long as the particle velocity does not exceed 100 ft/s, the valve will be safe. When the valves are closed and the ball is impacted the line speed of 20 ft/s is not a enough to be a cause for concern.

Compressive Heating: The only scenario when there will be gas present at the valve is when the LOx starts boiling during the fill procedure. This GOx bubble will be compressed when the pressurization procedure begins. Since the press valve is designed to be a slow actuation, there is no instantaneous compression that would heat the gas faster than it can dissipate through the cryogenic environment. All materials are metal except for PTFE which has an ignition temperature of 813 F. The system temperatures will not reach anywhere near 800 F.

Friction/Galling: There are no rubbing materials. The body and the stem will rub when the ball valve is turned, but the rubbing speed is minimal compared to the 1.5 x 10^6 psi-ft/min required to ignite SS.

Mechanical Impact: Mechanical impact will not be an issue when the ball valve is closed. The velocity in the lines is not enough to cause ignition nor is there any nonmetal material present on impact.

Electric Arc/Spark: Since, the body is metallic there shouldn't be a potential difference that will cause an electric arc.

Flow Friction: Risks are introduced when there is a channeled flow created by a leak on the PTFE valve seat. Depending on the severity the leak, it is possible for the Teflon valve seat to be ignited due to flow friction.

5. Fill Ball Valve

<u>Vendor</u>: Sharpe
<u>Part Number</u>: ¾ Inch C89 Full Port Cryogenic Ball Valve
<u>P&ID P/N</u>: PBV-OX-352
<u>Function Description</u>:
The fill ball valve's sole function is to act like a door and allow the filling of the system. Opening the fill ball valve will allow for LOx to enter the system and then allow us to seal the opening when the fill valve is in the closed position. The fill valve will be exposed to LOx for the entire duration of the test-- from fill to end of the test. Due to the position of the valve, boiling oxygen bubbles would travel upwards to the tank and not accumulate locally.
<u>Oxygen Contact</u>:
The fill valve is the first component to come into contact with LOx. Both ends will be in constant contact while fill is occurring and then only the output end will be in contact with LOx.

Material Assessment :

		Worst-Case Operating Conditions		Material Flammable?			
Component	Materials	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body, Stem	SS 316	1480	-361.82	200 psi	N/A	1888.15	Yes
Stem Packing	PTFE	1480	-361.82	95-100 %	813	1701.24	Yes
Seat	PCTFE (Kel-F)	1480	-361.82	N/A	N/A	N/A	Yes
Body Seal	Impregnated Graphite	1480	-361.82	N/A	N/A	N/A	Yes

**note: LOx will pool during fill within the valve. Will be oxygen rich until fill is complete.

Ignition Mechanism Ratings:

Ignition Mechanism Ratings							Kindling Chain?	Reaction Effect (A-D)
Particle Impact	Compression Heating	Friction / Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
1	1	0	0	0	3	0	Yes	A

Ignition Mechanism Analysis:

Particle Impact: Particle velocity will not exceed 100 ft/s and no there will be no impact as the particles run straight through the valve when it is open. As long as the particle velocity does not exceed 100 ft/s, the component will be safe.When the valves are closed and the ball is impacted the 20 ft/s will not be significant enough to be a cause for conce

Compressive Heating: All materials are metal except for PTFE which has an ignition temperature of 813 F.; system temperatures will not reach anywhere near 800 F.

Friction/Galling: No rubbing materials; the body and the stem will rub when the ball valve is turned, but the rubbing speed is minimal compared to the 1.5 x 10^6 psi-ft/min required to ignite SS.

Mechanical Impact: Mechanical impact will not be an issue when the ball valve is closed. The velocity in the lines is not enough to cause ignition nor is there any nonmetal material present on impact.

Electric Arc/Spark: Since, the body is metallic there shouldn't be a potential difference that will cause an electric arc.

Flow Friction: Risks are introduced when there is a channeled flow created by a leak on the PTFE valve seat. Depending on the severity the leak, it is possible for the Teflon valve seat to be ignited due to flow friction.

6. Vent Ball Valve

Vendor: Sharpe
Part Number: 1.5 Inch C89 Full Port Cryogenic Ball Valve
P&ID P/N: PBV-OX-351
Function Description:
The venting ball valve allows the GOx to escape the system as it boils off. It will prevent the LOx tank from self pressurizing. The valve will be in contact with GOx for the duration of the filling process as well as during the firing process. During the firing process there is now ambient pressured GOx which is very unlikely to cause fire but still a concern.
Oxygen Contact:
The vent valve is in contact with cryogenic temperature GOx as soon as LOx filling starts. As the tank is filled to the desired liquid level constraint by the dipstick of the tank, GOx carrying LOx droplets will flow through this valve. When this valve is closed prior to pressurization of the tank, LOx will continue to boil off and self pressurize. During this period, this valve is in contact with pure GOx. As soon as the tank is pressurized by GN2, the concentration of Oxygen in the gas mixture will drop.

Material Assessment :

		Worst-Case Operating Conditions		Material Flammable?			
Component	Materials	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body,	SS 316	1480	-361.82	200 psi	N/A	1888.15	No

Stem, Ball							
Stem Packing	PTFE	1480	-361.82	95-100%	813	1701.24	*
Seat	PCTFE (CTFE) (Kel-F)	1480	-361.82	100	811.4	1473.68	No
Body Seal	Impregnated Graphite	1480	-361.82	N/A	N/A	N/A	*

*Flammability: When LOx tank is filled but before pressurizing, the oxygen concentration will be near 100%, which yields all non-metal materials flammable. However, after system is pressurized by Nitrogen gas, the oxygen concentration drops below the materials oxygen index.

Ignition Mechanism Ratings:

Ignition Mechanism Ratings							Kindling Chain?	Reaction Effect (A-D)
Particle Impact	Compression Heating	Friction/ Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
1	1	0	0	0	3	0	Yes	B

Ignition Mechanism Analysis

Particle Impact: When the valve is fully open, particle impact is not possible for ball valves because there is nothing obstructing the line-of-flow of any incoming particles. When the valve is opening, there is a chance that particle impact may occur, but the chance is very low because the valve handle is pneumatically driven and the transient time is short.

Speed of Impact: Particles will not be undergoing speeds fast enough to cause ignition of nonmetal components.

Compressive Heating: This valve will be in contact with LOx only when the system is pressurized. There is no gas to be compressed.

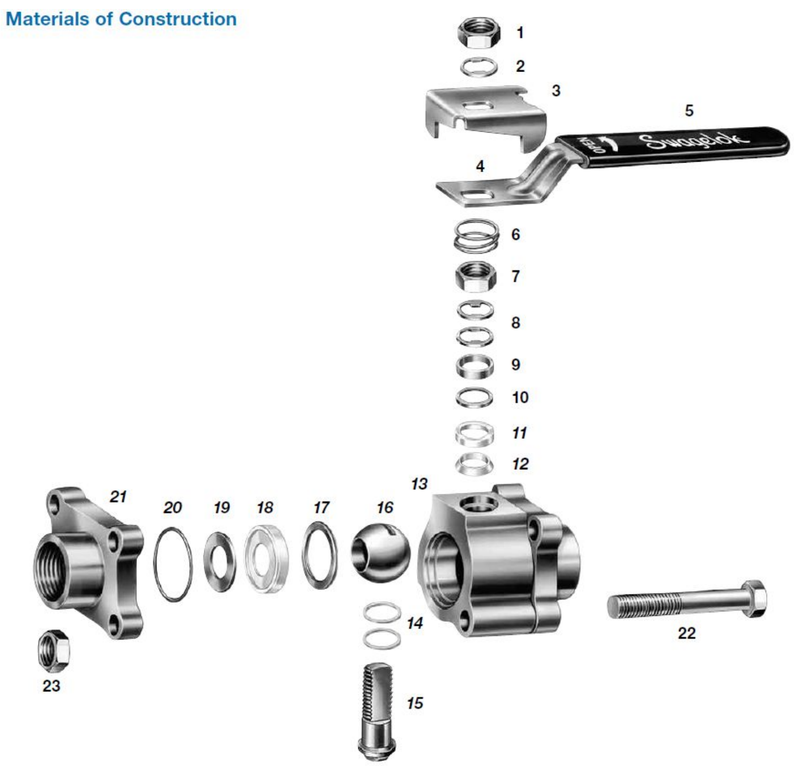
Friction/Galling: No rubbing materials; the body and the stem will rub when the ball valve is turned, but the rubbing speed is minimal compared to
the 1.5 x 10^6 psi-ft/min required to ignite SS.

Mechanical Impact: Will not be an issue when the ball valve is closed. The velocity is not high enough in the lines to cause ignition nor is there any nonmetal material present on impact

Electric Arc/Spark: The body is metallic, therefore there shouldn't be any potential difference within the body.

Flow Friction: Risks are introduced when there is a channeled flow created by a leak on the PTFE valve seat. Depending on the severity the leak, it is possible that the Teflon valve seat gets ignited due to flow friction. Flow friction is increased with the greater velocity of GOx. Our calculated velocity coming out of the vent valves will be 778 ft/s.

7. Press Ball Valve



Vendor: Swagelok
Part Number: ½ Inch SS-63TF8-33C
P&ID P/N: PBV-OX-350
Function Description:
The press ball valve will allow pressure provided by the regulator to go through the stainless steel lines and into the tank. It controls the start of the tank pressurization.
Oxygen Contact:

In the unlikely event of press check valve failure, GOx may backflow to the press ball valve when the vent valve is closed. Under this circumstance, the press ball valve will be in contact with 100% GOx up to 1440 psi set by the pressure relief valve.

Material Assessment :

		Worst-Case Operating Conditions		**Material Flammable?**			
Component	**Materials**	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body, Stem, Ball	SS 316	1440	-361.82	200 psi	N/A	1888.15	Yes
Stem Packing	PTFE	1440	-361.82	95-100%	813	1701.24	Yes
Seat	PTFE	1440	-361.82	95-100%	813	1701.24	Yes
Body Seal	Fluorocarbon FKM	1440	-361.82	57	462.2	12640	Yes

Ignition Mechanism Ratings:

Ignition Mechanism Ratings								
Particle Impact	Compression Heating	Friction Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other	Kindling Chain?	Reaction Effect (A-D)
1	0	0	0	0	1	0	No	B

Ignition Mechanism Analysis:

Particle Impact: Particle impact would not be possible to ignite any part of this component because its only contacts Oxygen when GOx leaks through the check valve seat for flows through a failed check valve at low speed.

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Compressive Heating: All materials are metal except for PTFE which has an ignition temperature of 813 F.; system temperatures will not reach anywhere near 800 F.

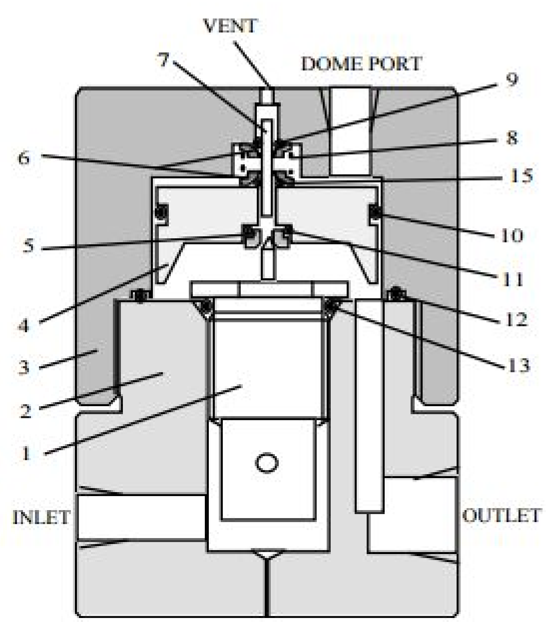
Friction/Galling: No rubbing materials; the body and the stem will rub when the ball valve is turned, but the rubbing speed is minimal compared to
the 1.5 x 10^6 psi-ft/min required to ignite SS.

Mechanical Impact: Will not be an issue when the ball valve is closed. The velocity is not high enough in the lines to cause ignition nor is there any nonmetal material present on impact

Electric Arc/Spark: The body is metallic, therefore there shouldn't be any potential difference within the body

Flow Friction: Risks are introduced when there is a channeled flow created by a leak on the PTFE valve seat. Depending on the severity the leak, it is possible that the Teflon valve seat gets ignited due to flow friction. Flow friction is increased with the greater velocity of GOx. Our calculated velocity coming out of the vent valves will be 778 ft/s.

8. Press Dome Regulator



Vendor: Aqua Environment
Part Number: 873-D High Flow Dome Loaded Reducing Regulators
P&ID P/N: DLR-N2-300
Function Description: The psi that exits the k-bottle is roughly around 3,000. That much psi is too much for a system like this,therefore we must decrease the pressure. The regulator will take the input pressure and only allows the set pressure out the other side. This allows us to regulate the psi through the system,

Oxygen Contact:

In the highly unlikely event of a check valve failure combined with insufficient pressure from the external K-bottles, self pressurized GOx may backflow to the regulator in event of trying to pressurize. In this case, GOx will flow through the vent of the regulator then to the environment.

Material Assessment :

		Worst-Case Operating Conditions		Material Flammable?			
Component	Materials	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body, Cap	Anodized Aluminum	1440 psi	-361.82(Lo), 150(Hi)	12.4 psia	N/A	7425.9	No
Stem	316 Stainless Steel			200 psia	N/A	1888.15	No
Poppet	Brass*			N/A	N/A	790.58	N/A
Seal	Viton/Kel-F			Viton=57 Kel-F=100	Viton=462.2 Kel-F=811.4	Viton=3019.01 Kel-F=1473.68	Viton = no, Kel-F = low

*Note: The brass values used are those for cartilage brass to provide for a bigger factor of safety. Information on the brass used in this part is unavailable.

Ignition Mechanism Ratings:

Ignition Mechanism Ratings (0 - 4)							Kindling Chain?	Reaction Effect (A - D)
Particle Impact	Comp. Heating	Friction/ Galling	Mechanical Impact	Elect. Arc/Spark	Flow Friction	Other (Chatter)		
1	1	2	0	0	3	2	No	A

Ignition Mechanism Analysis:

Particle Impact: Valve does not meet particle impact ignition criteria. Component will be taken apart and LOx cleaned, eliminating . existence of foreign particles inside. The impact point of any particles does not exist between a 45-90 ° angle. If there exists particles within the regulator, it is possible that they will exceed 100 ft/s. At maximum intended operating conditions, the impact of the flow of gaseous nitrogen is ~125 ft/s.

Compression Heating: Assuming an inlet (from Nitrogen k-bottle) pressure of 2800 psi and (max) outlet pressure of 1440 psi through the valve, the pf/pi pressure ratio will be 0.357. The small pressure ratio corresponds to a very low and non-concerning final temperature based of the isentropic compression equation. There is no exposed nonmetal in the heat affected zone. Rapid pressurization will not occur if there are positive pressures within the lines between the outlet of the regulator and lines that contain LOx. Because the regulator is intended to reduce pressure, the GOx coming from the failed check valve downstream will not be compressed from a low to a high pressure. In the event that there is an upstream negative pressure of GOx from the outlet to inlet of the regulator, and the inert gas in the k-bottle is depleted, there could exist rapid pressurization. This event is highly unlikely to occur but is still possible, so the ignition mechanism rating is 1.

Friction/Galling: Friction and Galling are possible due to the piston/seat/poppet assembly in the regulator moving up and down. This motion of the mechanical components is in contact with the working gas and fluid. As pressure changes in the inert k-bottle, the galling of the components may increase.

Mechanical Impact: Not likely due to the fact that the components are mostly non-reactive metals. Also, there will not be repeated and/or large mechanical impacts

Electric Arc and Spark: Not a probable occurrence because the valve is controlled manually/mechanically, and not electrically.

Flow Friction: Can occur in the rare event that there exists negative pressures in the system, causing flow of GOx/LOx upstream through the outlet of the regulator. The liquid/gas oxygen may come into contact with the Kel-F seals, which may generate heat. Also, if there exists a leak in the system, then the gas or fluid may escape the confines of the port and create friction within the piston/seat assembly.

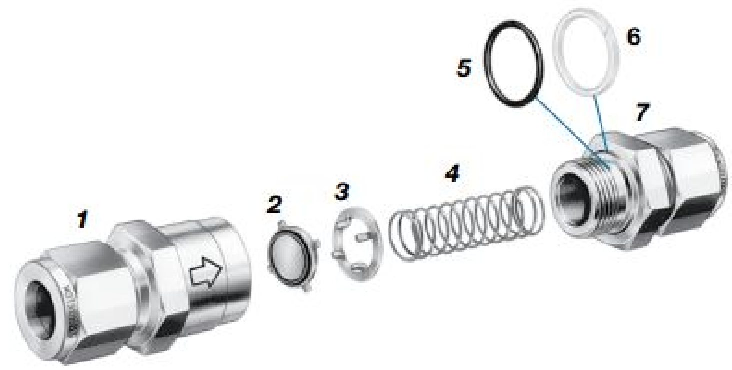
Other/Chatter: Chatter in the valve body is possible if there is an overpressurization in the tubing (could occur if incorrect line sizing) which requires the vent to be utilized. The continual use of the vent may wear down the valve components and the seat, which increase the change of ignition in an event of GOx back flow.

9. Press Check Valve

CH Series

Component	Material Grade/ ASTM Specification
1 Inlet body	*316 SS/A479*
2 Poppet	*Fluorocarbon FKM-bonded*① *316 SS/A479*
3 Poppet stop	*316 SS/A240*
4 Spring	*302 SS/A313*
5 O-ring	*Fluorocarbon FKM*
6 Backup ring	PTFE/D1710
7 Outlet body	*316 SS/A479*
Lubricant	*PTFE-based*

Wetted components listed in *italics*.
① Material Safety Data Sheet for bonding agent available on request.



Vendor: Swagelok
Part Number: ½ Inch SS-CHM8ST
P&ID P/N: CK-N2-370
Function Description: This valves acts as a one way passage for the nitrogen flow right before the tanks and after the regulator. This ensures that no pressure will backtrack and ensures all pressure will be forced to go into the direction of the tanks. This component will only be coming into contact with nitrogen on one end, and on the other it will be in contact with nitrogen and at some point GOx. This check is also here to ensure that no GOx travels to the press system during the fill process.
Oxygen Contact:
The press check valve is placed directly upstream to the LOx tank. Nominally, the check valve's poppet would stop any GOx from traveling up-stream. If the poppet gets too worn or is jammed by debris, it is possible that GOx may leak through the poppet and travel upstream.

Material Assessment :

		Worst-Case Operating Conditions		Material Flammable?			
Component	Materials	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body, Poppet stop	316 SS			200 psia	N/A	1888.15	Yes
Spring	302 SS	1440	-361.82(Lo),150(Hi)	200 psia	N/A	1888.15	Yes

Poppet,Backup ring	FFKM			100 %	617	1565.7	No
Oring	FFKM			100 %	617	1565.7	No
Lubricant	PTFE			95-100 %	813	1701.24	Yes

Ignition Mechanism Ratings:

Ignition Mechanism Ratings							Kindling Chain?	Reaction Effect (A-D)
Particle Impact	Compression Heating	Friction/ Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
0	0	0	0	0	1	0	Yes	C

Ignition Mechanism Analysis:

Particle Impact: The particle impact is not a possible source of ignition because the nominal direction of flow of this check valve should only allow N2 to flow through.

Heat of Compression: Since the cracking pressure of this check valve is below 30 psi, compression is not going to occur, as the valve poppet will open as soon as pressure starts accumulating.

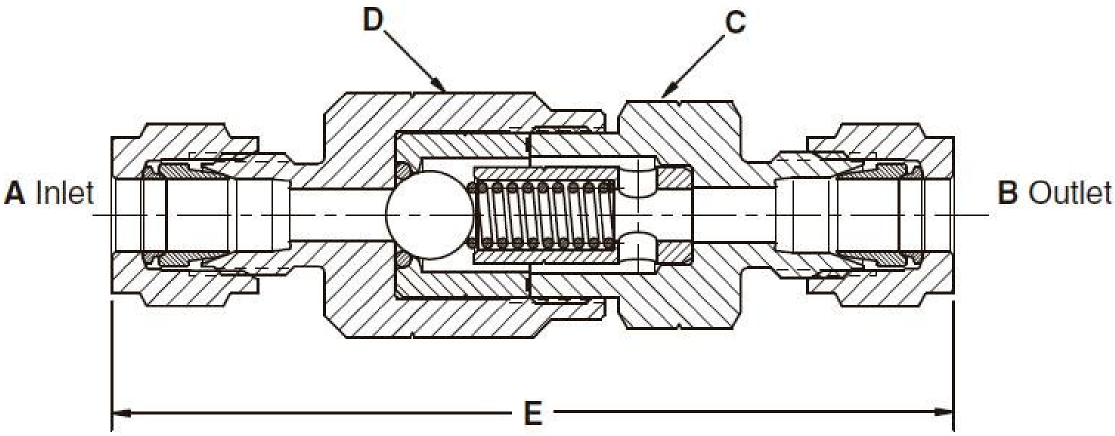
Mechanical Friction/Galling: Mechanical friction does not exist in this valve. There is no moving parts constantly rubbing against each other.

Mechanical Impact: When the downstream pressure difference is around the cracking pressure of the valve, the poppet ball will chatter and smash against the valve seat. Though this motion is menisque, the impulse may be high enough to provide the ignition energy to the PTFE valve seat. However, any pre-existing Oxygen in the valve body prior to the initial opening of the valve would have been purged away from the downstream high pressure nitrogen gas, thus ignition by mechanical impact is impossible.

Electrical Arc: This is impossible since there is not electrical fixtures near this device at all.

Flow Friction: Ignition by flow friction is only possible when there is a leak on the valve seat. Small stream of high velocity pure GOx would escape the tank and fill up the plumbing upstream to the check valve all the way to the press ball valve. To minimize this hazard, the check valve is placed close to the press ball valve to minimize the escape reservoir volume for the leaked GOx.

10. Purge Check Valve



Vendor: Generant
Part Number: ¾ Inch SS-63TF8-33C
P&ID P/N: CK-N2-171
Function Description: The purge check valve allows high pressure N2 gas to flow in only one direction to purge out the main oxidizer line, and prevents Oxygen from entering the purge lines.
Oxygen Contact:
The purge check valve is located past the main valve. It is in contact with cryogenic GOx which is boiled off from the LOx flowing from the main valve to the engine. Since there is static N2 sitting between the purge check valve and the main propellant line, the GOx which enters the branch to this valve is blended with the N2 creating a homogeneous O2-N2 mixture.

Material Assessment :

		Worst-Case Operating Conditions		Material Flammable?			
Component	Materials	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body, Poppet, Spring	316 SS	1440	-361.82(Lo),150(Hi)	200 psia	N/A	1888.15	No
O-ring Seat	Viton			57	462.2	3019.01	No

Body Gasket	PTFE			95-100%	813	1701.24	Yes

Ignition Mechanism Ratings:

Ignition Mechanism Ratings							Kindling Chain?	Reaction Effect (A-D)
Particle Impact	Compression Heating	Friction / Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
0	0	0	1	0	0	0	No	A

Ignition Mechanism Analysis:

Particle Impact: The normal direction of flow will only allow N2 to flow downstream to the engine. The downstream particles will not cause a fire as there is not enough oxygen present. Even if the valve fails, it will not allow particles to accelerate upstream. Therefore, particle impact is not possible.

Heat of Compression: When the main valve is opened, high pressure LOx will flow down to the engine. Since this valve is located on a service branch, there is no direct compression that occurs near the valve.

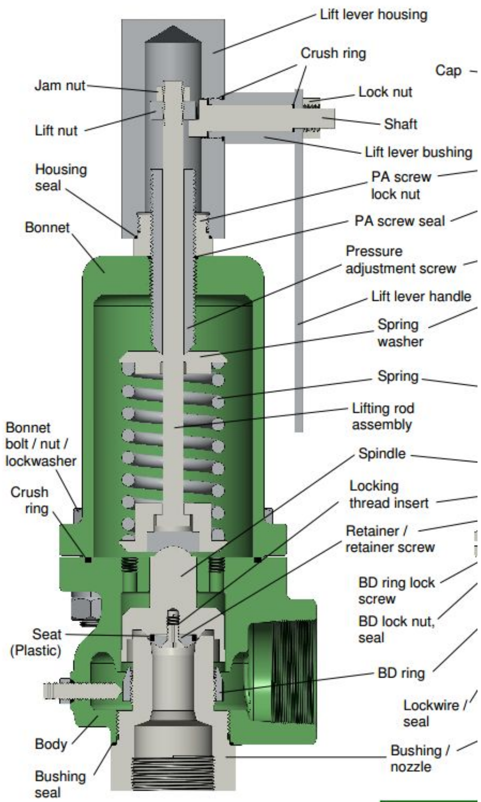
Mechanical Friction: There is no metal to metal contact that would cause sufficient amount of heat to become an ignition source. Ignition by friction or galling would be impossible in this case.
Mechanical Impact: Chattering is possible if there is a failure with the regulator for the purge system. The valve poppet would chatter back and forth, this makes ignition possible but unlikely.

Electrical Arc: There are no electrical parts that are attached to this valve. The valve body is also fully metallic, which allows for no potential difference. Therefore, no risk of electrical arcing

Flow Friction: Flow friction from the upstream N2 will not cause any fire. However, when the purge valve is closed and the check valve poppet is worn and damaged, small amount of GOx and N2 mixture may leak through the valve assembly. However, PTFE have a OI over 99.5%, therefore ignition by flow friction is not possible.

Kindling Chain: In the unlikely event of this component catching fire, the fire would not propagate further as the concentration of oxygen is not sufficient for Stainless Steel piping to burn.

11. Pressure Relief Valve



Vendor: Flowsafe
Part Number: ¼ inch F84-6
P&ID P/N: PRV-N2-380
Function Description: The pressure relief will be calibrated at a set psi that we do not want our tank pressure to reach. In the event that this given pressure is reached the relief valve will automatically release enough pressure until it drops back down to the calibrated psi. This is a safety factor installed to limit the chance of the tanks blowing up and causing someone injury.
Oxygen Contact: The pressure relief valve has the exact same oxygen contact schedule as the vent ball valve. It is in contact with cryogenic temperature GOx as soon as LOx filling begins. As the tank is filled to the desired liquid level constraint by the dipstick of the tank, GOx carrying LOx droplets will flow through this valve. When this valve is closed prior to pressurization of the tank, LOx will continue to boil off and self pressurize. During this period, this valve is in contact with pure GOx. As soon as the tank is pressurized by GN2, the concentration of Oxygen in the gas mixture will drop.

Material Assessment :

		Worst-Case Operating Conditions		Material Flammable?			
Component	Materials	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Body,	316 SS			200 psia	N/A	1888.15	No
Seat, seals	PTFE			95-100%	813	1701.24	Yes
Cap	6061 Aluminium	1440	-361.82(Lo) ,150(Hi)	12.4 psia	N/A	7425.90	No

Ignition Mechanism Ratings:

Ignition Mechanism Ratings							Kindling Chain?	Reaction Effect (A-D)
Particle Impact	Compression Heating	Friction / Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
1	0	0	1	0	2	0	No	A

Ignition Mechanism Analysis:

Particle Impact: When the valve is discharging in an event of overpressurization, any foreign debri added to the system during fill may get carried to the pressure relief valve and hit the seat-spindle assembly of the valve. When discharging to atmosphere, the air velocity is above 100 ft/s. This would ignite the valve seat given the pressure and oxygen concentration of the environment. However, since the GOx is from the boiling of LOx in the tank, it is less likely to carry debri upwards against the pull of gravity.

Heat of Compression: Ignition by heat of compression is not possible for this pressure relief valve because there is not trapped volume of air being compressed at any moment.

Mechanical Friction: Since there is no mechanical moving parts in constant relative motion, this ignition source is not possible.

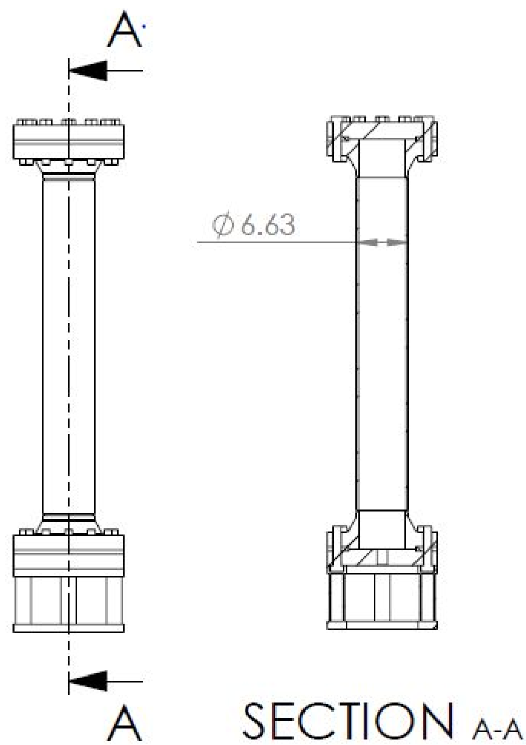
Mechanical Impact: Due to the nature of the pressure relief valve, is it possible to activate the chattering motion of the valve spindler when the tank pressure is maintained slightly above the relief threshold of the valve. Though very unlikely, if the valve does start chattering, there is a good chance that the PTFE is ignited since it is exposed to 100% GOx.

Electrical Arc: Electrical Arc ignition is not possible without the presence of any electrical power source.

Flow Friction: If the spindle becomes stuck and fails to open all the way then threshold pressure have been reached, flow would be pinched and really high friction can be observed

Kindling Chain: If this valve is caught on fire, the positive pressure from inside of the tank will prevent the fire from propagating into the rest of the system.

12. Oxidizer Tank



Custom Made; 6.63 inch ID, weld neck flange with ¾ inch exit port

<u>Material Assessment </u>:

		Worst-Case Operating Conditions	Material Flammable?

Component	Materials	Pressure (psi)	Temperatur e (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Straight Section	Stainless Steel 304	1440	-361.82(Lo) ,150(Hi)	200 psia	N/A	1888.145	Yes
Neck Flange	Stainless Steel 304	1440	-361.82(Lo) ,150(Hi)	200 psia	N/A	1888.145	Yes
Blind Flange	Stainless Steel 304	1440	-361.82(Lo) ,150(Hi)	200 psia	N/A	1888.145	Yes
Ring Gasket	PTFE	1440	-361.82(Lo) ,150(Hi)	95-100 %	813	1701.24	Yes

Ignition Mechanism Ratings:

Ignition Mechanism Ratings							Kindling Chain?	Reaction Effect (A-D)
Particle Impact	Compressi on Heating	Friction / Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
0	0	0	0	0	1		Yes	C

Ignition Mechanism Analysis:

Particle Impact: Since the propellant line speed is 20 ft/s, then the propellant speed exiting the tank is 20 ft/s and the 100 ft/s condition for particle impact will not be met. Because not all conditions for particle impact are present, then particle impact will not occur at either the entrance port or the exit port of the pipe tanks.

Heat of Compression: Assuming the worst-case initial temperature of 150 F and initial pressure of 14.7psia, the final temperature in the pipe tanks is 557.47 F. Since the Autogenous ignition temperature of PTFE is 813 F, then the 180 F gap recommended by the ASTM G Committee is met. As a result, the heat from compression will not pose a risk to the PTFE gasket O-ring. Additionally, the PTFE gasket ring will not be in direct contact with LOx or GOx during rapid pressurization.

Friction/ Galling: Since there are no moving parts within the pipe tanks or moving parts that make up the pipe tanks, there is no mechanical friction present and no ignition mechanism associated with mechanical friction.

Mechanical Impact: Since no non metals are present in the flow of oxygen within the pipe tanks, this ignition mechanism will not occur. There are additionally no large impact or repeated loading within the pipe tanks.

Electrical Arc/Spark: Since the pipe tanks are not electrical components, then there is no electric arcing ignition mechanism present.

Flow Friction: This ignition mechanism is present due to a PTFE ring gasket sealing the interface between the blind flanges and neck flanges. The ring gasket is along the flow path in an area of possible leakage due to the high pressures, However, because the flow path is very small, the conditions are present but weak.
Kindling Chain: Though extremely unlikely, if the tank is ever caught on fire, there will be sufficient enough of oxygen in the tank to sustain burning of the entire tank. This would to catastrophic to the system. However, it is unlikely to have personnel loss due to this failure because all personnel are required to be evacuated when the system is pressurized.

**Note: materials selected should have a 180 F margin between the worst-case operating temperature and the material's AIT (suggestion by ASTM G Committee)
1. This data has been obtained by calculation not experimentation.
2. The value found for SS 304 is specific to 300 series not 304 specifically.
3. Values based on a pressure = 300 psi instead of system pressure (1440 psi)
4. Note 3 will need to be corrected for.

13. Oxidizer Tubings

Vendor: McMaster Carr
Main: ¾ inch, Press: ½ inch

Material Assessment :

		Worst-Case Operating Conditions	Material Flammable?

Component	Materials	Pressure (psi)	Temperature (F)	OI (%) or PCT (psia)	AIT (F)	HoC (cal/g)	Flammability
Tube	SS 304	1440	150	200	N/A	1888.145	Yes
Cavitating Venturi Tube	SS 304	1440	150	200	N/A	1888.145	Yes

Ignition Mechanism Ratings:

Ignition Mechanism Ratings							Kindling Chain?	Reaction Effect (A-D)
Particle Impact	Compression Heating	Friction / Galling	Mechanical Impact	Electric Arc/Spark	Flow Friction	Other		
0	1	0	0	0	0	0	No	A

Ignition Mechanism Analysis:

Particle Impact: Because the maximum propellant line speed is 20 ft/s which does not exceed the 100 ft/s necessary condition of particle impact, particle impact ignition will not occur within the stainless steel tubing

Compressive heating: Compressive heating will not occur because gas will not be exposed to nonmetal in just the tube assuming that the system is completely cleaned prior to use. GOx is a possibility but due to the cleaning process will not ignite any nonmetal materials. (Note: depends on if there is nonmetal parts in
components such as valves that creates downstream "dead end" but compressive heating will not happen in just the SS tube itself)

Friction/Galling: There are no rubbing surfaces present.

Mechanical Impact: Mechanical Impact will not occur because there will not be any large impact or repeated impact loading that occurs

Electric Arc/Spark: The stainless steel tubes are not electrically powered components.

Flow Friction: Flow friction ignition mechanism will not occur because oxygen will not be exposed to nonmetal materials in flow path. (Note: also depends on parts such as the regulators and valves and whether or not nonmetal material is present in these components.

Kindling chain: A kindling chain does not exist because even though the component is flammable under the temperature and pressure condition, it lacks possible ignition mechanism. However, the piping can serve as the propagating medium in the event of other components catching on fire.