VCS Tank & Test Cart HAZOP

Study approach: Deviation by Deviation Table Drawing No.:
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HAZOP Team: Patrick Adam, Ian Richardson, Eli Shoemake, Sean Dimmer, Drew Boettner, Jake Leachman

Node: __VCS Tank_____

Intent: ____Store liquid and supply gaseous hydrogen at 20 psi_____

Guide Word	Deviation	Causes	Consequences	Safeguards	Recommendations
High Flow	Too much flow from regulator (higher than FC can use)	Heater overpower, failure of insulation, oversupply from dewar, See high temperature.	See high pressure.	Heater control system, ortho-para converter, designed for multiple boil-off rates, low-pressure fills from dewar.	Quantify nominal flow rate range for FC.
High Flow	Too much flow for PRD.	Same as above.	Rupture.	Design, test, and validate PRD operation. Dual-redundant PRDs.	Determine max flow rate of single PRD.
High Flow	Too much flow for tank passageways	Oversupply from dewar to hot tank, obstruction to passageway.	Rupture.	Tank passageway designed to pressure relief standards, low pressure fills.	Determine max LH2 flow and evaporation rate (hot tank) and where/what will choke first.
High Flow	Too much flow for 1/4” Valve TN709	Same as above	See high pressure.	Designed to pressure relief standards, low pressure fills.	Test.
Low/no flow	Too little flow from regulator (lower than FC needs)	Obstruction/blockage, damage, changed heater setpoint or broken heater, low pressure.	Unable to supply adequate hydrogen to FC, see high pressure.	Routine maintenance and operation.	Verify advertised temperature operating range of components.

Guide Word	Deviation	Causes	Consequences	Safeguards	Recommendations
Low/no flow	Too little flow from PRDs	Obstruction/blockage, see high flow, heater setpoint, choked flow/high pressure, poor purge, see impurity.	See high pressure. Rupture, tank fragment blockage.	Routine maintenance and operation.	Develop maintenance log/schedule.
Low/no flow	Too little flow through passageways	Obstruction/blockage (print powder or catalyst, poor purge), heater setpoint, choked flow/high pressure.	Rupture, see high pressure.	Ensure pure gas and proper purge. Test for blockage at room temperature.	Investigate whether gas sampling is required.
Low/no flow	Too little flow through 1/4” valve TN709	Obstruction/blockage (print powder or catalyst, poor purge), heater setpoint, choked flow/high pressure.	Rupture, see high pressure.	Visually inspect and manually operate prior to fill.	Test.
Low/no flow	Too little flow through quick connect	Obstruction/blockage, heater setpoint, choked flow/high pressure.	Unable to fill or operate	Cap when not in operation.	
High level	Overfill of tank resulting in liquid within vapor passageway	Overfill of 90% of tank capacity.	Failure to shutoff liquid fill.	Tank passageway will naturally boil outer shell to prevent high level.	

High Pressure (liquid space)	Overpressure in liquid space 30<P<45 psig	PRD failure, obstruction/blockage, heater overpower, failed insulation,	Overpressure above MAWP, see high flow.	Proper purge, pure gases, liquefier condenses impurities, scope if refurbishing/recertification.	Will consider new pressure tap.
High Pressure (liquid space)	Overpressure in liquid space P>45 psig	PRD failure, obstruction/blockage, heater overpower, failed insulation,	Rupture	Proper purge, pure gases, liquefier condenses impurities, scope if refurbishing/recertification.	Will consider new pressure tap.

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High Pressure (insulation)	P>2 psig delta from liquid space	Leak	Loss of insulation, rupture	Cryopumping, aerogel insulation,	Determine nominal pressure values for insulation space. PRD device for insulation layer.
High Pressure (vapor passageways)	Overpressure 30<P<45 psig	PRD failure, obstruction/blockage, heater overpower, failed insulation,	Overpressure above MAWP, see high flow.	Proper purge, pure gases, liquefier condenses impurities, scope if refurbishing/recertification.	
High Pressure (vapor passageways)	Overpressure P>45 psig	PRD failure, obstruction/blockage, heater overpower, failed insulation,	Rupture	Proper purge, pure gases, liquefier condenses impurities, scope if refurbishing/recertification.	
Low Pressure	P<20 psig	Heater control loop failure, leak,	FC Failure	Precheck heat control loop prior to operation.	
Low pressure	P<4 psig	Improper storage, left open vent valve,	Impurities, rupture,	Follow proper storage guidelines	Write operating manual for tank storage.

		improper purge procedure.			
High Temperature	T>350F	Fire, heater run away in empty tank	Melting, leak, rupture, deflagration 💥🔥	Follow standards and procedures to minimize risk	Consider bonding temp sensor to heater to monitor output with feedback loop to shutoff heater above 40C
Low Temperature	T< -40C	Flow rate too high, operating tank in cold conditions, liquid level too high flowing in to vapor channels	Possible leakage out of non-cryo rated seals	Follow operating manual	Confirm lower temp limit for polymer seals

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High concentration in vapor passages	>0.001% for gas impurities	Impurities in hydrogen stream	Blockage of vapor passages & PRDs, see high pressure	Proper purge, pure gases, liquefier condenses impurities, scope if refurbishing/recertification. Follow operating/storage procedures for fuel connection	Investigate if tank bake out process for moisture removal in nylon is required
High Power	Heater power > 10W	Heater control loop failure	Heater lead wire burns out – loss of heater, unable to operate		Investigate if fuse can be utilized on control board, or transistorized switch to meet Div1 Class1 rating
Leak	Leak from LH2 disconnect	Incomplete seal after valve closure	Gentle h2 stream, unable to build pressure in tank, deflagration		Design fluid tight cap
Leak	Fluid plumbing component leaks	Improper installation, thermal contraction, thermal cycling, vibration	Small H2 leak	Leak check	
Leak	Tank wall crack	Thermal cycling, impact, H2 fire from adjacent leak	Fire from leak		
Rupture	Tank wall	Thermal cycling, impact, H2 fire from adjacent leak, see high pressure, see low	Deflagration, detonation	Transportation case, secured to test stand	

		pressure, crushing in mount device			
Guide Word	Deviation	Causes	Consequences	Safeguards	Recommendations
No movement	Manual vent valve handle departs	Improper installation or operation	Valve won't open – cannot fill; valve won't close – cannot fly		
Unintended movement	Regulator set point screw	Vibration	Change in flow pressure to FC	Ensure jam nut is secure	
Unintended movement	Quick connect hold-down screws	Vibration, improper installation	H2 leak, low pressure in tank, deflagration		Future installation of aircraft safetywire
Unintended movement	PRD collector screws	Vibration, improper installation	Misdirected flow into electric motor		Future installation of aircraft safetywire
Unintended movement	Control board screws	Vibration, improper installation	Disconnect from tank temp sensors and heater, loss of data flow and ability to control heater		Future installation of aircraft safetywire