Investigative Report on Chemistry 301A Cylinder Explosion

By

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Introduction

On January 12, 2006, at approximately 3 AM in the morning, an explosion occurred in the Chemistry Building (Building Number 484). The explosion was centered in Laboratory 301A of the 28 Wing, causing extensive damage to 301A from a blast wave of unknown origin. The area was unoccupied at the time, and the results of the explosion were not noticed until around 5:30 AM by Physical Plant who was investigating a sudden drop in water pressure. Physical Plant notified the Radio Room and a subsequent response from the Fire Department and Environmental Health and Safety Department secured the blast area.

Subsequent investigation revealed a massive explosion had occurred, blowing out two windows in 301A, the wall leading into the hallway, and that a cylindrical hole approximately 24 inches in diameter had been blown through the ceiling. A nitrogen cylinder was found lying in the penthouse mechanical room, its forward momentum apparently stopped by piping in the mechanical room. Damaged piping had caused significant water damage throughout the wing. Additionally, a support beam under where the tank explosion had occurred had sustained significant structural damage in Room 201A. A hood in 301A was completely destroyed as was a chemical glove box; the wall adjoining 301B was also significantly damaged. Of immediate concern was the large amount of chemical spillage that occurred as a result of damage to containers within the laboratory. Physical Plant took steps to control water breaks and a massive cleanup operation was undertaken. An outside contractor (Steamatic) also began the water damage recovery on surrounding areas and lower floors. On Thursday, January 19, 2006, the majority of chemical cleanup had been completed, and operations within the Building were turned over to the Occupational Safety and Health Unit to begin evaluations on reoccupancy and for investigation into the cause of the explosion. The following sections summarize the observations and conclusions of that investigation.

Debris Field

The debris field consisted mostly of Room 301A and the penthouse, as well as the planting bed outside of the laboratory windows. Another device dislodged from what was later determined to be the glove box had exited 301A through the door area, passing across the corridor and braking through a window. The part was recovered by Physical Plant, but had little bearing on the nitrogen tank thought to be the source of the explosion. The bottom portions of the internal and external cylinders were found in Room 301A while the majority of parts, including the cylinder, were found in the penthouse mechanical room. Parts and debris from the initial explosion had been carefully collected and transported to Building 1165 for storage. After examining collected materials, Occupational Health and Safety (OHS) made a detailed search of 301A, the penthouse, and the planting area, but were unable to locate any additional parts. Of particular interest were two parts, the pressure relief valve and the rupture disk for the internal tank, neither of which had been previously located.

Tank Observations

The tank (see photos in Appendix C) was badly damaged from the blast, but still revealed a great deal of information. Upon examination, it was evident that a catastrophic failure of the internal cylinder had occurred; causing a rapid expansion of nitrogen that blew out the bottom of the internal and external tanks, propelling the cylinder upward. The upward part of the cylinder retained its shape, but was badly deformed when it struck and penetrated the floor of the penthouse. Despite this damage, the plate indicating the tank description and manufacturer was obtained. The original manufacture was a company called Minnesota Valley Engineering (MVE), who had constructed and tested the tank in December of 1980. Attempts to locate a sister tank failed, but after determining that Minnesota Valley Engineering had been purchased by Cryogenics in 1998, who were subsequently purchased by Chart

Industries, Inc, a schematic of what the tank would have looked like was obtained (see Appendix B). The schematic was used to reassemble the attachments as they would have existed on the tank. Initially, it was thought the rupture disk for the interstitial space between the tanks was present, owing its presence to internal tank swelling protecting it from the pressure. However, it was later determined that the disk was missing, most probably due to impact with the penthouse floor.

Tank Reconstruction

Based on schematics supplied by Chart Industries, OHS was able to reconstruct the tank and account for most, if not all of the pieces dislodged during the explosion and subsequent damage when penetrating the floor. Both regulators were found, as indicated in the drawing and as described by laboratory personnel. Two pressure gauges were found, although the laboratory personnel initially argued that only one gauge was present. Various pieces of small piping were found, along with the quarter inch cross (junction fitting for four outlets) where the internal tank pressure relief and rupture disk would have been attached. However, additional searches did not reveal the presence of any additional parts. After reconstruction was as complete as possible, on January 23rd, 2006, OHS contacted Chart explaining that an explosion had occurred in the tank in question and asking for assistance in evaluation. On the same day a call was received by EHSD from Tom Carey, President of the Distribution and Storage Division of Chart. Mr. Carey offered the assistance of Keith Gustafson, an experienced engineer originally from Minnesota Valley Engineering, but now with Chart's Biomedical Division. Mr. Gustafson arrived on site the following day.

Outside Engineer's Observations

Upon examining the tank on January 24, 2006, Mr. Gustafson immediately pointed out that the cross where the internal tank regulator and the rupture disk should have been attached had been sealed with two brass plugs. Mr. Gustafson also pointed out

that you could see on the external tank where the vaporizer piping that loops around the internal tank had been pressured by the swelling of the internal tank, forming visible rings on the external tank. All of these, according to Mr. Gustafson, were a direct indication that the pressure relief and the rupture disk had probably failed at sometime in the past and the openings sealed. Without these two safeguards in place, it was only a matter of time until an explosion occurred. When queried as to why it had not exploded earlier, Mr. Gustafson pointed out it depended on how quickly the nitrogen was used after filling.

Conclusion

Based on observations by OHS and subsequent observations by Keith Gustafson of Chart Industries, Inc., the catastrophic failure of the nitrogen tank in room 301A was a direct result of the removal and subsequent sealing of the internal tank pressure relief devices. Without the devices in place, it was indeed only a matter of time until a catastrophic failure of the internal tank occurred. In short, the tank was improperly modified by an unidentified person or persons resulting in catastrophic failure of the tank. However, in the written report provided by Mr. Gustafson in Appendix A, OHS does not agree with his conclusion over the pipe plugs being of the same size and type, and therefore possibly installed at the same time. Although we may never know the timing of the plug installations, OHS would note that one plug appeared to have corrosion, indicating it may have been in place for a longer period of time. Additionally, the two plugs are not identical. In fact, although of the same shape and size, one plug appears to be of an aluminum alloy (silver in color) and the other is brass (yellow in color). The use

of Teflon tape appears to be a widespread practice as evidenced on other tanks subsequently examined in the Building.

Recommendations

All nitrogen tanks and similar vessels should be examined to determine that proper safety devices (regulator and rupture disk) are in place. OHS has already begun to examine tanks in Chemistry, and have found no similar problems to date. OHS will also develop an online training program and will strongly recommend anyone working with cryogenics avail themselves of this resource. All future laboratory inspections conducted will include tank inspections.

Finally, Keith Gustafson of Chart Industries has recommended that all cylinders of the type involved in this incident have the pressure relief valves replaced every five years. This suggestion would seem prudent and EHSD is evaluating how to implement this suggestion on a campus-wide basis.

Concluding Remarks

I would like to personally acknowledge the hard work and cooperative attitudes of all personnel involved, including the faculty and staff of the Chemistry Department, the College Station Fire Department, and the staff of Environmental Health and Safety. I would also particularly like to thank Chart Industries and Mr. Keith Gustafson for their immediate and invaluable support.

APPENDIX A

Chart Engineer's Report

Mattox, Brent S

From: Gustafson, Keith [Keith.Gustafson@Chart-ind.com]
Sent: Thursday, January 26, 2006 2:51 PM
To: Mattox, Brent S
Cc: Carey, Tom; Haukoos, Bill; Drube, Tom; Dosdall, Roger
Subject: Trip Report Texas A&M
Attachments: Cause.JPG; Effect.JPG; Effect2.JPG

Brent,

A good source of information on safe handling and maintenance of liquid cylinders is the Compresses Gas Association, 1725 Jefferson Davis Hwy., Arlington, VA 22202. http://www.cganet.com CGA P-12 Safe Handling of Cryogenic Liquids and CGA S1.1 Pressure Relief Device Standards for Compressed Gas Cylinders are two good reference publications.
CGA S1.1 Section 9.1 Discusses maintenance requirements for CG-7 type relief valves. If you need any more information feel free to contact me or Bill Haukoos, the Engineering Manager at the Canton, GA site where the cylinders are currently produced and we'll be glad to help.

Keith Gustafson
Chart Industries

Tuesday Jan 24, 2005

Met with Brent Mattox, Manager of Industrial Hygiene, Environmental Health & Safety Department for Texas A&M University to see the remains of a 1981 VGL-160, SN 30480A, that exploded in the Chemistry building early Saturday morning 1/14/06.

We first saw the remains of the cylinder that had been collected and stored in a maintenance building. Since the explosion was contained in the Chemistry building virtually all of the pieces of the cylinder were recovered. The cause of the explosion was immediately evident from the parts. The cylinders two safety devices, the 230 psi relief valve and 400 psi rupture disk, had been removed and replaced with pipe plugs. The resulting overpressure failure of the cylinder was a textbook example. With no outlet for the gas the cylinder slowly built pressure until the hoop stress exceeded the yield strength of the inner vessel. The inner vessel expanded until it contacted the outer vessel, as clearly seen by the impressions the gas use tube made on both the inner and outer vessel as it was crushed between them. The outer vessel reinforced the inner against much further circumferential expansion and the pressure continued to build until the longitudinal stress in the cylinder exceeded its yield strength, resulting in the separation of the bottom head from the vessel. As this separation occurs between 1000-1200 psi the 250,000 pounds of force drove the inner bottom head through the outer and propelled the cylinder into the ceiling of the lab causing extensive damage to the building. The remains of the inner vessel showed no signs of corrosion or abuse, so overpressure appears to be the sole cause of the failure.

We next visited the Chemistry building to view the damage caused by the explosion and inspect the condition of other liquid cylinders on the property. The cylinder had been standing

at one end of a ~20' x 40' laboratory on the second floor of the chemistry building. It was on a tile covered 4-6" thick concrete floor, directly over a reinforced concrete beam. The explosion blew all of the tile off of the floor for a 5' radius around the tank turning the tile into quarter sized pieces of shrapnel that embedded themselves in the walls and doors of the lab. The blast cracked the floor but due to the presence of the supporting beam, which shattered, the floor held. Since the floor held the force of the explosion was directed upward and propelled the cylinder, sans bottom, through the concrete ceiling of the lab into the mechanical room above. It struck two 3 inch water mains and drove them and the electrical wiring above them into the concrete roof of the building, cracking it. The cylinder came to rest on the third floor leaving a neat 20" diameter hole in its wake. The entrance door and wall of the lab were blown out into the hallway, all of the remaining walls of the lab were blown 4-8" off of their foundations. All of the windows, save one that was open, were blown out onto the courtyard. Fortunately nobody witnessed the explosion which probably occurred around 3 am. The accident wasn't discovered until the physical plant noticed a drop in water pressure, caused by the broken mains on the third floor, and went to investigate.

We saw 3 other liquid cylinders on the property, a Ryan, a Linde, and another MVE (Dura 5500). All were well maintained, none had ever been tipped over, probably due to the use of Harper carts for handling. All the correct rupture disks and relief valves were in place. I recommended that they institute a training and PM program for their remaining cylinders based on CGA guidelines and at minimum retest or replace the primary relief valves every five years.

The only remaining issue is why were both relief devices replaced with pipe plugs? When this has happened in the past the typical scenario is something like this. The rupture disk on the cylinder blows from age. The local maintenance person doesn't have a rupture disk so it is replaced with a pipe plug and the cylinder is returned to service. Everything is fine for years until something causes the relief valve to leak and it too is replaced with a plug, leading to the inevitable failure soon after. When this happens the pipe plugs typically look different, since they were replaced at different times. The only thing a bit unusual about this accident is that the plugs looked identical. Both the same size, shape and apparent age, both installed with Teflon tape, leading you to believe that both were replaced at the same time by someone that understood plumbing. This being said realize that they weren't in pristine condition, after traveling through 6 inches of concrete. While there were many pictures taken at the site the three attached sum it up.

Keith Gustafson
Chart Industries

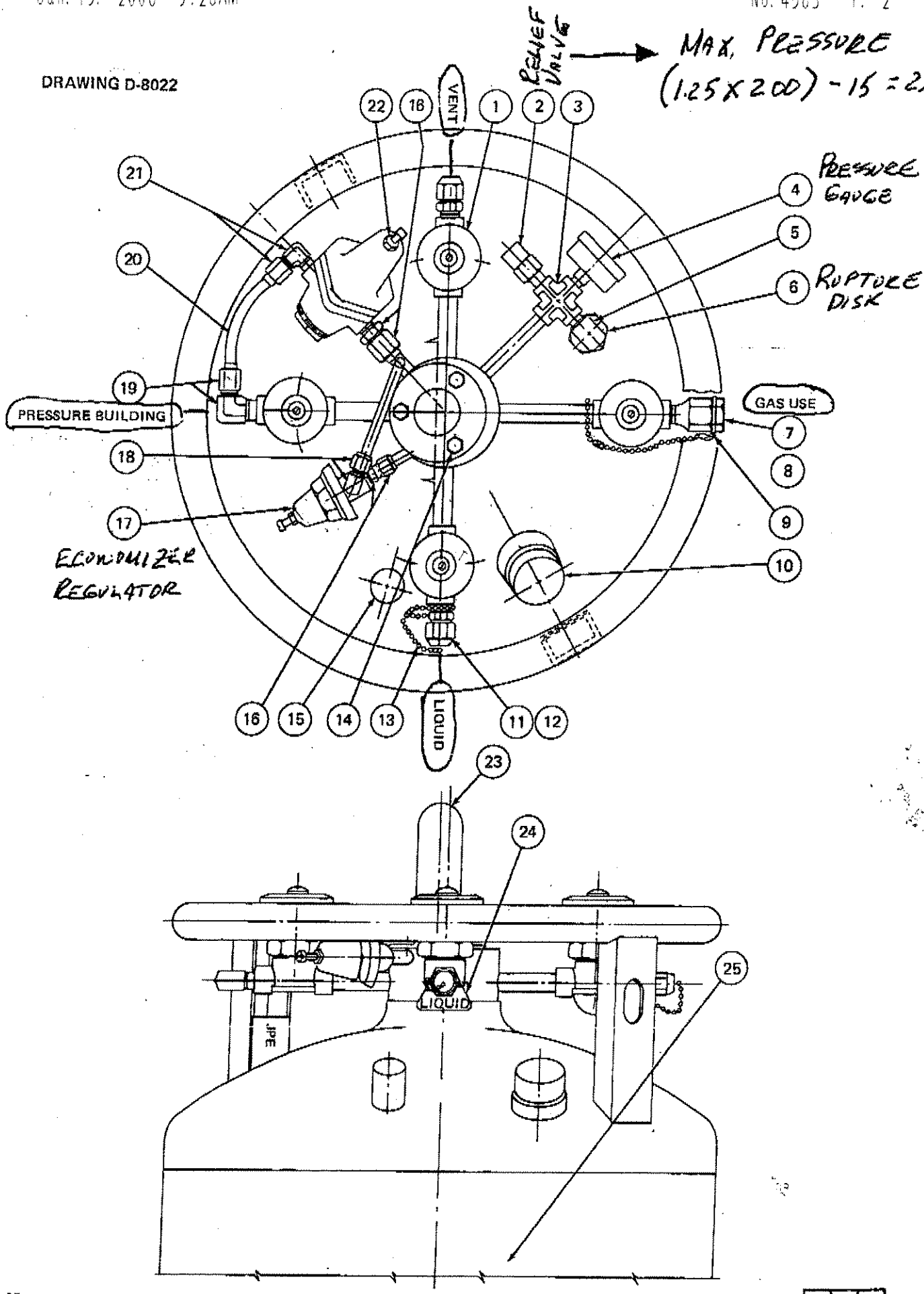

LIQUID NI


STOP

APPENDIX B

Chart Corporation's Facsimile of Tank Design

DRAWING D-8022



MVE Cryogenics

APPENDIX
MODEL VGL-160L
PARTS LIST

(3) 17-1001-2
(1) 17-1002-2 PB Valve

Item No.	Part or Code No.	No. Req'd	Description
1	17-1001-2	4	GLOBE VALVE, BRASS, 3/8" NPT BORE INLET FOR 3/8" PIPE X 1/2" DEEP.
2	18-1006-2*	1	RELIEF VALVE, 1/4" NPT, BRASS, 235 PSIG SET PRESSURE.
3	12-1076-2	1	CROSS 1/4" NPT.
4	20-1009-4*	1	PRESSURE GAUGE, 0-400 PSIG, RANGE 1/4" NPT CBM 2" DIAL LOX CLEANED.
5	12-1046-2	1	1/4" NPT 90° STREET ELBOW.
6	19-1001-2*	1	SAFETY RUPTURE DISC, 1/4" NPT 425 PSIG BURST AT 72°F.
7	40-1001-2*	1	OXYGEN CGA 541, 3/8" NPT.
	40-1002-2*	1	INERT CGA 581, 3/8" NPT.
8	40-1004-2*	1	OXYGEN DUST CAP
	40-1005-2*	1	INERT DUST CAP
9	45-1002-2*	1	BEADED CHAIN COUPLING, AUTO SWAGE #10AN.
10	39-1031-6*	1	RUPTURE DISC COVER.
11	11-1007-2*	2	INERT MALE CONNECTOR, 1/2" ODT X 3/8" NPT, BRASS, HEAVY DUTY 45° FLARE.
	11-1011-2*	2	OXYGEN MALE CONNECTOR, 5/8" ODT X 3/8" NPT, BRASS, HEAVY DUTY 45° FLARE.
12	11-1046-2*	2	INERT DUST CAP, 1/2" ODT BRASS.
	11-1042-2*	2	OXYGEN DUST CAP, 5/8" ODT BRASS.
13	80-1450-2*	3	BEADED CHAIN, CHROME PLATED BRASS 10" LG., AUTO SWAGE #10 OR EQUAL.
	45-1005-2*	3	COUPLING, BRASS CHROME PLATED WITH EYELET, AUTO SWAGE #10AN OR EQUAL.
	45-1003-2*	3	SLEEVE, BRASS, CHROME PLATED, AUTO SWAGE #FS-10 OR EQUAL.
14	29-1050-1	3	CAP SCREW 1/4"—20NC X 5/8" LG. HEX HD. SS.

Item No.		Part or Code No.		No Req'd	Description
14 (continued)	.008	29-1060-1	.02	3	LOCK WASHER, 1/4" SPLIT TYPE SS.
	.039	29-1146-6	.10	3	NYLON GASKETS.
15	.83	39-1038-5	2.09	1	PUMPOUT CAP.
16	3.24	10-1007-1	8.10	2	MALE CONNECTOR, 3/8" ODT X 1/4" NPT OR EQUAL.
17	21.52	21-1002-2*	53.70	1	BACK PRESSURE (ECONOMIZER) REGULATOR, 1/4" NPT SIDE INLET 1/4" NPT BOTTOM OUTLET BRONZE FOR -300°F. 50-175 PSI RANGE.
18	5.69	10-1042-1	14.23	1	MALE 90° ELBOW, 3/8" ODT X 1/4" NPT.
19	2.29	10-1043-2	5.73	1	MALE ELBOW, 3/8" NPT X 3/8" ODT.
20		69-1070-3		1	3/8" ODT COPPER, FORM AS SHOWN.
21	2.05	10-1039-2	5.13	1	MALE ELBOW, 3/8" ODT X 1/4" NPT OR EQUAL.
22	25.418	21-1003-2*	63.55	1	PRESSURE REGULATOR, 50-230 PSI.
23	1.7	54-1036-5*	4.25	1	GAUGE SIGHT PROTECTOR.
24	.146	38-1160-9*	.37	1	LABEL VENT
		38-1161-9*		1	LABEL PRESSURE BUILDING
		38-1158-9*		1	LABEL LIQUID
		38-1159-9*		1	LABEL USE
25	.394	38-1173-9*	.78	1	DECAL LIQUID OXYGEN
	.312	38-1170-9*	.78	1	DECAL LIQUID NITROGEN
	.288	38-1172-9*	.78	1	DECAL LIQUID ARGON
		97-1558-2*		1	RENEWAL KIT, PRESSURE BUILDING REGULATOR
		97-1557-2*		1	RENEWAL KIT, ECONOMIZER REGULATOR

*Recommended spare parts.

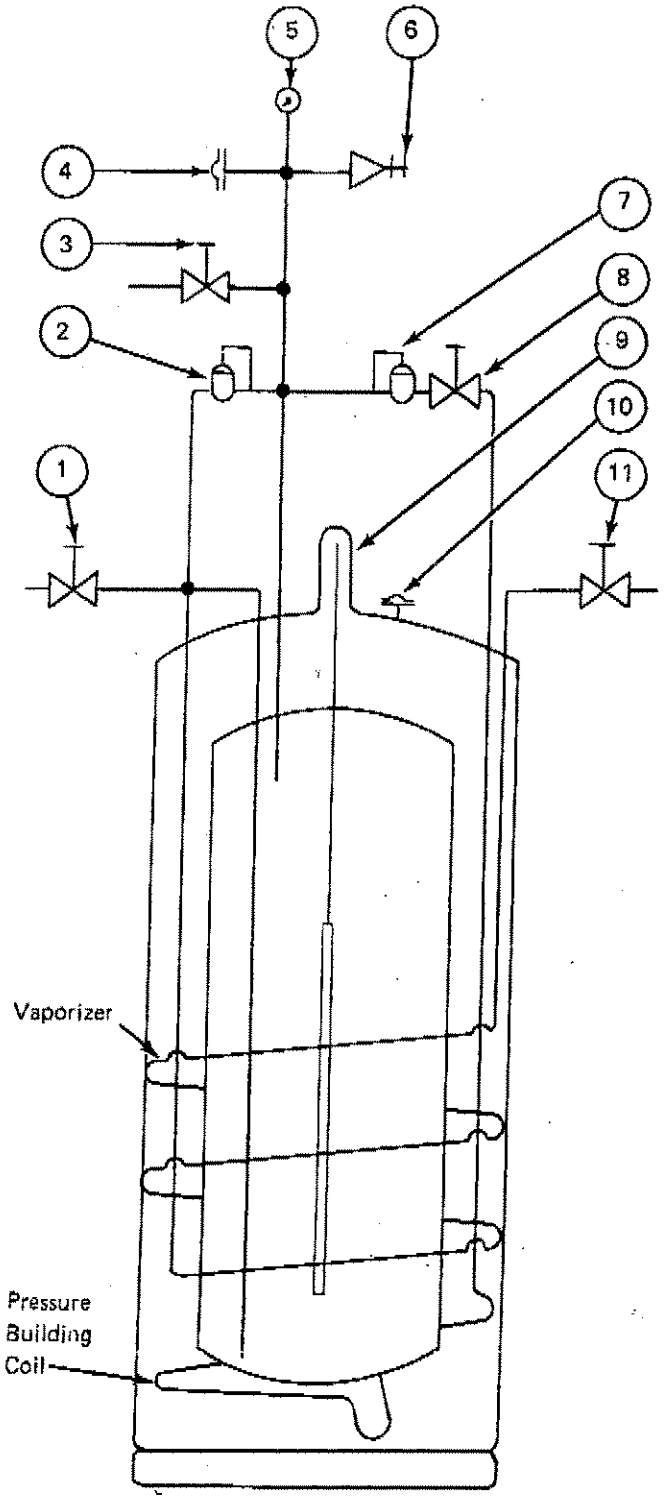
64-1070-3 3/8" ODT Copper 6" long with nut + ferrule 3/8 ODT - PN 10-1007-2 and 10-1007-2 ea end. $3.00

MVE Cryogenics

FLOW SCHEMATIC

MODEL VGL-160L

FIGURE 1



1. Liquid Valve
2. Economizer Regulator
3. Vent Valve
4. Burst Disc, 425 PSI
5. Pressure Gauge
6. Relief Valve, 235 PSI
7. Pressure Building Regulator
8. Pressure Building Valve
9. Liquid Level Gauge
10. Vacuum Casing Burst Disc
11. Gas Use Valve

APPENDIX C

Additional Tank Photos