E706 CRYOSYSTEM DESIGN NOTE

E706EN020

TITLE: Liquid Argon Calorimeter

Analysis of Trapped Volume Relief Requirements

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The purpose of this note is to provide calculational verification that several E706 cryosystem subsystems and components are adequately relieved.

The diagrams and component nomenclatures have been taken from the "E-706 Flow Sheet," Revision 8, RD-Cryogenics, and the E706 "Valve and Instrument Summary." If the proper drafts and revisions are not available, the diagrams and nomenclatures used in this report are to be considered most current.

The separate calculations are presented in the following appendices:

Appendix A: Analysis of Trapped Volume Relief Capacity

Appendix B: Isolation of the LAr Pump

Appendix C: Overpressurization of Lines Due to Improper Valve Line Up @ the GAr Reference Bottle

Appendix D: Overpressurization of Lines Due to an Improper Valve Line Up During an Argon Dewar Tank Truck Fill Operation

The E706 Transfer Line List has also been included in this report for reference.

New Appendices will be added, as needed, to complete this report and attached by separate E706 Cryosystem Design Notes.

REVIEWED BY:

Name	Date	Project Manager	Date

APPENDIX A Analysis of Trapped Volume Relief Capacity

This note is to verify that all isolatable (trapped) volumes of cryogens are adequately relieved. All such trapped volumes are relieved using a CIRCLE SEAL, K-5120T1-2MP, relief valve. This is a 1/4 inch nominal size adjustable valve set to 100PSIG cracking pressure. The flow capacity is 70SCFM, air. Please refer to the "E706 Flow Sheet," 2220.1-ME-183293, Rev. 8, RD/Cryogenics, and the "Liquid Argon Calorimeter Valve and Instrument Summary" for specific information.

According to *Cryogenic Systems*, R. Barron, McGraw-Hill, 1966, Page 504, a heat flux value is $575\frac{BTU}{Hr-ft^2}$, this value will be used to make the evaluations for the following pipe sizes:

$$\begin{aligned} \text{3/4 IPS,} \quad & \text{A} = 0.275\ ft^2/ft, \text{ (surface area per foot of pipe)} \\ \text{1-1/2 IPS,} \quad & \text{A} = 0.497\ ft^2/ft, \\ \text{2 IPS,} \quad & \text{A} = 0.622\ ft^2/ft. \end{aligned}$$

The heat flux per foot of pipe is therefore $Q = 575 \times A/60$, or, for the above sizes:

$$\begin{aligned} \text{3/4 IPS,} \quad & \text{Q} = 2.635\ \frac{BTU}{min-ft}, \text{ per foot of length,} \\ \text{1-1/2 IPS,} \quad & \text{Q} = 4.763\ \frac{BTU}{min-ft}, \text{ per foot of length,} \\ \text{2 IPS,} \quad & \text{Q} = 5.961\ \frac{BTU}{min-ft}, \text{ per foot of length.} \end{aligned}$$

The relief capacity required (RVQ), which is just the vapor generation rate per foot of length, can be found from:

$$\begin{aligned} \text{RVQ} &= \frac{QV_{STP,AIR}}{H_{FG}}, \text{ SCFM, air per foot of length,} \\ \text{where Q} &= \text{heat flux per foot of length,} \\ V_{STP,AIR} &= 13.55\ ft^3/lbm, \\ H_{FG} &= \text{latent heat of vaporization.} \end{aligned}$$

Therefore the total vapor generated, the vapor that must be relieved, is $RVQ \times L$. This value must be less than or equal to the maximum relief capacity of the relief device (SVQ), that is:

$$RVQ \times L \leq SVQ.$$

From this relation, the maximum acceptable length of run can be found from:

$$\begin{aligned} \text{L} &\leq \tfrac{SVQ}{RVQ}, \\ \text{where RVQ} &= \text{vapor generation rate per foot of run, SCFM, air} \\ \text{SVQ} &= \text{relief device maximum capacity, 70 SCFM, air,} \\ \text{L} &= \text{maximum acceptable length, feet.} \end{aligned}$$

For Nitrogen at 100PSIG, where $H_{FG} = 68.86\frac{BTU}{lbm}$, the maximum length of run is: ($V_{STP,AIR} = 13.55 ft^3/lbm$)

NITROGEN

3/4 IPS,	134 feet 10 inch
1-1/2 IPS,	74 feet 8 inches
2 IPS,	59 feet 3 inches

For Argon @ 100PSIG, where $H_{FG} = 60.0\frac{BTU}{lbm}$, the maximum length of run is: ($V_{STP,AIR} = 13.55 ft^3/lbm$)

ARGON

3/4 IPS,	117 feet 7 inch
1-1/2 IPS,	65 feet 1 inch
2 IPS,	51 feet 9 inches

The longest LN_2 pipe run is $1 - 1/2''$ IPS and the trapped volume, relieved by SV 4001, is between PV 400 and MV 2015, LN_2-9490 $(1 - 1/2 \times 3)$, MAWP $=$ 150 PSIG. The longest LAr run is $1 - 1/2''$ IPS and the trapped volume, relieved by

SV 2005, is between MV 2002 and MV 2006, LAr-9191 $(1-1/2\times 3)$, MAWP $= 150$ PSIG.

Since no runs of these sizes exceed the above maximum lengths for either cryogen, the system is adequately relieved.

APPENDIX B Isolation of the Liquid Argon Pump

As can be seen by the diagram, it is possible, by closing MV 2006, or at other valves downstream, to dead-head the LAr pump. This Cosmodyne, Mod. TC-30 pump is capable of producing 135 ft. of head at zero flow (see the attached curve for this pump). The maximum downstream pressure produced by the pump, while the L.A.C. is full and at 7 PSIG is

$$\begin{aligned} P_2 - P_1 &= \gamma H/144 \\ P_1 &= P_{dewar} + \gamma h = 7 + 85.25(10\frac{7}{12})/144 PSIG \\ P_1 &= 22.266 PSIG \end{aligned}$$

so

$$P_2 = 7 + 85.25(135)/144$$
$$P_2 = 86.92 PSIG .$$

This pressure is substantially less than the 150 PSIG MAWP of the flex lines that could be pressurized. Note that the trapped volume relief valves would not be open and flowing liquid, since the valves are set to 100 PSIG C.P., and that the pressure reducing function of these valves need not be considered, unless considerable heat is added to the liquid. In this event, conservatively converting the full horsepower of the pump into heat added to the liquid, the following calculations apply.

1. Convert the pump horsepower to work rate

$$5(550\frac{lb_f ft}{sec}) = 2750\frac{lb_f - ft}{sec} .$$

2. Convert this rate of work into equivalent heat: $2750 \, \frac{lb_f - ft}{sec} \cdot \frac{BTU}{778 lb_f - ft} = 3.535 \frac{BTU}{sec}$.

3. The vapor generation rate is therefore:

$$V = 3.535\frac{BTU}{sec}/h_{fg} BTU/lb .$$
$$\text{For Argon, } h_{fg} = 69\frac{BTU}{lb} .$$
$$V = 0.051\frac{lb}{sec} \text{ of Argon vapor} .$$
$$\text{This is } V_s = 0.051\frac{lb}{sec} \times \frac{60sec}{min} \times \frac{13.55 ft^3}{lb} STP, AIR .$$
$$V_s = 41.648 SCFM, \text{ air must be relieved} .$$

For this relief requirement, there are at least two Circle Seal, K-5120T1-2MP relief valves, SV 2011, and SV 2010, whose cracking pressure is 100 PSIG, C.P. At 140 PSIG (or higher), each of the these valves will relieve 70 SCFM, air. Since the vapor generated is less than just one of the valve capacities, the lines will not exceed the MAWP of 150 PSIG for the flex lines.

APPENDIX C Overpressurization of Lines Due to Improper Valve Line Up @ the GAr Reference Bottle

As can be seen in the above circuit, it may be possible to pressurize transfer line sections, downstream of MV 1028, to the size 1A argon bottle pressure of 2490 PSIG, were it not for RV 107. The maximum flow capacity of the CGA-580 bottle seal off value is 25000 ACFH STP argon ($\rho = 9.7 lb/ft^3$). Since the specific heat ratio, K, is $K = 2.2578$ @ 2500 PSIA, this flow rate will exist until the backpressure is greater than $P_2 = 2500(\frac{2}{3.2578})^{\frac{2.2578}{1.2578}} = 1041.3PSIA$. This pressure is intolerable, since the MAWP of the transfer lines is 150 PSIG. In addition, the maximum possible flow capacity of the circle seal relief valves at 100 PSIG C.P. is 70 SCFM, air, or approximately 1/8 of the conservative required capacity of 25000 ACFH, argon = 582 SCFM, air.

However, RV 107 is a Matheson high purity stainless steel 316 regulators, whose specifications are:

Max Inlet Pressure	:	3000 PSIG
Temperature Range	:	-40 to 200 F
Maximum Flow	:	3800 Series, 420 cfh
Inlet Port in Body	:	1/4″ NPT
Outlet	:	1/4″ NPT
3800 Series Delivery Pressure	:	0-100 PSIG
Bottle Sealoff Valve	:	CGA-580

The regulator is helium leak rate certified at $2 \times 10^{-10} ccs$, and is a two stage regulator with a 400 PSIG 1st state relief valve to protect against overpressure by relieving the 1st stage in the event of a diaphragm failure. The stage relief, the maximum delivery pressure (100 PSIG), and maximum flow rate (420 cfh), are much smaller than those flows and pressures which would exceed the 150 MAWP of the transfer lines.

APPENDIX D Overpressurization of Lines Due to an Improper Valve Line Up During an Argon Dewar Tank Truck Fill Operation

As can be seen by the above diagram, it is possible to pressurize lines to the tanker pump dead head pressure, which could go as high as 250 PSIG, were it not for SV 1027. SV 1027 is an AGCO $1 - 1/2 \times 2$, 81S1216-F, relief valve for liquid argon service set to relieve at 100 PSIG.

According to AGCO and API RP-520, the valve sizing can be obtained from:

$$F = \frac{38AKK_PK_WK_V(P_1 - P_2)^{1/2}}{G^{1/2}}$$

Where

$$
\begin{aligned}
A &= 0.307 sq.in. - F \text{ orifice} \\
K &= 0.816 \\
K_P &= 1.00 \text{ (for an AGCO valve)} \\
K_W &= 1.00 \text{ (atmospheric backpressure)} \\
K_V &= 1.00, \text{ Reynolds number} > 100{,}000 \\
G &= 73 lb/ft^3 / 62.4 lb/ft^3 = 1.17 \\
F &= \text{ Flow capacity, gpm} \\
P_1 &= 140\ PSIG \\
P_2 &= 0\ PSIG \\
F &= \frac{38(.307)(.816)(1.0)(1.0)(1.0)(140-0)^{1/2}}{(1.17)^{1/2}} \\
F &= 104 gpm\ .
\end{aligned}
$$

This flow exceeds the delivery capacity of the tanker pumping against a 276ft head ($= 140 \times 144/73 lb/ft^3$). The transfer lines whose MAWP is 150 PSIG will be adequately protected.

APPENDIX E L.A.C. Purge System Relief Capacity

The relief capacity for the L.A.C. purge system, whose schematic is on the following page, and has been extracted from the "E-706 Flow Sheet," Rev. 8, RD/Cryogenics, is the subject of this Appendix E. The schematic given in this report should be considered most current; *i.e.*, it may reflect changes or revisions not yet made to the "E706 Flow Sheet," Rev. 8.

The L.A.C. purge system is designed to function as an integral and important part of the L.A.C. insulation system and must not be interrupted. The MAWP of this system should not exceed approximately two inches of water, and, given the following tests and computations, this pressure will not be reached. The primary device which limits the pressure, by limiting the maximum possible flow into the system, is RO 315, a 0.030 inch diameter sharp edged orifice.

The first failure mode considered demonstrates that, even for very high LN_2 storage dewar pressure, that the maximum possible flow will remain less than the flow capacity of the relief system. The second failure mode examines the possibility that the GN_2, Size 1A bottle, which must flow through RV 311, might overpressurize the purge system.

The L.A.C. purge system relief is provided by SV 3029, SV 3030, SV 3031, and SV 3032, these are Circle Seal check valves with the springs removed. The flow characteristics of the valves can be found in the attached test results.

The very conservative maximum possible flow through RO 315 assumes the following:

1. No valve or fitting losses in nearly 100ft of 1/2″sch 10S pipe are considered.

2. The regulator, RV 312, offers no resistance to flow and provides no pressure control.

3. The κ value for the orifice is 1.0, the maximum possible value.

4. the LN_2 storage dewar is at 116% of its MAWP=78 PSIG, or $Pe = 105.176 PSIA$. This value, Pe, will be taken as the inlet pressure to the orifice.

The maximum flow through the orifice can be found from:

$$W = a\kappa c Pe(\frac{M}{T})^{1/2}$$

where

$$\begin{aligned}
a &= \text{orifice area} = 1/4\pi d^2 \\
&= 1/4\pi(.030)^2 \\
&= 706.8584 \times 10^{-6} sqin \\
\kappa &= 1.00 \\
c &= \text{the expansion factor, taken} \\
&\quad \text{from Fike Technical Bulletin No. 8100,} \\
&= 0.0989 \\
m &= N_2 \text{ molecular weight} \\
&= 28 \\
T &= 520R \\
Pe &= 105.176\ PSIA\,.
\end{aligned}$$

The maximum flow is therefore:

$$
\begin{aligned}
W &= (706.858 \times 10^{-6})(1.00)(.0989)(105.176)(\frac{28}{520})^{1/2} \\
&= 1.7062 \times 10^{-3} lb/sec\ GN_2 \\
&= 1.3871\ SCFM, air \\
&= 429.96 \times 10^{-3} ft^3/hr@STP \\
&= 202.92\ CCM@STP
\end{aligned}
$$

The above sonic flow will exist for all downstream pressures (backpressures) of

$$
\begin{aligned}
P_b &= 0.528(105.176) \\
P_b &= 55.56\ PSIA, \text{backpressure; } i.e.,
\end{aligned}
$$

for all pressures less than or equal to, P_b, sonic flow will exist across RO 315. Obviously, this backpressure will not develop so long as the flow rate through the relief system and normal vent check valves, CV 3033, CV 3034, CV 3035, and CV 3036 exceeds the maximum flow rate across RO 315. This relief system flow rate was tested at values of $P_b \leq 2in$ of water, or about 0.867 PSIG.

These test results are documented on the following page. As can be seen from these results, any <u>one</u> of the four valves used, even without consideration of the flow capacity of the vent check valves, would provide adequate relief capacity, *i.e.*, test capacity $\gg 203CCM@STP$.

Flow Test Results, May 24, 1986, B. Sanders

Measurements of the flow versus pressure for two Circle Seal 249B-8PP (1″ size) and two Circle Seal 259B-6PP-.15 (3/4″ size) relief valves were made with their springs removed.

The relief valves were connected to the same 3/4″ line and so had the same upstream pressure.

Pressure, Inches Water	Flow Rate
0.25	12CFH = 5663.37 CCM @ STP
0.50	18CFH = 8495.05 CCM @ STP
0.75	24CFH = 11326.74 CCM @ STP
1.0	29CFH = 13686.48 CCM @ STP
1.5	38CFH = 17934.00 CCM @ STP
2.0	50CFH = 23597.37 CCM @ STP

The two 1″ size 249B-8PP Circle Seal relief valves were then plugged and the flow rate through the two 3/4″ 259B-6PP-.15 Circle Seals was measured as 3CFH at 2″ water pressure. Hence most of the flow goes through the 1″ valves.

Overpressurization of the system by the GN_2, Size 1A, bottle @ 2490 PSIG is easily handled by SV 3038, a Circle Seal relief valve, Mod. K-5120T1-2MP, and RV 311, whose specifications are given in Appendix C. Since the regulator is a two stage regulator with interstage relief, and contains many flow restrictions, the maximum possible flow through the device is 420cfh or 7 SCFM, air. Since the flow capacity of SV 3038, given in Appendix A, is 70 SCFM, air, high pressures will not develop in the L.A.C. purge system.