Argon Dewar Required Relief Flow Capacity

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INTRODUCTION:

This report calculates the required fire relief valve flow capacity, the required vaporizer failure relief valve flow capacity, and the required loss of vacuum relief valve flow capacity of the liquid argon storage tank in use at the D-Zero site.

REQUIRED FIRE RELIEF FLOW CAPACITY:

The required flow capacity under fire conditions is given by the largest of the following values for Q, since the annular space may consist of any of these gases under different failure conditions;

$$\begin{array}{llll}
 Q_{\text{air}} & = G_{\text{I argon}} & * U_{\text{air}} & * A^{0.82} \\
 Q_{\text{nitrogen}} & = G_{\text{I argon}} & * U_{\text{nitrogen}} & * A^{0.82} \\
 Q_{\text{argon}} & = G_{\text{I argon}} & * U_{\text{argon}} & * A^{0.82}
 \end{array}$$

where Q is the flow capacity in cubic feet per minute of free gas (SCFM), G_I is the gas factor, U equals the thermal conductivity (denoted by K) (Btu/hr-ft-°F) of one atmosphere of 1200°F gas divided by the annular space (denoted as ΔR) (in.) , and A is the surface area of the inner vessel (ft²).

REQUIRED VAPORIZER FAILURE RELIEF FLOW CAPACITY:

The vaporizer is sized to maintain a constant pressure in the inner vessel while a maximum of 40 GPM of liquid Argon is being removed. Thus, it vaporizes a small amount of liquid to provide a maximum of 40 GPM of Argon gas. If it gets "stuck" at full flow when no liquid is being withdrawn, this 40 GPM of gas would have to be relieved.

REQUIRED LOSS OF VACUUM FLOW CAPACITY, WITH INSULATION:

This case involves the heat transfer by conduction through air (at one atmosphere and ambient temperature through a distance equal to the annular space (ΔR)) to the inner vessel of surface area A, filled with L_{ar} , that may boil off and create a pressure that must be relieved.

using; **Heat Transfer (conduction) = $U * A * \Delta T$**

and the latent heat of vaporization of Argon and its density, the flow capacity can be calculated.

CALCULATED REQUIRED FLOW CAPACITIES

	<u>Q (SCFM)</u>
<u>Fire Conditions</u>	202.2 (AIR)
<u>Vaporizer Failure</u>	6.89 (AIR)
<u>Loss of Vacuum</u>	27.75 (AIR)

METHOD OF CALCULATIONS FOR FIRE CONDITIONS:

The largest value for Q results in the case of Q_{nitrogen} . The following explains this worst case calculation. The other cases are attached for comparison at the end of this report.

Proceed as follows using: $Q = G_1 * U * A^{0.82}$
 $T_R = T_F + 459.67$
 $U = K / \Delta R$

1) Gas constant, $G_1 = 10.2$ (see ref. 1)

2) Thermal conductivity, $K = .0313$ Btu/(hr-°F-ft²) (see ref. 5)

Due to the fact that, according to ref. 5, there exists a near direct linear relationship between temperature and thermal conductivity, a linear extrapolation of the data in ref. 5, will reveal the above stated value for K. (see calculations)

3) Annular space, $\Delta R = .8350$ ft.

The annular spacing is calculated via the capacity of the inner vessel given in ref. 3, and involves the solution of a cubic equation. (see calculations)

4) $U = .0376$ Btu/(hr-°F-ft²) , $U = K / \Delta R$

5) Area, $A = 1688.6$ ft.²

The area A was computed considering the inner vessel to be a cylinder with semi-ellipsoidal heads, and using surface area = (overall length + .3 * O.D.) * O.D. * π ; Note this area is the safest approximation while we are not given any information on the nature of the heads (ie. hemispherical, semi-ellipsoidal, etc...)

6) Fire Flow Capacity, $Q = 170.0$ SCFM-argon = 202.2 SCFM-air, via formula. (see ref. 6 also)

METHOD OF CALCULATIONS FOR VAPORIZER FAILURE CONDITIONS:

$$Q = 6.22 \text{ SCFM-argon} = 6.89 \text{ SCFM-air}$$

If the vaporizer were "stuck" at full flow, delivering 40 GPM of vapor to the inner vessel, and liquid Argon was not being withdrawn, a 40 GPM volume of Argon gas would have to be relieved. This is a simple conversion from gallons per minute of gas to standard cubic feet per minute of gas. (see calculations and ref. 6)

METHOD OF CALCULATIONS FOR LOSS OF VACUUM CONDITION:

$$Q = 25.03 \text{ SCFM-argon} = 27.75 \text{ SCFM-air}$$

Using the previously stated formula's, the above results were obtained.
(see calculations)

CONCLUSIONS:

Based on the calculations presented in this report, a relief device for the liquid argon dewar needs to handle a flow of 202.2 SCFM-air when considering an unexpected condition such as fire. The primary relief device that handles expected modes of failure should be sized to handle a flow of 27.75 SCFM-air when considering loss of vacuum or vaporizer failure independently.

REFERENCES

1. Pressure Relief Device Standards, "S-1.3-Compressed Gas Storage Containers, "Compressed Gas Association, Inc., 1980.
2. Kreith, "Principles of Heat Transfer", International Textbook Co., Scranton, Pennsylvania, 1959.
3. Liquid Argon Storage Tank, Customer Drawing from Process Engineering Inc., Plaistow NH, drawing no. CS-10383.
4. "Specification for 20,000 Gallon Liquid Nitrogen Storage Tank", D-Zero Engineering Note: 3740.513-EN-79, Rev. B, July 1987, page 2, 2.6.1
5. Barron R.F., "Cryogenic Systems", McGraw-Hill Book Co., New York, 1966.
6. AGCO series 80 safety-relief valves, Anderson, Greenwood & Co., 1981, pgs. 6-7.
7. Cryenco, Cryogenic Data Chart, Denver, Colorado.

CALCULATE ΔR , The Annular space

Given CAPACITY is 20,000 GAL for inner Vessel (Ref. 4)

$$\therefore; 20,000 \text{ gal} \times \frac{3.785 \times 10^{-3} \text{ m}^3}{1 \text{ GAL}} \times \frac{35.33}{1 \text{ m}^3} = 2674.77 \text{ ft}^3$$

$$\text{So; } V = 2674.77 = (L_o - 2\Delta R) \pi (O.R. - \Delta R)^2$$

$L_o = 50.75 \text{ ft.}$ (outer vessel length from Blueprint)

O.D. = 10 ft., So O.R. = 5.00 ft.

$$\text{So; } 2674.77 = (50.75 - 2\Delta R) \pi (5.00 - \Delta R)^2$$

Solve for ΔR (Let $\Delta R = x$)

$$2674.77 = (50.75 - 2x) \pi (5.00 - x)^2$$

$$851.41 = (50.75 - 2x) (5.00 - x)^2$$

$$= 50.75(5.00 - x)^2 - 2x(5.00 - x)^2$$

$$= 50.75(25.00 - 10.00x + x^2)$$

$$- 2x(25.00 - 10.00x + x^2)$$

$$851.41 = 1268.75 - 507.5x + 50.75x^2 - 50x + 20x^2 - 2x^3$$

$$\therefore; 2x^3 - 70.75x^2 + 557.5x - 417.34 = 0$$

$$\therefore; x = .7486 + .1269x^2 - .0036x^3$$

By TRIAL & error:

$$x_i = 0$$

$$x_f = .7486$$

$$x_i = .7486$$

$$x_f = .8182$$

$$x_f = .8316$$

$$x_f = .8343$$

$$x_f = .8348$$

$$x_f = .8349$$

$$x_f = .8349$$

$$x_f = .83497$$

TAKE $x \approx .8350$

$$\text{So } x = \Delta R = .8350 \text{ ft.}$$

Area Considerations

- ① consider A cylindrical container w/ hemispherical Heads.

$$\begin{aligned}
 A &= L_o * (O.D.) * \pi \\
 &= 50.75 (10.00) \pi \\
 &= 1594.36 \text{ ft}^2
 \end{aligned}$$

- ② consider A cylindrical container w/ semi-ellipsoidal Heads.

$$\begin{aligned}
 A &= (L_o + .3(O.D.)) * (O.D.) * \pi \\
 &= [50.75 + .3(10.0)] * (10.0) \pi \\
 &= 1688.6 \text{ ft}^2
 \end{aligned}$$

- ③ consider just A cylinder w/ flat end caps.

$$A = L_i (2\pi)(I.R.) + 2\pi(I.R.)^2$$

$$L_i = L_o - 2\Delta R = 50.75 - 2(.8350) = 49.08 \text{ ft}$$

$$I.R. = O.R. - \Delta R = 5.00 - .8350 = 4.165 \text{ ft.}$$

$$A = (49.08)(2\pi)(4.165) + 2\pi(4.165)^2$$

$$A = 1393.39 \text{ ft}^2$$

Conclusion: use Largest Area in calculations

$$A = 1688.6 \text{ ft}^2$$

*When the surface area is not stamped on the name plate or when the marking is not legible, the area can be calculated by using one of the following formulas:

(1) Cylindrical container with hemispherical heads:
Area = (overall length) x (outside diameter) x (3.1416).

(2) Cylindrical container with semi-ellipsoidal heads:
Area = (overall length + .5 outside diameter) x (outside diameter) x (3.1416).

(3) Spherical container:
Area = (outside diameter)² x (3.1416)

Calculate THE Fire Relief flow capacity of Argon Dewar

CASE 1: $Q_{air} = (G_{\text{Argon}}) (U_{air}) (A^{.82})$

~~$G_{\text{Argon}} = 10.2$~~ $G_{\text{Argon}} = 10.2 = G_{\text{Argon}}$

$$U_{air} = \frac{K_{air}(1200 F^{\circ})}{\Delta R}$$

(See Ref. 2)

$$K_{air}(1200 F^{\circ}) = K_{air}(1000 F^{\circ}) + \left[(K_{air}(1500 F^{\circ}) - K_{air}(1000 F^{\circ})) \right] * \frac{200 F^{\circ}}{500 F^{\circ}}$$

$$K_{air}(1200 F^{\circ}) = .0351 \frac{\text{Btu}}{\text{hr-ft-F}^{\circ}}$$

$$\therefore U_{air} = \frac{.0351}{.8350} = .0420 \frac{\text{Btu}}{\text{hr-F}^{\circ}}$$

$$A^{.82} = (1688.6)^{(.82)} = 443.2$$

$$\therefore \boxed{Q_{air}} = (10.2) (.0420) (443.2) \\ = \boxed{189.9 \text{ SCFM-air}}$$

CASE 2: $Q_{nitrogen} = (G_{\text{Argon}}) (U_{nitrogen}) (A^{.82})$

$$G_{\text{Argon}} = 10.2$$

$$U_{N_2} = \frac{K_{N_2}(1200 F^{\circ})}{\Delta R}$$

(See Ref. 2)

$$K_{N_2}(1200 F^{\circ}) = K_{N_2}(1000 F^{\circ}) + \left[(K_{N_2}(1500 F^{\circ}) - K_{N_2}(1000 F^{\circ})) \right] * \frac{200 F^{\circ}}{500 F^{\circ}}$$

$$K_{N_2}(1200 F^{\circ}) = .0367 \frac{\text{Btu}}{\text{hr-ft-F}^{\circ}}$$

$$\therefore U_{N_2} = \frac{.0367}{.8350} = .0439 \frac{\text{Btu}}{\text{hr-F}^{\circ}}$$

$$A^{.82} = 443.2$$

$$\therefore \boxed{Q_{N_2}} = (10.2) (.0439) (443.2) = 198.7 \text{ SCFM-N}_2 * \frac{\sqrt{29}}{\sqrt{28}} * \frac{35}{35.5} \\ = \boxed{202.2 \text{ SCFM-Air}}$$

↓ see Ref. 6

CASE 3: $(G_{\text{Argon}})(U_{\text{Argon}})(A^{.82})$

$$G_{\text{Argon}} = 10.2$$

$$U_{\text{Argon}} = \frac{K_{\text{Argon}}(1200 F^{\circ})}{\Delta R}$$

(See Ref. 5)

$$\frac{K_{\text{Argon}}(1200 F^{\circ})}{1660^{\circ}R} = \frac{.01021}{540^{\circ}R}$$

$$K_{\text{Argon}}(1200 F^{\circ}) = .0313$$

$$\therefore U_{\text{Argon}} = \frac{.0313}{.8350} = .0376 \frac{\text{Btu}}{\text{hr-ft-F}^{\circ}}$$

$$A^{.82} = 443.2$$

$$\therefore \boxed{Q_{\text{Argon}}} = (10.2)(.0376)(443.2) = 170.0 \text{ SCFM-Ar}$$

$$170.0 \text{ SCFM-Argon} * \frac{\sqrt{40}}{\sqrt{29}} * \frac{356}{377}$$

$$= \boxed{188.5 \text{ SCFM-Air}}$$

Conclusion: worst case of flow is an equivalent of 202.2 SCFM-Air, for CGA Fire conditions under 5.3.5 & 5.3.6.3 in Ref. 1.

Problem: Calculate The Vaporizer Relief flow capacity

Given: Maximum Discharge Capacity = 40 GPM

$$\frac{40 \text{ gal (gas)}}{\text{min}} \times \frac{4.404 \times 10^{-3} \text{ m}^3}{\text{gal (dry)}} \times \frac{(100)^3 \text{ cm}^3}{\text{m}^3} \times \frac{1 \text{ ml}}{1 \text{ cm}^3} \\ \times \frac{1 \text{ L}}{1000 \text{ ml}} = 176.16 \frac{\text{L}}{\text{min}}$$

$$176.16 \frac{\text{L}}{\text{min}} \times \frac{1000 \text{ ml}}{1 \text{ L}} \times \frac{1 \text{ cm}^3}{1 \text{ ml}} \times \frac{1 \text{ m}^3}{(100)^3 \text{ cm}^3} \\ \times \frac{1 \text{ ft}^3}{2.83 \times 10^{-2} \text{ m}^3} = 6.22 \frac{\text{ft}^3}{\text{min}} \text{ Argon gas}$$

Conversion of SCFM-Argon to SCFM-Air (see Ref.6)

using: $A = \frac{V \sqrt{MTZ}}{6.32 CKP_1}$

where: A = valve orifice Area (in^2)

V = flow capacity (SCFM)

M = molecular weight of flowing media

T = inlet Temperature (Absolute)

Z = Compressibility factor (≈ 1.00)

C = GAS constant based on Ratio of specific Heats at standard conditions

K = Valve Coefficient of Discharge ($= .816$)

P_1 = Pressure at valve inlet during flow (psia)

Rearranging; $V = \frac{6.32 CKP_1 A}{\sqrt{MTZ}}$

ALL values except C & $\sqrt{M}$ are independent of the gas under consideration.

$$C_{\text{Air}} = 356$$

$$\sqrt{M_{\text{Air}}} = \sqrt{29}$$

$$C_{\text{Argon}} = 377$$

$$\sqrt{M_{\text{Argon}}} = \sqrt{40}$$

$$\text{So } V_{\text{Air}} = V_{\text{Argon}} * \frac{\sqrt{M_{\text{Argon}}}}{\sqrt{M_{\text{Air}}}} * \frac{C_{\text{Air}}}{C_{\text{Argon}}}$$

$$V_{\text{Air}} = 6.22 * \frac{\sqrt{40}}{\sqrt{29}} * \frac{356}{377}$$

$$\boxed{V_{\text{Air}} = 6.89 \text{ SCFM-air}}$$

CALCULATION OF flow Rate for Loss of VACUUM, w/insulation

Assume VACUUM space AT 1 ATM.

Use K_{air} since it is LARGER Than K_{Ar} or K_{N_2} at 80°F

$$\begin{aligned}
 \text{Heat Transfer (conduction)} &= U * A * \Delta T \\
 &\stackrel{\text{(see Ref. 2)}}{=} \frac{K_{air}(80^\circ F)}{\Delta R} * A * \Delta T \\
 &= \frac{(.01516)}{(.8350)} (1688.6) (80 - (-323)) \\
 &= \boxed{11,741.9 \frac{BTU}{hr}}
 \end{aligned}$$

Now to get to A flow RATE;

$$\begin{aligned}
 Q_{Argon} &= \text{Heat transfer} \left(\frac{BTU}{hr} \right) * \left(\frac{1}{\text{Latent Heat of Vaporization Argon}} \right) * \left(\frac{1}{\text{Argon Density}} \right) \\
 &\quad * \text{Conversions} \\
 &= 11,742 \frac{BTU}{hr} * \frac{1 \text{ gm}}{39.1 \text{ cal}} * \frac{252 \text{ cal}}{BTU} * \frac{1 \text{ L}}{1.78 \text{ gm}} * \frac{1 \text{ hr}}{60 \text{ min}} \\
 &\quad * \frac{.1337 \text{ ft}^3}{3.785 \text{ L}} = 25.03 \text{ SCFM-Argon}
 \end{aligned}$$

$$25.03 \text{ SCFM-Argon} * \frac{\sqrt{40}}{\sqrt{29}} * \frac{356}{377} = \boxed{27.75 \text{ SCFM-Air}}$$

TABLE 1
5-1.3
VALUES OF C_1 AND C_2 FOR MINIMUM RECOMMENDED MAWP AND
COMMONLY USED FLOW RATING PRESSURES (1)

GAS	(5) Minimum Rec- ommended MAWP (psig)	Flow Rating Pressure (psig)	Value of C_1	Value of C_2
Anhydrous ammonia	265	318	2.80	22.1
Anhydrous dimethylamine	150	180	3.76	21.0
Anhydrous monomethylamine	150	180	3.55	29.4
Anhydrous trimethylamine	150	180	5.33	41.8
Argon pressurized liquid (2)	—	100	10.2	59.0
—	—	200	11.8	69.0
—	—	300	13.8	82.0
—	—	400	17.9	108.0
Butadiene, inhibited	100	120	4.17	35.8
Carbon dioxide (refrigerated) (See 173.315)	100	360	7.94	37.7
—	100	390	6.46	47.4
Carbon monoxide, liquefied (2)	—	100	10.2	59.0
—	—	200	11.8	69.0
—	—	300	13.8	82.0
Chlorine	225	270	6.74	54.3
Chlorodifluoroethane (R-142B)	100	120	6.82	55.7
Chlorodifluoromethane (R-22)	250	300	7.92	64.0
Dichlorodifluoromethane (R-12)	150	180	8.94	72.0
Dichlorodifluoromethane-difluoroethane mixture (R-500)	250	300	8.75	71.9
Dichlorodifluoromethane-dichlorotetra- fluoroethane mixture (R-12/R-114 mixture)	150	180	9.34	81.0
Dichlorodifluoromethane-trichlorofluoro- methane mixture (R-12/R-11 mixture)	150	180	8.94	72.0
Difluoroethane (R-152A)	150	180	6.07	49.0
Ethylene, liquefied	—	100	5.42	36.8
Helium (3) (4)	—	200	52.5	—
Hydrogen, liquefied (3) (4)	—	50	8.6	45.8
—	—	100	10.6	56.0
—	—	140	14.5 (6)	77.1 (6)
Liquefied petroleum gas	See 173.315	300	6.56	53.6
Methyl chloride	150	180	4.96	40.4
Methyl mercaptan	100	120	6.05	51.2
Neon, pressurized liquid (4)	—	100	17.0	92.0
—	—	200	20.8	113.4
—	—	300	28.0	153.0
Nitrogen, pressurized liquid	—	100	10.2	59.0
—	—	200	11.8	69.0
—	—	300	13.8	82.0
—	—	400	17.9	108.0
Nitrous oxide (refrigerated) See 173.315	100	120	5.36	37.2
—	—	120	6.20	46.0
Oxygen, pressurized liquid (2)	—	100	10.2	59.0
—	—	200	11.8	69.0
—	—	300	13.8	82.0
—	—	400	17.9	108.0
Sulfur dioxide	150	180	4.84	40.0
Vinyl chloride	150	180	5.61	46.8