Cryostat "UV" Relief Valve Selection and Process Flow

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8/11/87

D-Zero Engineering note 3740.000-EN-100

Approved

Introduction

This report describes the selection of the relief valves for the D-Zero cryostats. The selection was based on the flow requirements calculated in D-Zero engineering note 3740.214,224-EN-6 under fire conditions (1200 ^{0}F, no vacuum) for the central cryostat; 264 SCFM (see attached calculations). This value was calculated from section 5.3.5 of "Pressure Relief Device Standards; S 1.3- Compressed Gas Storage Containers", published by the Compressed Gas Association, Inc.

Selection

The choice is made from the Anderson Greenwood & Co. "90 series" line of "UV", pilot operated, "pop" operation valves. Valves of this type are in wide and demanding use in industry and at the laboratory; the nitrogen reliquefaction facility (NRL), for example. There have been some reservations with the old fixed nozzle aluminum internals design (@NRL) in extreme and unusual service. Stainless steel internals will be chosen here to avoid these shortcomings.

The low pressure choices are types 93, 93T or 95. Of these only the 93T is recommended for operation below -260 ^{0}F, and to -320 ^{0}F. The one atmosphere equilibrium temperature of liquid argon is -302.6 ^{0}F (87.3K).

Flow Capacity of the 93T

The flow capacity at 110% MAWP in the selected 2"X3" 93T, aluminum body, stainless steel trim valve with a 13 psig relief set pressure is subsonic. The subsonic flow, calculated for a flow temperature of -302.6 ^{0}F, and worst case 2 psi inlet drop and 2 psi outlet backpressure is 1395 SCFM (See the attached relationships & calculations).

Conclusions

The flow calculated above is far greater than the required fire condition flow capacity of 264 SCFM. The improbable 70 ^{0}F flow temperature value of 738 SCFM is still much greater than the required fire capacity. The flow capacity of the paralleled supplemental[1] rupture disc is 2640 SCFM, independently greater than than the fire condition flow requirement.

1. "Supplemental" as in the ASME disc application definition.

PILOT OPERATED

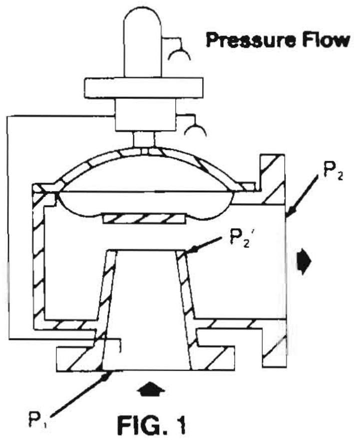


FIG. 1

RELIEF VALVES

VALVE SIZE INLET × OUTLET FLANGE SIZE	ORIFICE AREA (SQ. IN.)		
	TYPE 91/94	TYPE 93/93T	TYPE 95
2" × 3"	2.92	2.29	2.92
3" × 4"	6.24	5.16	6.25
4" × 6"	10.33	8.74	10.32
6" × 8"	22.22	19.56	22.15
8" × 10"	39.57	36.40	N/A
10" × 12"	56.75	51.00	N/A
12" × 16"	89.87	84.00	N/A

Before sizing a valve, pressure at the inlet of the valve (P_1) must be evaluated under flowing conditions, with any piping pressure losses due to the upstream piping configuration taken into consideration. Pressure at the outlet (P_2) must also be determined, taking into account any discharge header piping losses due to built-up or superimposed backpressure.

A pressure drop occurs between nozzle exit (P_2') and valve outlet (P_2) due to body geometry. This pressure is unique for each type of valve and because of it, P_2' is greater than P_2. Subcritical flow (sub-sonic) depends on pressure drop across the nozzle (P_1-P_2'), therefore, P_2' *must* be determined for applications where set pressure is 15 psig or less. Formulas to determine P_2'/P_1 are given for Types 93/93T and 91/94/95 valve designs.

For vacuum sizing, $P_2' = P_2$, with P_2 on the inlet (small) flange and P_1 on the outlet (large) flange. Flow is reversed. See capacity charts for K_d.

method 1 (15 psig and below)

Low Pressure Flow: Use for set pressures 15 psig or less or for set pressures above 15 psig where flow becomes sub-sonic due to subcritical pressure drop across valve.* (See Figure 1.)

Sub-Sonic Flow Formulas:

$A = \dfrac{V\sqrt{MTZ}}{4645\,K_dP_1F'}$	(1)* Flow in SCFM
$A = \dfrac{W\sqrt{TZ}}{735\,K_dP_1F'\sqrt{M}}$	(2)* Flow in Lbs/Hour
$\left.\dfrac{P_2'}{P_1}\right\|_{93/93T} = \dfrac{P_1 - 0.55(P_1 - P_2)^{0.98}}{P_1}$	(3) - or refer to Fig. 2
$\left.\dfrac{P_2'}{P_1}\right\|_{91/94/95} = \dfrac{P_1 - 0.62(P_1 - P_2)^{1.04}}{P_1}$	(4) or refer to Fig. 2
$F' = \sqrt{\left(\dfrac{k}{k-1}\right)\left[\left(\dfrac{P_2'}{P_1}\right)^{\frac{2}{k}} - \left(\dfrac{P_2'}{P_1}\right)^{\frac{k+1}{k}}\right]}$	(5) or refer to Fig. 3

*When set pressure is greater than 15 psig but sub-sonic, use K (ASME) in formulas (1) and (2) and use $\frac{P_2}{P_1}$ in lieu of $\frac{P_2'}{P_1}$ in Formula (5).

sizing

method 2 (above 15 psig)

High Pressure Flow: Use for set pressure above 15 psig (see Fig. 1). If backpressure during flow results in $\frac{P_2}{P_1}$ ratio greater than critical ratio $\frac{P_{CF}}{P_1}$ use Method 1.

$A = \dfrac{V\sqrt{MTZ}}{6.32\,CKP_1}$	(6)	Flow in SCFM
$A = \dfrac{W\sqrt{TZ}}{CKP_1\sqrt{M}}$	(7)	Flow in Lbs/Hour
$\dfrac{P_{CF}}{P_1} = \left(\dfrac{2}{k+1}\right)^{\frac{k}{k-1}}$	(8)	

Supplemental Formulas and Conversions

To convert flow from volumetric to weight flow or vice versa (flow in SCFM and Lbs/hour).

$W = V\dfrac{M}{6.32}$	(9)	$V = W\dfrac{6.32}{M}$	(10)

definition of sizing terms

A = Required orifice area in sq. in.

C = Gas Constant and is based on k. If unknown use C = 315. Table 1 shows representative values.

F' = Factor based upon ratio of specific heats and pressure drop across valve nozzle. Use Formula (5) or Fig. (3) for solution.

k = c_p/c_v the specific heat ratio of the flowing vapor or gas. If unknown use k = 1.0 (or 1.001 where solution would otherwise be indeterminate). Table 1 shows representative values.

K_d = Actual average measured nozzle coefficient. Use 0.939 for 93/93T, 0.855 for 91/94 and 0.947 for 95 valves, pressure relief. Use 0.75, all valves, vacuum relief.

K = Certified nozzle coefficient (certified by the National Board of Boiler and Pressure Vessel Inspectors and equal to 0.9 × K_d). Use 0.845 for Type 93/93T, 0.770 for Type 91/94 and 0.852 for Type 95 valves.

M = Molecular weight of flowing vapor or gas. Refer to Table 1 for list of molecular weights of typical vapors and gases.

P = Set pressure in psig (pounds per sq. in. gauge).

P_1 = Flowing inlet pressure in psia (absolute) and is equal to set pressure (P) plus overpressure plus 14.7 (minus inlet loss in psi if considered).

P_2 = Flowing outlet pressure in psia (absolute) and is equal to valve outlet pressure (under flowing conditions) plus 14.7.

P_2' = Flowing pressure in psia (absolute) at valve nozzle exit. See Formulas (3) and (4) or Fig. 2 for solution of P_2'/P_1.

P_{CF} = Critical pressure, psia. See Formula (8) or Table 1 for value of P_{CF}/P_1.

W = Required capacity in #/h or lbs/h (pounds per hour).

V = Required capacity in scfm (standard ft³ per minute, sea level conditions, 14.7 psia, 60°F).

T = Flowing temperature in degrees Rankin (°R) and equal to °F + 460.

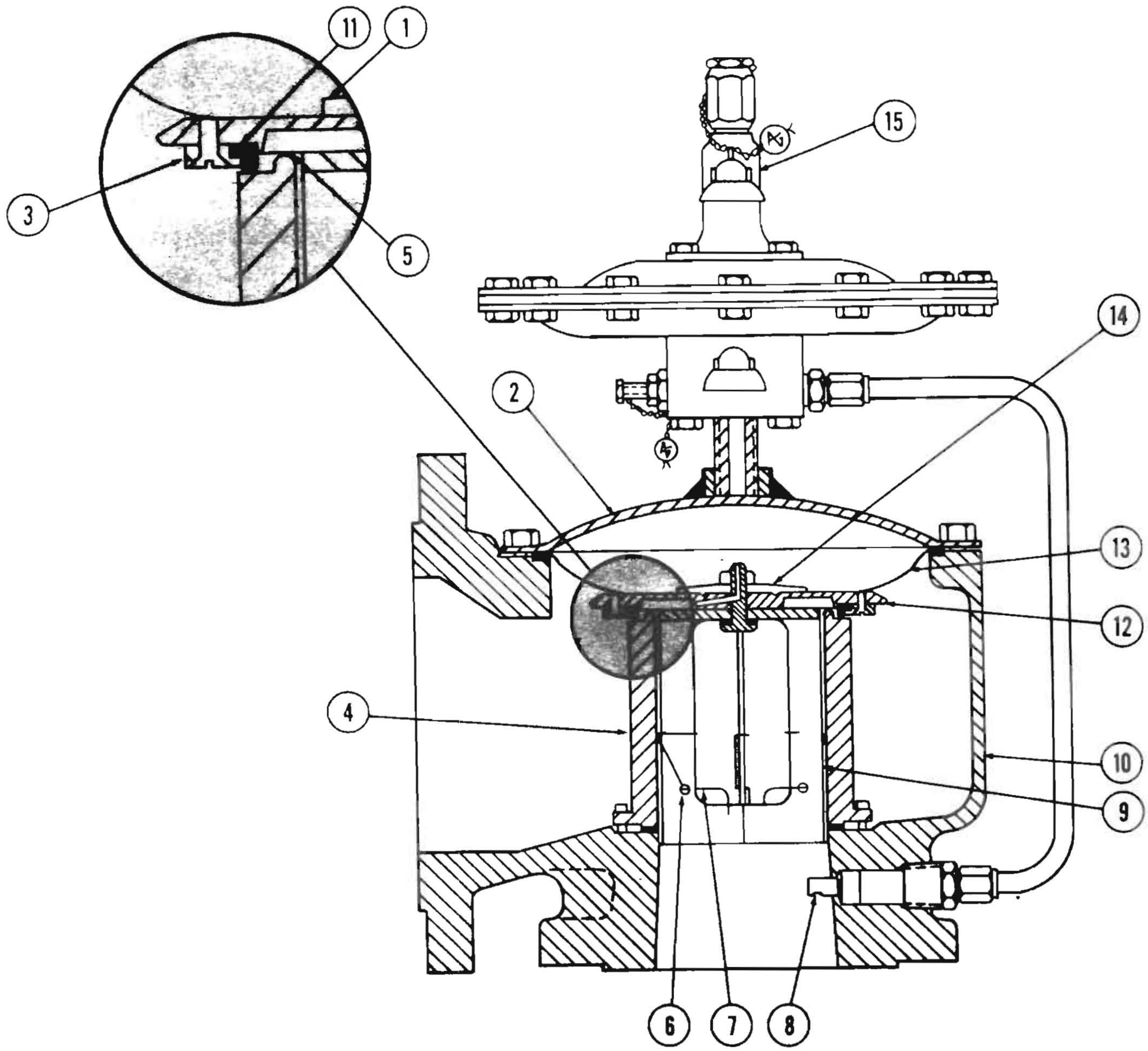
Z = Compressibility factor for the deviations of the actual gas from a perfect gas. If unknown, use Z = 1.

Note:
Formulas shown are usable only with units of flow, pressure, and temperature shown. Other units of measure must be first converted to these units for solution. If sizing values for altitudes considerably above sea level, use local barometric pressure expressed in psia in place of 14.7 psia.

type 93T

main valve construction

- TEFLON DIAPHRAGM, SEAT AND SEALS
- REPLACEABLE NOZZLE
- FILM TYPE MAIN VALVE SEAT
- PRESSURE RANGE 29″ Hg VACUUM to 13 PSIG
- SIZES 2″ to 12″
- ORIFICES 2.29 in.^{2} to 84.0 in.^{2}

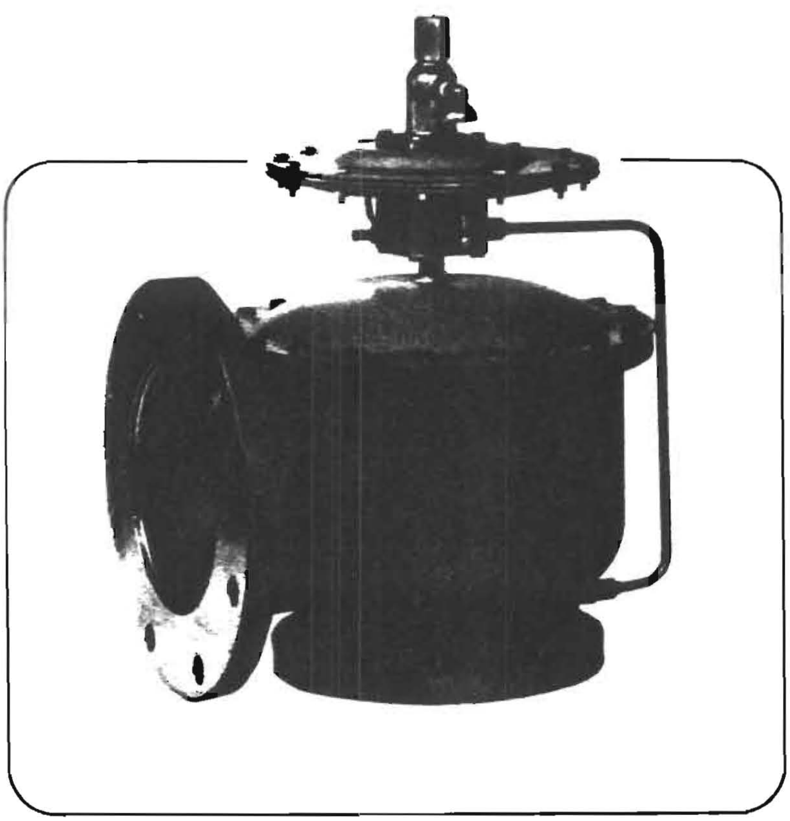


type 93T

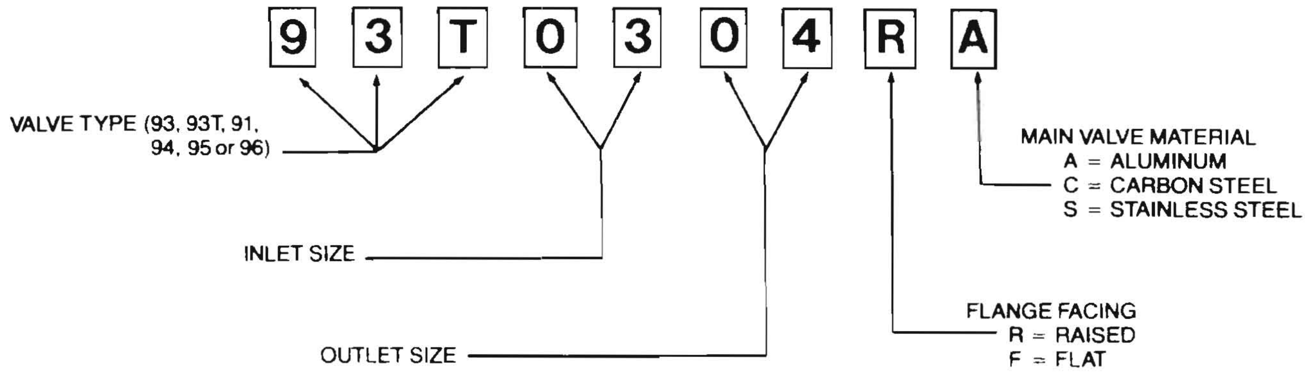
main valve construction

NO.	DESCRIPTION	MATERIAL	
		ALUMINUM	STAINLESS STEEL
1	DIAPHRAGM RETAINER	AL 6061-T6	316 S.S.
2	CAP	AL 6061-T6	316 S.S.
3	SEAT RETAINER	AL 6061-T6	304 S.S.
4	NOZZLE	316 S.S.	316 S.S.
5	PRIMARY SEAT	TEFLON	TEFLON
6	SPRING PIN (1)	302 S.S.	302 S.S.
7	GUIDE SPRING	316 S.S.	316 S.S.
8	DIPPER TUBE	17-4 S.S.	17-4 S.S.
9	GUIDE	AL 6061-T6	316 S.S.
10	BODY	AL B26 SG70A-T6	S.S. A351-CF8M
11	SECONDARY SEAT	TEFLON	TEFLON
12	SEAT PLATE	AL 6061-T651	304 S.S.
13	DIAPHRAGM	TEFLON	TEFLON
14	TOP PLATE	AL 6061-T651	303 S.S.
15	PILOT VALVE	AL	S.S.
—	SEALS	TEFLON	TEFLON
—	NUTS/BOLTS/TUBING	18-8 S.S.	18-8 S.S.

(1) Use on 6" and larger sizes.

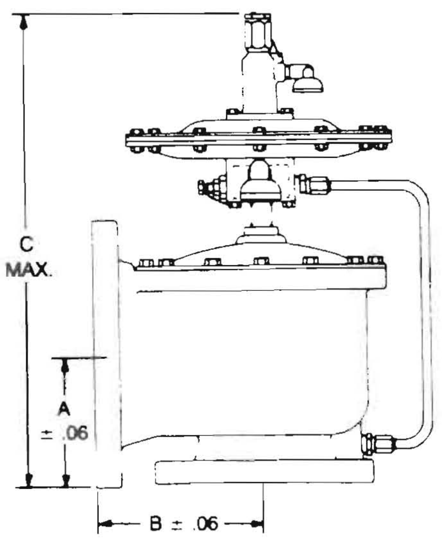


valve selection

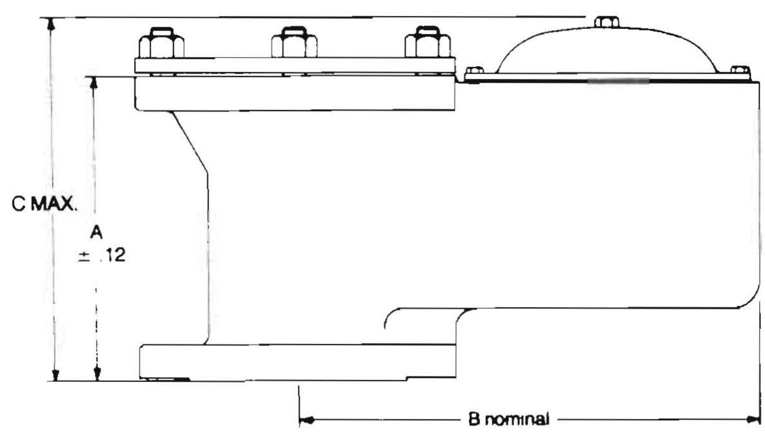


dimensions and weights

Types 93, 93T, 91/94, 95



Type 96



SIZE INLET × OUTLET 150# RF or FF	DIMENSIONS A (3)	B (3)	C max. (2) (3)	WEIGHT Al. MAX. LBS. (KGS.) (1) (2)
2" × 3"	3.75 (95.25)	5.00 (127.00)	16.7 (424.18)	15# (6.80)
3" × 4"	4.50 (114.30)	5.75 (146.05)	18.0 (457.20)	23# (10.43)
4" × 6"	5.50 (139.70)	7.00 (177.80)	20.3 (515.62)	33# (14.97)
6" × 8"	6.75 (171.45)	9.31 (236.47)	22.9 (581.66)	58# (26.30)
8" × 10"	8.00 (203.20)	11.00 (279.40)	25.0 (635.00)	95# (43.09)
10" × 12"	9.50 (241.30)	12.50 (317.50)	26.5 (673.10)	130# (58.97)
12" × 16"	11.75 (298.45)	14.25 (361.95)	32.0 (812.80)	180# (81.65)

SIZE	DIMENSIONS									WEIGHT Al MAX LBS. (KGS.) (1)
	A (3) RELIEF VALVE CONNECTION							B NOM. (3)	C MAX. (3)	
	CAPPED	3"	4"	6"	8"	10"	12"			
4"	9.82 (249.43)	8.57 (217.68)	8.57 (217.68)	—	—	—	—	13.2 (335.28)	10.1 (256.54)	30 (13.6)
6"	10.57 (268.48)	—	9.32 (236.73)	9.32 (236.73)	—	—	—	16.5 (419.10)	11.0 (279.40)	40 (18.14)
8"	13.89 (352.81)	—	—	12.02 (305.31)	12.02 (305.31)	—	—	21.3 (541.02)	14.0 (355.60)	60 (27.2)
12"	18.58 (471.93)	—	—	—	—	16.33 (414.78)	16.33 (414.78)	25.5 (647.70)	18.7 (474.98)	120 (54.43)

(1) Weight Steel Valve Equals Al. x 3
(2) Will Vary With Accessories
(3) Inches (Millimeters)
(4) 125 #FF Optional

FIRE CONDITION REQUIRED FLOW RATES

	SURFACE AREAS (FT^2)	Q (SCFM)
EC	741.3	214.6
CC	956.8	263.8

$$Q = UA^{0.82} G1$$

$G1 = 10.2$

U = THERMAL CONDUCTIVITY OF 1200°F AIR DIVIDED BY RADIAL LENGTH

A = SURFACE AREA

$K_{AIR} = 0.0359$ BTU/HR-FT-F

RADIAL LENGTH = 4.625 in = 0.385 FT

$U = 0.093$ BTU/HR-FT^2-F

$$Q_{EC} = 10.2\,(0.093)(741.3)^{0.82} = \underline{214.6 \text{ SCFM}}$$

$$Q_{CC} = 10.2\,(0.093)(956.8)^{0.82} = \underline{263.8 \text{ SCFM}}$$

SJW 7/22/87

CALCULATION OF 93T FLOW CAPACITY

$$V = \frac{4645\, K_d P_1 F' A}{\sqrt{MTZ}}$$

$A_{93T} = 2.29\ in^2$

$K_d = 0.939$

$P_2 = 2\ psig + 14.7 = 16.7\ psia$

$P_1 = 13.0\ psig + 14.7 = 27.7\ psia$

$M = 40\ g/mol$

$T = -302.6\ °F + 460 = 157.4\ °R$

$Z = 1$

$$F' = \sqrt{\left(\frac{K}{K-1}\right)\left[\left(\frac{P_2'}{P_1}\right)^{2/K} - \left(\frac{P_2'}{P_1}\right)^{\frac{K+1}{K}}\right]}$$

K = specific heat ratio = 1.67

$$\frac{P_2'}{P_1} = \frac{P_1 - 0.55(P_1 - P_2)^{0.96}}{P_1} = 0.8016$$

$F' = 0.4$

$$V = \frac{4645(0.939)(27.7)(0.4)(2.29)}{\sqrt{(40)(157.4)(1)}} = \underline{1395\ SCFM}$$

RUPTURE DISC FLOW CAPACITY

3" DISC

$V_{AIR\ @\ 500\ PSIA}$ = 40000 SCFM (FIKE CAT. 7380 p46-47)

∴ V_{AIR} @ 33 PSIA = 2640 SCFM

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