Muon Design Note #5

TITLE: New Muon Hall Liquid Nitrogen Transfer Line

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Description

The liquid nitrogen supply dewar is located approximately 100 feet to the east of the New Muon Hall. The transfer line consists of a 3/4" pipe inner line and a 3" pipe vacuum jacket. The line is located inside a 10" casing and buried several feet underground. A couple of feet inside the building there is a vacuum break. The line then continues along the east and north walls of the cryoroom and over to the CCM magnet. The section of line under the road is solid pipe with contraction being taken up by a braid covered flexible hose. This hose is in the short vertical leg which brings the line above ground. Inside the building thermal contraction is handled by several bellows. The trapped volume relief is located outside. Each section of the vacuum has a 3" parallel plate relief as well as two one inch pumpout port/relief valves. An u-tube connects the transfer line with the liquid nitrogen dewar. A 50 psig AGCO relief on the supply line before the u-tube is adequate sized to protect the line from any failure associated with the dewar. See Fig. 1.

System Components and Pressure Ratings for the Internal Line

Component	MAWP (psid)	
3/4" Sch 5 SS pipe	1533	(A)
1/4" 0.035 SS tube	3587	(A)
1" braid covered flex hose	580	(B)
3/4" bellows	140	(B)
Circle Seal relief	5000	(B)
Cryolab shut-off valve	400	(B)
Bayonet with 1/2" flex hose	150	(B)

(A) Calculation shown in Appendix A.
(B) MAWP from manufacturer.

The MAWP of the lowest component is 140 psid. Therefore the MAWP of the system is chosen as 140 psid. The trapped volume relief is set for 100 psig which is 115 psid for those components under vacuum.

Trapped Volume Relief

The trapped volume relief is a half inch Circle Seal set for 100 psig. At 10% overpressure (or 110 psig) this valve is rated for 164 CFM. Under normal conditions we only have to consider the heat leak through the vacuum plus conduction along connecting pieces (such as a bayonet or vacuum break). This results in a heat leak of 33.1 watts with a resultant venting rate of 0.38 SCFM. See Appendix B.

If we lose vacuum the required venting rate becomes 15.8 SCFM. This assumes a crack in the vacuum pipe or the relief leaks. The vacuum shell is still basically in tack. See Appendix C.

AGCO Relief

The nitrogen dewar is rated for 220 psi and has reliefs on it which are set to protect it at this pressure. In order to protect the line components from this high dewar pressure an AGCO safety relief valve was placed on the liquid supply line a few feet from the nitrogen dewar. The relief valve is set for 50 psig and has a G orifice (0.503 inch diameter). At 50 psig it will vent 533 SCFM of nitrogen gas or 130 gallons per minute of liquid nitrogen.

An occassional problem with nitrogen tanks has been pressurization during filling. The pump capacity of the nitrogen tankers is a maximum of 100 gal/min. Therefore this valve with a capacity of 130 gal/min is adequately sized for this problem.

For loss of vacuum the required vent rate is 24 SCFM of air and for fire it is 310 SCFM of air. See Apendix D. Therefor we need to have a total capacity of 334 SCFM air for fire and loss of vacuum combined. We actually have 523 SCFM of air venting capacity.

Vacuum Piping

The short vertical section which brings the transfer line above ground consists of 9 feet of 8" Sch 10 pipe with flat plates welded on either end. The pipe has two penetrations, one towards either end and each sized for a 3" pipe. Each flat plate is 3/8 inch thick. The bottom plate is solid and the top plate has two penetrations.

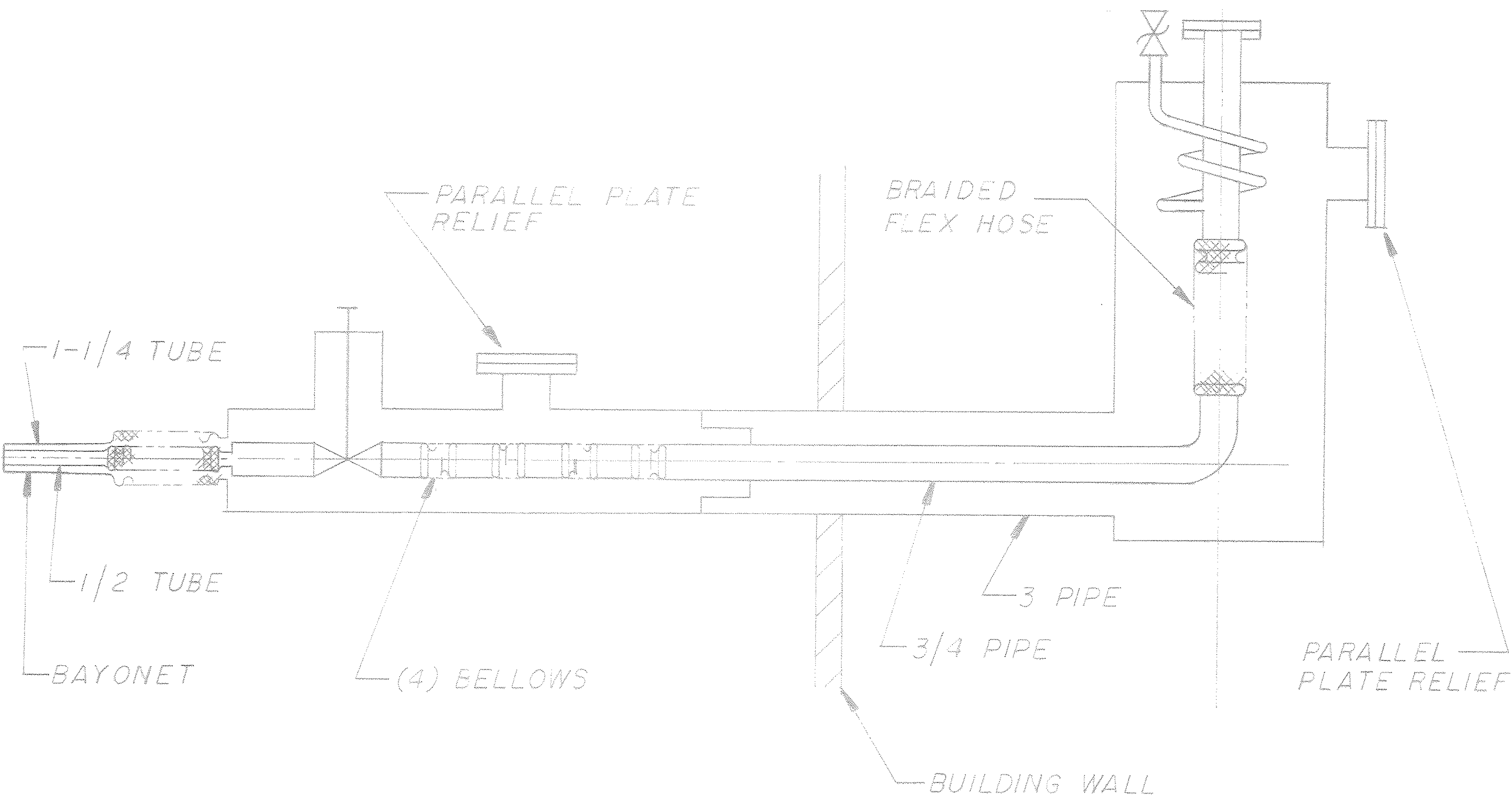
Allowable Pressure Differentials of Components of Vacuum Piping

Component	External Pressure	Internal Pressure
8" Sch 10 Pipe *	103	524
Lower Flat Head **	93	93
Upper Flat Head ***	23	23
3" Sch 10 Pipe ****	456	1060

*   Appendix E
**   Appendix F
*** Appendix G
****Appendix H

Parallel Plate Reliefs

The two 3" parallel plates have the springs ad bolts removed. The cover is held in place by vacuum. Thus if the vacuum space is pressurized the cover will fall free. A vacuum break is in the middle of the transfer line. The section within the New Muon Hall has the relief centrally located. The section outside has the relief on the end nearest the dewar. Obviously this outdoor section would experience the larger pressure drop. Using conservative assumptions the pressure drop in this sections will be less than 26 psi, see Appendix I. The maximum pressure drop in the 8" vertical section would be 0.32 psi or less.


1-1/4 TUBE
1/2 TUBE
BAYONET
(4) BELLOWS
PARALLEL PLATE
RELIEF
BRAIDED
FLEX HOSE
3 PIPE
3/4 PIPE
BUILDING WALL
PARALLEL
PLATE RELIEF

Appendix A

The internal MAWP = $\frac{2\ S\ E\ t}{D-2yt}$

SE = maximum allowable stress = 12,800 psi
(includes E = 0.8 and in house fabrication)

t = wall thickness (actual-tolerance allowed by Code)

D = outside diameter of pipe or tube

y = coefficient from ASME B31.1 = 0.4

3/4" Sch 5 Pipe

OD = 1.050 inches

wall = 0.060 = 0.065 nominal - 7.5% tolerance

$$\text{MAWP} = \frac{2\ (12{,}800)\ (0.060)}{1.050 - [2(0.4)(0.060)]} = 1533 \text{ psi}$$

1/4" x 0.035 Tube

OD = 0.25 inches

wall = 0.0315 = 0.035 nominal - 10% tolerance

$$\text{MAWP} = \frac{2\ (12{,}800)\ (0.0315)}{0.25 - [2(0.4)(0.0315)]} = 3587 \text{ psi}$$

Appendix B

The heat conduction along a pipe is given by

$$Q = A/L \int_{T_1}^{T_2} k \, dT$$

where

Q = heat leak (watts)

A = cross sectional area (cm^2)

L = length (cm)

$\int_{T_1}^{T_2} k \, dT$ = thermal conductivity integral (watt/cm)

A sample calculation

Vacuum Break

2 ft of 2" Sch 5 pipe (OD = 2-3/8" - wall = 0.065")

$A = 3.04 \ cm^2$

$L = 60.96$ cm

$\int k \, dT = 27.1$ watt/cm

$$Q = \frac{3.04}{60.96}(27.1) = 1.35 \text{ watts}$$

Sources of Conduction Heating

Vacuum break	1.35 watts	
Dewar end bayonet	3.27	
Manual valve	1.71	(catalog)
Relief valve line	.03	
Total	6.36 or 6.4 watts	

Heat Input Through The Vacuum Space

In the range of 80 K to 300 K a vacuum with an inch of multilayer insulation has an apparent mean thermal conductivity of between 0.5 and 2 μW/cm K. We have approximately 200 feet of transfer line with a vacuum jacket of 3-1/2" diameter and an inner line which is 1" in diameter. The vacuum jacket surface area is ~183 ft^2 or 1.77×10^5 cm^2. The vacuum space is 1.1 inches or 2.8 cm wide. Therefore the heat input, if using the 2 μW/cm K, is

$$Q = \frac{1.7 \times 10^5 \ cm^2}{2.8 \ cm} \times 2 \times 10^{-6} \ W/cm\ K \times 220\ K$$

$$= 26.7 \text{ watts}$$

Thus the total heat leak into the system would be a maximum of 26.7 + 6.4 = 33.1 watts.

At 125 psia (100 psig + 10% overpressure + 15) the heat of vaporization is 159 j/g. The boiloff rate is, therefore, 0.21 g/sec or 12.5 g/min. This is only 0.38 SCFM which must be vented.

Appendix C

Consider the heat leak into the system due to loss of vacuum. The required flow capacity of the relief is given by

$$Q_a = \frac{(130 - t)}{4(1200-t)} G_i UA$$

G_i = gas factor = 10.2 at 100 psig

U = thermal conductance

$$= \frac{\text{thermal conductivity of insulation at average temperature}}{\text{thickness of insulation}}$$

$$= \frac{0.0112}{0.092} = 0.122$$

A = area = 183 ft^2

t = temperature of product = $-270^\circ F$

$$\therefore Q = \frac{130 - (-270)}{4[1200-(-270)]} (10.2)(0.122)(183)$$

$$= 15.8 \text{ SCFM}$$

At this flow rate the pressure drop in the quarter inch line to the relief valve is 8.3 psi.

Using $\Delta P = 0.0001078 \; K \; \rho \; v^2$

ρ = 2.08 lb/ft^3 at 125 psia and 190 R

k = 14.2

v = 50.9 ft/sec

ΔP = 8.3 psi

Appendix D

Loss of Vacuum

$$Q_a = \frac{(130 - t)}{4(1200 - t)} G_i \; UA$$

G_i = gas factor = 10.2 at 100 psig. It decreases for pressures below 100 psig but we'll use this value

A = ~265 ft^2 = surface area

$$U = \frac{\text{thermal conductivity of insulation at average temperature}}{\text{thickness of insulation}}$$

Acquiring information about the tank has been very difficult. Actual insulation thickness is not known but 1" seems a conservative guess.

$$= \frac{0.0106}{0.083} = 0.128$$

$$Q_a = \frac{130 - (-290)}{4[1200 - (-290)]} (10.2)(0.128)(265)$$

= 24.4 SCFM of air

Fire

$$Q_a = G_i \; UA^{0.82}$$

$$G_i = 10.2$$

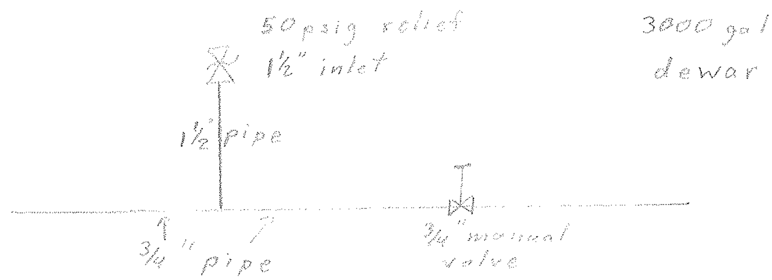
$$U = \frac{K \text{ (at 1200 F)}}{T} = \frac{0.026}{0.083} = 0.313$$

$$A^{0.82} = (265)^{0.82} = 97$$

$$Q_a = (10.2)\ (0.313)\ (97)$$

= 309.7 SCFM of air

We have the following piping



The pressure drop between point A and the relief valve is only 0.12 psi.

$\Delta P = 0.0001078\ K\ \rho v^2$

$\rho = 1.20/ft^3$ = gas density at relieving pressure and 170 R

$v = 22.5$ ft/sec

$k = 1.86$

Appendix E

For cylindrical shells under internal pressure the required thickness shall be the greater of $t = PR/(SE - 0.6P)$ (1) [circumferential stress] or $t = PR/(2SE + 0.4P)$ (2) [longitudinal stress]. In our case the greater t is required by (1). Rearranging we have $P = SEt/(R + 0.6t)$. Single openings or openings far removed from each other and not greater than a 3" pipe do not require reinforcement if the shell is 3/8" or less (Sec. VIII Div. 1).

$$P = SEt/(R + 0.6t)$$

where

P = maximum pressure
S = maximum allowable stress = 18.8 ksi
E = joint efficiency = 0.8 for in house fabrication
t = shell thickness = 0.148 in
R = inside radius = 4.156 in

$$P = (18800)(0.8)(0.148)/[4.156 + (0.6)(0.148)]$$

$$= 524.4 \text{ psi}$$

For external pressure we need to calculate

$$L/D_o = \text{length/outer diameter} = 108/8.625 = 12.5$$

$$D_o/t = \text{outer diameter/thickness} = 8.625/0.148 = 58.3$$

These values are compared with Fig. 5-UGO-28.0 Section VIII Div. 1 to find an A factor. In out case A = 0.00033. This is then compared with the correct materials chart in Appendix 5 to get a B factor. Our B factor is 4500. Finally using

$$P_a = \frac{4B}{3(D_o/t)} = \frac{4(4500)}{3(58.3)} = 102.9 \text{ psi}$$

we get a maximum external pressure for the shell.

Appendix F

The minimum required thickness of flat unstayed circular heads, covers and blind flanges is give by $t = d\sqrt{CP/SE}$. (From Section VIII Div. 1).

Rearrainging

$$P = \left(\frac{t}{d}\right)^2 \frac{SE}{C}$$

where

d = diameter of plate = 8.312 in
t = thickness of plate = 0.375 in
S = maximum allowable stress = 18.8 ksi
E = joint efficiency = 0.8 for in house
C = method of attachment factor = 0.33 (conseervative)
P = maximum pressure

$$\therefore P = \left(\frac{0.375}{8.312}\right)^2 \frac{(18800)(0.8)}{0.33}$$

$$= 92.8 \text{ psi}$$

This is for both internal and external pressure.

Appendix G

The upper flat head has two openings neither of which is greater than a 3" pipe size; however, they are less than twice their average diameter apart (but greater than 1-1/3 times their average diameter). Thus it is necessary to reinforce the openings.

The amount of reinforcement required is

$A = 0.5\ dt$
t = required thickness of flat head
d = diameter (or sum of diameters) of the openings

At least half of this area must be between the two penetrations. This last requirement will be the limit on the maximum pressure differential.

We have two holes -2.890 in and 1.265 in in diameter - with their centers 3.125 inches apart. There is therefore a 1.047 inch section of material between the holes.

Area available for reinforcement = 1.047 x (0.375 - t). Area required for reinforcement = 1/2 [0.5 x (2.890 + 1.265)t]. Setting these equal and solving 1.047 x (0.37 - t) = 1/2[0.5 x (2.890 + 1.265)t]. t = 0.188 = maximum required plate thickness. Now solve for maximum pressure differential.

$$P = \left(\frac{t}{d}\right)^2 \frac{SE}{C}$$

$$= \left(\frac{0.188}{8.312}\right)^2 \frac{(18800)(0.8)}{0.333}$$

$$= 23.4 \text{ maximum pressure differential}$$

Required area of reinforcement = 0.3906. Area of reinforcement available = 0.5406. Area required between penetrations = 0.1953. Area available between penetrations = 0.1958.

Appendix H

The three inch Sch 10 pipe which forms most of the vacuum shell is in several lengths. Consider the longest only (i.e. lowest external pressure rating).

The maximum internal pressure is given by $P = SEt/(R + 0.6t)$ where $R = 1.63$ in and $t = 0.120$ inches.

Then

$$P = \frac{(18800)(0.8)(0.170)}{1.63 + (0.6)(0.120)}$$

$$= 1060.4 \text{ psi}$$

The maximum external pressure is found using D_o/t, L/D_o and tables in Section VIII Div. 1.

$$D_o/t = \frac{\text{outer diameter}}{\text{wall thickness}} = \frac{3.50}{0.120} = 29.2$$

$$L/D_o = \frac{\text{pipe length}}{\text{outer diameter}} = \frac{107 \text{ ft}}{3.5 \text{ in}} = \frac{107 \times 12}{3.5} = 366.9$$

(for $L/D_o > 50$ use 50)

From Fig. 5-UGO-28.0 Factor A = 0.0013
From the material chart (304 SS) Factor B = 10,000

$$\therefore P = \frac{4B}{3(D_o/t)} = \frac{4(10,000)}{3(29.2)} = 456 \text{ psi}$$

Appendix I

For a rupture of the internal pipe, the pressure drop within the vacuum pipe will depend on where the rupture occurs. Consider a worse case. Consider the section of pipe outside the building. Take the maximum leak into the vacuum space and place it at the end away for the parallel plate relief. The maximum flow rate is 22 gallons/min and occurs if the inner line is broken immediately inside the vacuum jacket. Calculate the pressure drop as if the gas temperature were 520 R (very conservative) and gas pressure were 20 psia.

22 gallons of liquid = 1471 ft^3 at 520 R, 20 psia. Pipe diameter is equivalent to 3.086 in.

$$\therefore \text{Gas Velocity} = \frac{\text{cfm}}{\text{cross section}} = \frac{1471\ ft^3/min}{0.052\ ft^2} = 28320\ ft/min$$

$$= 472\ ft/sec$$

At 520 R and 20 psia, $\rho = 0.1004$ lb/b/ft^3

$$R = \frac{\rho V D}{\mu} = \frac{(0.1004)(472)(0.184)}{1.17 \times 10^{-65}} = 7.45 \times 10^5$$

$\therefore f = 0.018$

$$\Delta P = 0.0001079\ K\ \rho\ V^2$$

$$K = f\ (\text{equivalent length}) + K_{enlarge} + K_{reduce} + K_{exit}$$

$$= 0.018 \left\{ \frac{107 \times 12}{3.086} + 20_{elbow} + 20_{elbow} + 20_{run\ tee} + \frac{106}{8.329} \left(\frac{3.086}{8.329} \right)^4 \right\}$$

$$+ 0.75 + 0.4 + 1.0 = 8.75 + 2.15 = 10.72$$

$$\Delta P = 0.0001078\ (10.72)\ (0.1004)\ (472)^2$$

$$= 25.8\ psi$$

Actual ΔP would be considerable less if more realistic assumptions (i.e. $T < 520$ R) were made.

What is the maximum pressure which would occur in the 8" vertical section? Since this is close to the relief take P = 15 psi, T = 520 R.

$$\rho = 0.07532\ lb/ft^3$$

The flow rate of 22 gpm of liquid would be 1961 cfm of gas at these conditions.

$$\text{Gas velocity} = \frac{1961\ ft^3/min}{0.358\ ft^2} = 5480\ ft/min$$

$$= 91\ ft/sec$$

$$R = \frac{(0.07532)(91)(0.675)}{1.17 \times 10^{-5}} = 3.95 \times 10^5$$

and

$$\therefore f = 0.0166$$

$$K = 0.0166\ [207] + 1.4$$

$$= 4.8$$

$$\Delta P = 0.0001078\ (4.8)\ (0.0753)\ (91)^2$$

$$= 0.32\ psi$$