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Comparison of Deliverable and Exhaustible Pressurized Air Flow Rates in Laboratory Gloveboxes		ECN No. N/A

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7. Abstract

Calculations were performed to estimate the maximum credible flow rates of pressurized air into Plutonium Process Support Laboratories gloveboxes. Classical equations for compressible fluids were used to estimate the flow rates. The calculated maxima were compared to another's estimates of glovebox exhaust flow rates and corresponding glovebox internal pressures. No credible pressurized air flow rate will pressurize a glovebox beyond normal operating limits. Unrestricted use of the pressurized air supply is recommended.

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1. INTRODUCTION

Glovebox pressurization could cause a release of plutonium with the potential for inhalation by workers in the affected room. A release requires breaching a High Efficiency Particulate Air (HEPA) filter where air normally flows into the glovebox from the room. Pressurization of a glovebox is normally assumed possible only if pressurized gases are forced into the glovebox; generation of gases by chemical reaction is assumed to be too slow to present a problem under all credible experimental conditions. The likelihood of breaching a filter depends on the strength of the filter medium and the pressure inside the glovebox. The pressure inside the glovebox is a function of the air flow rate into the glovebox, the operability of the glovebox exhaust system, and the number and size of HEPA filters at the glovebox ventilation inlet.

Glovebox pressurization is assumed not to be a problem if the glovebox exhaust ventilation system is operating properly. Proper operation of the exhaust system increases the area for air flow significantly (usually doubles the area) and any releases to the exhaust system would still be contained within a doubly HEPA-filtered duct for personnel and environmental protection.

The air supply lines into the gloveboxes owned by the Plutonium Process Support Laboratories (PPSL) have been locked out since December, 1991 due to a concern about overpressurization. The concern is that overpressurization would cause a release of plutonium into the laboratory room if the air supply valves were left open and unattended. Primarily, there is no interlock to shut off air flow into the gloveboxes in case a seismic event required an immediate evacuation of the building while the air supply system was in use.

This document uses standard English units for all calculations. All gauges used with the pressurized air systems indicate in standard English units; this document needs to use the same units to be applicable for reference use in the field. A previous report that calculates the exhaust flow rates from laboratory gloveboxes was also written in standard English units and the results here must be comparable.

2. PURPOSE

Calculations in this document are used to determine if acceptable pressure limits will be exceeded at the inlet HEPA filters of gloveboxes in the PPSL. The maximum potential flow rates into each glovebox from the pressurized air system are calculated and compared to calculated air flow rates leaving the gloveboxes via the inlet HEPA filters. If the internal pressures are acceptably low at the possible flow rates, then interlocks or additional flow restrictors are not needed in order to resume use of the air supply lines.

3. SUMMARY

The air flow rate entering any PPSL glovebox will not pressurize the glovebox beyond the normal operating limit for a HEPA filter. The highest estimated deliverable flow rate into any glovebox is 75.2 standard cubic feet per minute (scfm). That flow rate would be exhausted through the inlet HEPA filters at a glovebox interior pressure of only about 1.1 inches of water, which is within the normal operating limits for a HEPA filter. There are no circumstances where sufficient air could flow into a glovebox and raise the pressure beyond the pressure difference used by the manufacturer in initial filter testing.

4. SCOPE

This assessment pertains only to Gloveboxes 179-4, 179-6, 179-9, and 188-1 in the PPSL. Air flowing into the gloveboxes from the building pressurized air system after reduction from a nominal 90 pounds per square inch gauge pressure (psig) to a nominal 40 psig is the only gas source considered for pressurizing the gloveboxes. Simultaneous failure of the pressure reducing valves (PRV) that reduce the air pressure from 90 psig to 40 psig and then from 40 psig to 15 psig was not considered; their simultaneous failure would also have to occur during use of the air system, which is also rare. The glovebox exhaust system is assumed to be inoperable.

5. DISCUSSION

5.1 Calculation Method

The potential maximum air flow rates into the 4 gloveboxes were calculated using an iterative process centered on the equation for compressible fluid flow as found in Perry[1] for piping whose length greatly exceeds its diameter:

$$P_1 - P_2 = (f \cdot L_{eq} \cdot G^2)/(2 \cdot g_c \cdot \rho_{ave} \cdot R_H) \qquad \text{(Eq. A)}$$

where P_1 = starting (higher) pressure for a piping segment
P_2 = ending (lower) pressure for a piping segment
f = Fanning friction factor determined from standard charts[2]
L_{eq} = equivalent length of straight pipe with all fittings and bends added
G = mass flow rate of fluid per unit area within the piping
g_c = gravitational conversion constant = $32.174\ lb_m \cdot ft/s^2 \cdot lb_f$
ρ_{ave} = average density of fluid within the piping segment
R_H = hydraulic radius of the piping segment under study

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[1]Perry, R. H. and D. Green, *Perry's Chemical Engineer's Handbook*, Sixth Edition, McGraw-Hill Book Company, New York, 1984, Equation 5-91, page 5-28.

[2]Ibid., Figure 5-28, page 5-25.

The Fanning friction factor, f, is determined as a function of the flowing fluid's Reynolds number (Re), piping surface roughness (ϵ), and piping inside diameter (D). The surface roughness, ϵ, is selected from a standard table[3]. The Reynolds number is a dimensionless number defined as:

$$Re = D \cdot V \cdot \rho / \mu \qquad \text{(Eq. B)}$$

where V = average fluid velocity through the piping segment
μ = fluid viscosity = $1.225 \cdot 10^{-5}$ $lb_m/ft \cdot s$ at room temperature[4]

The equivalent length of piping, L_{eq}, is calculated by adding the measured length of piping and adding appropriate lengths for each bend and fitting in the segment under study. The equivalent lengths of piping for different types of bends and fittings are found in Robinson[5]. The equivalent lengths for sudden contractions and expansions for 3/8-inch tubing were determined by plotting Robinson's values and extrapolating to an inside diameter of 0.30 inch (0.025 ft) as shown in Figure 1.

Potential maximum flow rates were calculated for two possible failure conditions. The first set of calculations assumes that the PRV inside the laboratory room fails and that ample air is available at P_{source} = 40 psig inside a 2½-inch header located in the building duct level. The second set of calculations assumes that the PRV works and that an ample supply of air is available there at P_{source} = 15 psig.

The L_{eq} determinations are listed in Table 1 for each potential P_{source}. The table shows that much of the overall piping is not applicable when assuming that the PRV works properly.

The final pressure inside the glovebox was assumed to be -0.3 psig (14.4 psi absolute, psia) due to the successive pressure drops between (1) the atmosphere and the building non-radiation zone, (2) the building non-radiation zone and radiation zone, and (3) the building radiation zone and the glovebox interior. Pressure drops of 0.1 psi were assumed for each step.

The source pressures listed above, P_{source}, are assumed to be gauge pressures relative to the outside atmosphere due to their source at/near the outside atmosphere. The total pressure difference between the source and glovebox interior is, then, 40.3 psi or 15.3 psi, depending on the source used.

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[3] Ibid., Table 5-6, page 5-24.

[4] Kreith, F., *Principles of Heat Transfer*, Third Edition, Intext Educational Publishers, New York, 1973, Appendix III, Table A-3, page 636.

[5] Robinson, R. N., *Chemical Engineering Review Manual*, Third Edition, Professional Publications, Inc., San Carlos, CA, 1984, Figure 4.2, page 4-27.

FIGURE 1

Equivalent Length Estimations for Square-Mouthed Inlets

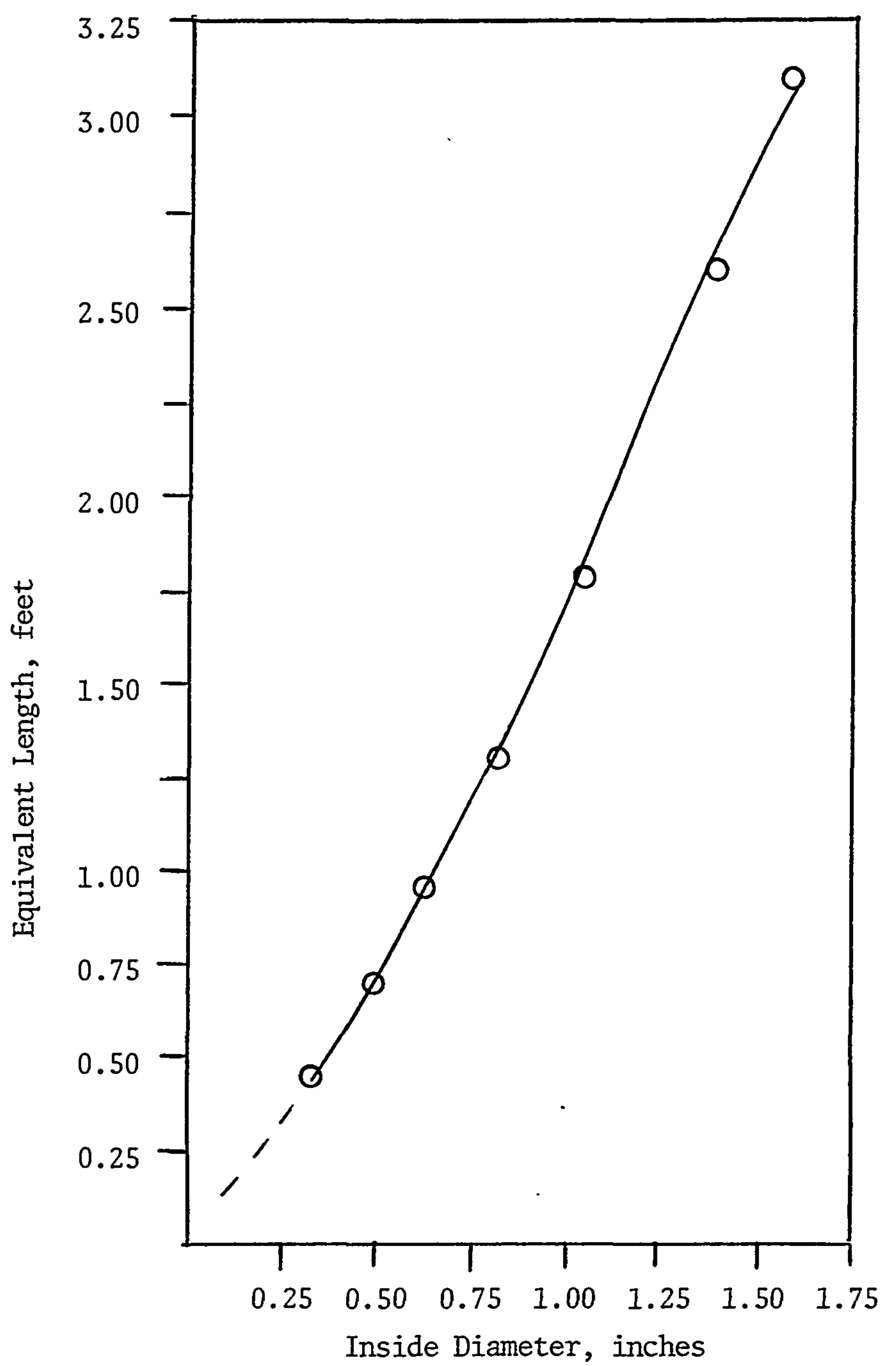

TABLE 1

List of Piping Restrictions and Equivalent Lengths

Segment	40 PSIG Supply	15 PSIG Supply
1-Inch Pipe	(feet) 1 sharp entrance, 2.5P→1P 1.8 5 ell, short radius @ 5.2 each 26 1 reducer, 1P→½P 0.96 1 gate valve 0.84 1 union 0.29 1 branch tee 6.6 pipe length 25 61.49	N/A
1/2-Inch Pipe	(feet) 1 flanged connect. 0.0 1 ball valve* 0.05 1 union 0.21 1 PRV (globe?) 22.0 1 sharp entrance, ½P→3/8T 0.32 2 ell, short radius, @ 3.6 each 7.2 1 run tee 1.7 1 branch tee 4.2 pipe length 6.25 41.93	(feet) 1 sharp entrance, ½P→3/8T 0.32 1 run tee 1.7 1 branch tee 4.2 pipe length 0.5 6.72
3/8-Inch Tubing	(feet) 6 ell, long radius @ 0.5 each 3.0 3 sharp exits, 3/8T→½P @ 0.64 each 1.92 1 sharp entrance, 3/8T→½P 0.32 1 ½-in. ball valve 0.05 tube length 10.25 15.54	(feet) 6 ell, long radius @ 0.5 each 3.0 3 sharp exits, 3/8T→½P @ 0.64 each 1.92 1 sharp entrance, 3/8T→½P 0.32 1 ½-in. ball valve 0.05 tube length 10.25 15.54

The assumed glovebox interior pressures and source pressures allow the highest potential pressure difference and, therefore, the maximum potential air flow rates. These assumptions are necessary because the glovebox interior pressure must remain below an acceptable limit and higher flow rates will increase the interior pressure. No credit is taken for increasing pressure within the glovebox if the ventilation system fails.

The calculational sequence for the flow rates is:

A. Assume an air mass flow rate, ϖ, through one of the 3/8-inch tubing branches entering the glovebox under study.

B. Assume a pressure loss through the 3/8-inch tubing segment and calculate the P_1 for the 3/8-inch tubing.

C. Calculate the following air properties in the order of P_{ave}, ρ_{ave}, V, G, Re, and f. Ideal gas behavior is assumed for calculating ρ_{ave}.

D. Calculate $P_1 - P_2$ (ΔP) for the 3/8-inch tubing segment using Equation A.

E. Compare the ΔP calculated to the ΔP estimated in Step B.

F. Repeat Steps B-E until the assumed and calculated ΔP's are equal. Note: In some cases, the assumed and calculated values do not converge exactly; round-off errors sometimes caused the assumed and calculated values to switch positions in a "vicious circle." The difference in final ΔP chosen is insignificant compared to the uncertainty in selecting f from the Fanning friction factor chart.

G. Calculate ϖ for the ½-inch pipe segment by multiplying ϖ assumed in Step A by the number of 3/8-inch tubing branches entering the glovebox.

H. Repeat Steps B-F with the appropriate values for the ½-inch piping segment.

I. Using the same ϖ from Step G, repeat Steps B-F for the 1-inch pipe segment (only applies for P_{source} = 40 psig).

J. Compare the final calculated starting pressure to the assumed starting pressure. If those pressures are equal $\pm$0.2psi, the calculations are acceptable. If not, start again at Step A with a new assumed ϖ.

K. Calculate the air flow rates as standard cubic feet per minute (scfm) in each segment by dividing ϖ (in lb_m/s) by the density of air at standard temperature and pressure (0.076 lb_m/ft^3 in these calculations) and multiply that quotient by 60 s/min.

The calculated maximum air flow rates into each glovebox can then be compared to the glovebox exhaust flow rates calculated by Wojdac[6]. The curves shown in the appropriate plots of Wojdac's Appendix B indicate the corresponding air flow rates and pressures inside the PPSL gloveboxes.

5.2 Results

Table 2 lists the estimated maximum air flow rates into the PPSL gloveboxes. The flow rates vary from 15.1-75.2 scfm, depending on the number of air lines entering the glovebox and the location and pressure of the air source. The estimates in Table 2 are considered to be maxima for the following reasons:

TABLE 2
COMPARISON OF DELIVERABLE FLOW RATES AND REQUIRED EXHAUST PRESSURES

Glovebox	Branches into Glovebox	Air Flow Rates and Exhaust Pressures from 40 psig Source[a]		Air Flow Rates and Exhaust Pressures from 15 psig Source[b]	
		Calculated Flow Rate (scfm)	Exhaust Pressure Required (in. H_2O)	Calculated Flow Rate (scfm)	Exhaust Pressure Required (in. H_2O)
179-4	2	52.3	0.57	29.5	0.18
179-6	4	75.2	1.17	54.0	0.60
179-9	3	66.3	0.91	42.4	0.39
188-1	1	29.8	0.21	15.1	0.05

[a] Starting pressure would be 40 psig inside the header in the duct level if the room PRV failed. The pressure would be 15 psig at the room PRV if the PRV operates properly.
[b] from Wojdac's Appendix B, Figures 6B-9B

(1) The glovebox exhaust ventilation system is assumed to be inoperative and sealed. Any use of the exhaust ventilation system would allow the glovebox internal pressure to exhaust larger air flow rates than those estimated by Wojdac.

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[6]Wojdac, L. F., SD-CP-DA-087, *Effects of Compressed Gas Sources on the Pressure Profiles of Laboratory Gloveboxes*, Westinghouse Hanford Company, Richland, WA, December 16, 1992, Appendix B, pages 23-45.

(2) The pressure inside the glovebox is assumed to be 14.4 psia even though the flow conditions would raise the glovebox internal pressure slightly, especially as the air flow rate increases. The loss of glovebox exhaust ventilation would also raise this pressure slightly. The loss of all ventilation in the building would raise this pressure to 14.7 psia. Any rise in the glovebox pressure decreases the pressure difference (ΔP) available to drive fluid flow and, therefore, decreases the flow rate.

(3) The lines delivering air into the gloveboxes are all assumed to be as short as the shortest route available, which was the only length measured. The extra length in the majority of the 3/8-inch tubing segments increases the overall flow resistance and, therefore, decreases the total flow rate.

(4) The pressure at the air source used in these calculations is assumed to be the nominal pressure for that air supply line. During flow conditions, the actual pressure would decrease between the PRV initially reducing the air presure to 40 psig and the source locations used in these calculations. The actual P_{source}, then, would be lower, resulting in a smaller pressure difference and flow rate available between the source used and the glovebox, especially when coupled with the loss of glovebox exhaust or building ventilation.

(5) The pipes and tubes are assumed to be clean inside, rather than rusted or fouled. Rusting and fouling increase the roughness of the piping surface, thereby decreasing the flow rate possible for a given pressure difference.

(6) Some of the pipes in the air supply system may be schedule 80 pipe, rather than the schedule 40 pipe assumed in these calculations. The smaller inside diameter of the schedule 80 pipes restricts the flow rate for the same available ΔP.

Tables A-1 through A-8 in the Appendix show the various flow conditions for each glovebox at each starting pressure during the final iteration of flow rate calculations. The volumetric flow rates (Q) listed at the bottom of Tables A-1 through A-8 are the deliverable flow rates listed in Table 2.

Figures 6B through 9B of Wojdac's Appendix B show that the calculated glovebox interior pressures barely exceed 1.1 inches of water (0.04 psi) when exhausting an air flow of 75.2 scfm, which is the maximum flow rate achievable in the PPSL gloveboxes. The HEPA filters on the gloveboxes operate routinely with a ΔP of up to 3 inches of water (0.11 psi); thus, filter breaching at an air flow rate of 75.2 scfm is extremely unlikely.

The filters are tested for filtering efficiency by the manufacturer (Flanders Filters, Inc.; Washington, NC) prior to shipment. The efficiency tests are performed at an air flow rate of 35 cfm per filter. The pressure difference in the test varies from filter to filter and ranges from 44-92 inches of water (1.6-3.3 psi) without breaching the filter[7], well beyond the pressure difference allowed for use on Plutonium Finishing Plant gloveboxes. The PPSL gloveboxes are normally installed with at least 4 inlet HEPA filters. A total flow rate of at least 140 scfm through the filters may be possible at each glovebox without breaching any filters.

The PFP Safety Analysis Report[8] estimates that the weakest point on a PPSL glovebox would be a glove, which should withstand at least 14 inches of water pressure (0.51 psig). This pressure would exhaust far more than the maximum available flow rate from the glovebox.

6. CONCLUSIONS AND RECOMMENDATIONS

Use of all available air supply lines into any of the PPSL gloveboxes does not deliver an air flow rate sufficient to cause a breach of containment. Additional flow restrictions are not necessary to keep the deliverable air flow rates less than safe exhaustible flow rates. Unrestricted use of the air supply lines into the gloveboxes, therefore, should resume.

7. REFERENCES

1. Kreith, Frank, *Principles of Heat Transfer*, Third Edition, Intext Educational Publishers, New York, 1973.

2. Perry, Robert H. and Don W. Green, *Perry's Chemical Engineers Handbook*, Sixth Edition, McGraw-Hill Publishing Company, New York, 1984.

3. Robinson, Randall N., *Chemical Engineering Review Manual*, Third Edition, Professional Publications, Inc., San Carlos, CA, 1984.

4. Westinghouse Hanford Company, WHC-SD-CP-SAR-021, Rev. 0 (unclassified), *Plutonium Finishing Plant Final Safety Analysis Report*, Richland, WA, January 31, 1991.

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[7]Flanders Filters, Inc., Tags placed on filter bodies used in other HEPA filter tests as documented by Compton, J. A., *Operational Problems Associated With the Use of Particulate Emission Control for MACT Compliance Applications*, WHC-SA-1280FP, Westinghouse Hanford Company, March, 1992.

[8]Westinghouse Hanford Company, WHC-SD-CP-SAR-021, Revision 0 (unclassified), *Plutonium Finishing Plant Final Safety Analysis Report*, Richland, WA, January, 1994, Chapter 9, "Accident Safety Analyses," Section 9.0.2, "Preliminary Analysis," Subsection 9.0.2.4, "Logic Tree. Plutonium release to Atmosphere, 234-5Z, 242-Z, 236-Z," Part C.2.2.2, "General Comment Elements D-10 through D-16.

5. Wojdac, Lawrence F., SD-CP-DA-087, Rev. 0 (unclassified), *Effects of Compressed Gas Sources on the Pressure Profiles of Laboratory Gloveboxes*, Westinghouse Hanford Company, Richland, WA, December 16, 1992.

APPENDIX A

CALCULATED CONDITIONS FOR AIR FLOW RATES INTO PPSL GLOVEBOXES

TABLE A-1
PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 179-4 AT 40 PSIG

Branches into glovebox 2

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225\cdot10^{-5}$ $lb_m/ft\cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅜-in. Tube	Total
ω	lb_m/s	0.0662	0.0662	0.0331	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	61.5	41.9	15.5	
P_{ave}	psia	54.5	50.2	30.3	
ρ_{ave}	lb_m/ft^3	0.282	0.260	0.157	
G	$lb_m/s\cdot ft^2$	11.0	31.4	67.4	
V	ft/s	39.2	121	430	
Re		78,800	133,000	137,000	
ϵ	ft	$8.5\cdot10^{-4}$	$8.5\cdot10^{-4}$	$1.5\cdot10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		0.0098	0.012	0.0082	
P_{start}	psia	54.8	54.2	46.2	
ΔP	psia	0.6	8.0	31.8	40.4
P_{end}	psia	54.2	46.2	14.4	
Q_{branch}	scfm	52.3	52.3	26.1	

TABLE A-2
PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 179-6 AT 40 PSIG

Branches into glovebox: 4

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225\cdot10^{-5}$ $lb_m/ft\cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅜-in. Tube	Total
ω	lb_m/s	0.0952	0.0952	0.0238	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	61.5	41.9	15.5	
P_{ave}	psia	54.25	44.25	24.65	
ρ_{ave}	lb_m/ft^3	0.280	0.229	0.127	
G	$lb_m/s\cdot ft^2$	15.9	45.1	48.5	
V	ft/s	56.6	197	380	
Re		113,000	191,000	98,800	
ϵ	ft	$8.5\cdot10^{-4}$	$8.5\cdot10^{-4}$	$1.5\cdot10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		0.0095	0.012	0.0083	
P_{start}	psia	54.9	53.6	34.9	
ΔP	psia	1.3	18.7	20.5	40.5
P_{end}	psia	53.6	34.9	14.4	
Q_{branch}	scfm	75.2	75.2	18.8	

TABLE A-3
PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 179-9 AT 40 PSIG

Branches into glovebox: 3

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225 \cdot 10^{-5}\ lb_m/ft \cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅜-in. Tube	Total
ω	lb_m/s	0.0840	0.0840	0.0280	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	61.5	41.9	15.5	
P_{ave}	psia	54.2	46.85	27.2	
ρ_{ave}	lb_m/ft^3	0.280	0.242	0.141	
G	$lb_m/s \cdot ft^2$	14.0	39.8	57.0	
V	ft/s	50.0	164	406	
Re		100,000	168,000	116,000	
ϵ	ft	$8.5 \cdot 10^{-4}$	$8.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		0.0095	0.012	0.00825	
P_{start}	psia	54.7	53.7	40.0	
ΔP	psia	1.0	13.7	25.6	40.3
P_{end}	psia	53.7	40.0	14.4	
Q_{branch}	scfm	66.3	66.3	22.1	

TABLE A-4

PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 188-1 AT 40 PSIG

Branches into glovebox 1

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225 \cdot 10^{-5}$ $lb_m/ft \cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅜-in. Tube	Total
ω	lb_m/s	0.0378	0.0378	0.0378	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	61.5	41.9	15.5	
P_{ave}	psia	54.6	53.3	33.25	
ρ_{ave}	lb_m/ft^3	0.282	0.276	0.172	
G	$lb_m/s \cdot ft^2$	6.30	17.9	77.0	
V	ft/s	22.3	65.0	448	
Re		44,900	75,700	158,000	
ϵ	ft	$8.5 \cdot 10^{-4}$	$8.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		0.0099	0.012	0.00815	
P_{start}	psia	54.7	54.5	52.1	
ΔP	psia	0.2	2.4	37.7	40.3
P_{end}	psia	54.5	52.1	14.4	
Q_{branch}	scfm	29.8	29.8	29.8	

TABLE A-5
PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 179-4 AT 15 PSIG

Branches into glovebox 2

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225 \cdot 10^{-5}$ $lb_m/ft \cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅛-in. Tube	Total
ω	lb_m/s	N/A	0.0374	0.0187	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	N/A	6.7	15.5	
P_{ave}	psia	N/A	29.35	21.7	
ρ_{ave}	lb_m/ft^3	N/A	0.152	0.112	
G	$lb_m/s \cdot ft^2$	N/A	17.7	38.1	
V	ft/s	N/A	117	339	
Re		N/A	75,100	77,600	
ϵ	ft	$8.5 \cdot 10^{-4}$	$8.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		N/A	0.012	0.0084	
P_{start}	psia	N/A	29.7	29.0	
ΔP	psia	N/A	0.7	14.6	15.3
P_{end}	psia	N/A	29.0	14.4	
Q_{branch}	scfm	N/A	29.5	14.8	

TABLE A-6
PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 179-6 AT 15 PSIG

Branches into glovebox: 4

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225 \cdot 10^{-5}\ lb_m/ft \cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅜-in. Tube	Total
ω	lb_m/s	N/A	0.0684	0.0171	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	N/A	6.7	15.5	
P_{ave}	psia	N/A	28.4	20.8	
ρ_{ave}	lb_m/ft^3	N/A	0.147	0.108	
G	$lb_m/s \cdot ft^2$	N/A	32.4	34.8	
V	ft/s	N/A	221	324	
Re		N/A	137,000	71,100	
ϵ	ft	$8.5 \cdot 10^{-4}$	$8.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		N/A	0.012	0.0085	
P_{start}	psia	N/A	29.6	27.2	
ΔP	psia	N/A	2.4	12.8	15.2
P_{end}	psia	N/A	27.2	14.4	
Q_{branch}	scfm	N/A	54.0	13.5	

TABLE A-7
PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 179-9 AT 15 PSIG

Branches into glovebox: 3

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225 \cdot 10^{-5}$ $lb_m/ft \cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅜-in. Tube	Total
ω	lb_m/s	N/A	0.0537	0.0179	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	N/A	6.7	15.5	
P_{ave}	psia	N/A	28.75	21.2	
ρ_{ave}	lb_m/ft^3	N/A	0.149	0.110	
G	$lb_m/s \cdot ft^2$	N/A	25.5	36.5	
V	ft/s	N/A	171	333	
Re		N/A	107,000	74,500	
ϵ	ft	$8.5 \cdot 10^{-4}$	$8.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		N/A	0.012	0.0084	
P_{start}	psia	N/A	29.5	28.0	
ΔP	psia	N/A	1.5	13.6	15.1
P_{end}	psia	N/A	28.0	14.4	
Q_{branch}	scfm	N/A	42.4	14.1	

TABLE A-8

PRESSURE LOSS SUMMARY TABLE FOR GLOVEBOX 188-1 AT 15 PSIG

Branches into glovebox 1

Compressible Fluid flow equation for L >> D :

$$P_1 - P_2 = (fL_{eq}G^2)/(2g_c\rho_{ave}R_H)$$

and $Re = DV\rho/\mu$ where $\mu = 1.225 \cdot 10^{-5}$ $lb_m/ft \cdot s$

Final Pressure 14.4 psia

Parameter	Units	1-in. Pipe	½-in. Pipe	⅜-in. Tube	Total
ω	lb_m/s	N/A	0.0191	0.0191	
D	ft	0.0874	0.0518	0.025	
R_H	ft	0.0437	0.0259	0.0125	
A	ft^2	0.006	0.00211	0.000491	
L_{eq}	ft	N/A	6.7	15.5	
P_{ave}	psia	N/A	29.5	21.9	
ρ_{ave}	lb_m/ft^3	N/A	0.153	0.113	
G	$lb_m/s \cdot ft^2$	N/A	9.05	38.9	
V	ft/s	N/A	59.4	344	
Re		N/A	38,300	79,500	
ϵ	ft	$8.5 \cdot 10^{-4}$	$8.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	
ϵ/D		0.0097	0.016	0.006	
f		N/A	0.0125	0.0084	
P_{start}	psia	N/A	29.6	29.4	
ΔP	psia	N/A	0.2	15.0	15.2
P_{end}	psia	N/A	29.4	14.4	
Q_{branch}	scfm	N/A	15.1	15.1	