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Vacuum System Pump Down Analysis

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INTRODUCTION

My assignment on the SP-100 Vacuum Vessel Vacuum System Team was to perform a transient pump down analysis for the vacuum vessel that will house the SP-100 reactor during testing. Pump down time was calculated for air and helium.

PUMPS

The baseline vacuum pumping system configuration consisted of a rotary piston or roots blower pump in parallel with one or two turbomolecular pumps. The rotary piston and roots blower pumps were used in the viscous and transitional flow regimes. The turbomolecular pumps operate in the molecular flow regime.

Pumps were evaluated on a pumping speed vs inlet pressure basis. For the rotary piston/roots blower pumps, the same pump curve were used for both air and helium according to manufacturer's recommendation. Air and helium were plotted separately for the turbomolecular pumps.

CONDUCTANCE

The conductance elements (pipes, elbows, bends, etc.) for the roughing line connecting the rotary piston/roots blower pump to the vessel were input to *VACTRAN (VACTRAN A Vacuum System Design Tool, version 2.0) based on configurations provided and the conductance was calculated by the program.

Conductance for the turbomolecular pumps was calculated based on configurations provided. The tube-only conductance for the ducting connecting the turbomolecular pump to the vessel was calculated using the equations for molecular flow (Santeler, 338-342).

GAS LOAD

Bake-out, heating the vessel for a period of 15 days, will accelerate outgassing and vaporize any water collected on the interior wall of the vessel. Following bake-out, this analysis assumed a steady outgassing rate of $1.1\text{E-}06$ torr-liters/second.

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PUMP DOWN

The pump down time is the amount of time it takes to achieve a target pressure for any given system model. Eight systems were modelled; 4-air and 4-helium. Pump curves were plotted for each case assuming duct sizes of 4, 6 and 8 inches and the results tabulated. The specified maximum time allowed for pump down is 24 hours.

ACCURACY

A subsequent analysis using the Vacuum System Design (VSD) (Vacuum System Design, version 2.2-2) software confirmed the results obtained from the VACTRAN program.

The necessary pump curve constants were calculated from the pump curves plotted on the VACTRAN system for air and helium and input to VSD (Vacuum System Design, 33).

Conductance was calculated by VSD (Vacuum System Design, version 2.2-2) using a rotary piston pump and 2-turbopumps with 4-inch ducting. The results of the two programs were compared and found to be in agreement. Therefore, the results obtained from VACTRAN were considered valid and reasonable.

CONCLUSION

For all cases the proposed vacuum system will be able to pump down the vessel within the required time. The use of a larger rotary piston pump (DUO250) improves the pump down time by 35 minutes and therefore should be considered. The 6-inch duct for the roughing line is optimal, however, because all cases are well below the 24 hour time frame, the 4-inch duct is sufficient. The use of the single turbomolecular pump during pump down is sufficient. A pump down with helium in the vessel and a helium inleakage delays the time to achieve the base pressure marginally and is acceptable.

NORCUS
SP-100 Vacuum System
Denise S Rohrdanz
July 27, 1990

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INTRODUCTION

The following is a transient pump down analysis for the vacuum vessel, shown in Figure 2, that will house a reactor during ground testing. The test facilities will be designed to simulate space by providing a vacuum environment for the reactor test assembly. The vessel volume is 34,130 liters with an inside surface area of 781,638 cm².

The baseline vacuum pumping system configuration consists of a rotary piston or roots blower pump in parallel with one or two turbomolecular pumps. Figure 3 is a schematic of the baseline vacuum system. The rotary piston/roots blower pump is assumed to be turned on at 760 torr and will operate until a pressure of 8E-03 torr is achieved. Once 8E-03 torr is reached the turbomolecular pump(s) is turned on and the rotary piston/roots blower pump turned off. The target pressure for this analysis is 1E-8 torr.

The vessel is initially assumed to contain air from the atmosphere during assembly. Helium will be used to backfill the vessel to avoid oxygen entering the vessel and reacting with the test assembly refractory metals. Therefore, pump down time is also calculated for helium.

PUMPS

The rotary piston (Figure 4) and roots blower (Figure 5) pumps are used in the viscous and transitional flow regimes. Rotary piston pumps normally operate at a speed of 400-500 rpm but can be as low as 300 rpm or as high as 1200 rpm. (O'Hanlon, 167-168) The rotors on the roots blower pump are synchronized and rotate in opposite directions at speeds ranging from 3000 to 3500 rpm (O'Hanlon, 169-170). The rotary piston pumps modelled are the Leybold DK200 and the Balzers DU0250A. The roots blower modelled is the Stokes 6210.

The turbomolecular pumps (Figure 6) (O'Hanlon, 174) operate in the molecular flow regime. If allowed to operate with the rear blades in viscous or transitional flow the rotor will be subjected to additional torque due to the viscous drag. This results in loss of pumping speed. The turbomolecular pump modelled is a Seiko STP2000, a turbomolecular pump with magnetic levitated bearings.

Pumps are evaluated on a pumping speed vs inlet pressure basis as shown in Appendix B. Data from the manufacturers' pump performance curve is input to *VACTRAN (VACTRAN A Vacuum System Design Tool, version 2.0) and plotted. For the rotary piston/roots blower pumps, the same pump curve is used for

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both air and helium according to manufacturer's recommendation. Air and helium are plotted separately for the turbomolecular pumps.

CONDUCTANCE

Flow in the roughing line connecting the rotary piston/roots blower pump to the vessel is assumed to be in the viscous or transitional flow regimes and is therefore a function of pressure. The conductance elements (pipes, elbows, bends, etc.) are input to VACTRAN (VACTRAN A Vacuum System Design Tool, version 2.0) based on the configuration shown in Figure 7 and the conductance is calculated by the program.

In the molecular flow regime, conductance, at a given temperature, is proportional to the molecular weight of the gas species. As stated above, the turbomolecular pumps are assumed to be in molecular flow. Conductance is calculated based on the configuration shown in Figures 8, 9 and 10. The tube-only conductance for the ducting connecting the turbomolecular pump to the vessel is calculated using the equations for molecular flow (Santeler, 338-342).

$$C_t = [\alpha/(1-\alpha)]C_{om}$$

where: C_t = tube-only conductance, liters/sec
 α = transmission probability of pump duct

$$\text{and, } C_{om} = 11.43(T/M) \cdot 5a^2$$

where: T = temperature (K)
 M = molecular weight
 a = radius of pump duct, cm

Transmission probability is taken from Figure 11 (O'Hanlon, 33). Figures 8 and 9 show the dimensions for the values A and B respectively.

For air at 366K, the system operating temperature, and transmission probability of .24, the conductance for the turbomolecular pumps is:

$$C_t = [\alpha/(1-\alpha)][11.43(T/M) \cdot 5a^2]$$

$$C_t = [.24/(1-.24)][11.43(366/28) \cdot 513.06^2]$$

$$C_t = 2226 \text{ l/s, Air}$$

Under the same conditions, the conductance for helium is:

$$C_t = [.24/(1-.24)][11.43(366/4) \cdot 513.06^2]$$

$$C_t = 5889 \text{ l/s}$$

Conductance models are defined in Appendix C.

GAS LOAD

The gas load is defined as the rate of gas introduction into the vacuum chamber in units of pressure-volume/time. The sources of gas to the chamber are material outgassing, permeation, leaks and backstreaming.

Outgassing by diffusion and desorption is the release of gases trapped in the vessel material during fabrication as well as gas and vapor adsorbed on the interior walls from the atmosphere after assembly. The release of these gases varies with time, temperature and vacuum conditions.

At equilibrium, permeation behaves as a slow leak. Gases collect on the outer wall of the vessel and work their way through the vessel material to the inner wall to be desorbed into the vessel. Permeation through stainless steel is predominantly hydrogen. Permeation in this case, calculated in Appendix D, is negligible compared to vessel leaks through flanges, etc. Leaks through the vessel flanges and mechanical penetration is specified at $1.1\text{E-}6$ torr-liters/sec as a design limit.

Backstreaming is that amount of gas which flows back into the vessel from the pump. This may also include pump oil if proper precautions are not taken such as sorption traps and gas purges. Oil backstreaming can be eliminated by using oil-free pumps such as the Seiko STP2000 turbomolecular pump.

Bake-out, heating the vessel at 423K for a period of 15 days, will accelerate outgassing due to diffusion and desorption as well as vaporize any water collected on the interior wall of the vessel. Once bake-out is complete, the initial volume of gas is pumped and the outgassing load is depleted, this analysis assumes a steady outgassing rate of $1.1\text{E-}6$ torr-liters/second.

PUMP DOWN

The pump down time is the amount of time it takes to go from an initial pressure of 760 torr at start-up to a final pressure of 10^{-8} torr for any given system model. Appendix A contains descriptions of eight system models; 4-air and 4-helium. In each case the gas load is assumed to be $1.1\text{E-}6$ torr-liters/second. Appendix E contains all pump down curves for each case. Each case has three curves marked A, B and C corresponding to duct sizes of

4-inch, 6-inch and 8-inch respectively. The results are listed in Table 1 below. The specified maximum time allowed for pump down is 24 hours.

TABLE 1
Pump Down Analysis Results

<u>Case Description</u>		<u>Pump Down Time</u>		
		<u>4-inch duct</u>	<u>6-inch duct</u>	<u>8-inch duct</u>
No.	AIR:	A	B	C
1	DK200 + 2-STP2000	2 hr-40 min	2 hr-20 min	2 hr-18 min
2	DUO250 + 2-STP2000	2 hr-05 min	1 hr-45 min	1 hr-41 min
3	DK200 + 1-STP2000	2 hr-45 min	2 hr-24 min	2 hr-20 min
4	STOKES 6210 + 2-STP2000	2 hr-20 min	2 hr-03 min	1 hr-59 min
	HELIUM:	A	B	C
5	DK200 + 2-STP2000	2 hr-44 min	2 hr-25 min	2 hr-22 min
6	DUO250 + 2-STP2000	2 hr-08 min	1 hr-50 min	1 hr-46 min
7	DK200 + 1-STP2000	2 hr-46 min	2 hr-28 min	2 hr-25 min
8	STOKES 6210 + 2-STP2000	2 hr-14 min	2 hr-00 min	1 hr-58 min

ACCURACY

A subsequent analysis using the Vacuum System Design (VSD) (Vacuum System Design, version 2.2-2) software confirms the results shown above. The model used is the same as for case 1A above with a Balzers DUO060A as a backing pump for the turbomolecular pump. Appendix F contains the pump down analysis for this study.

The necessary pump curve constants (given below) are calculated from the pump curves plotted on the VACTRAN system for air and helium (Figures 12 and 13, respectively) and input to VSD (Vacuum System Design, 33).

S_C = constant pump speed
 P_B = pressure at the intersection of constant speed
 (line A) and line B
 SL = slope of line B

$$\frac{\log(Q_2/Q_1)}{\log(P_2/P_1)}$$
 where Q = throughput
 (torr-liters/sec)
 P = pressure (torr)
 Q_M = horizontal constant throughput (line C)
 P_M = maximum operating pressure at full gas load

AIR:
 $SL = \frac{\log(3/1)}{\log(4.3E-3/8E-4)}$
 $SL = .653$
 $P_B = 8E-4 \text{ torr}$
 $S_C = 1920 \text{ l/s}$
 $Q_m = 3 \text{ torr-liters/sec}$

HELIUM:
 $SL = \frac{\log(2.6/1.3)}{\log(4E-3/8E-4)}$
 $SL = .4307$
 $P_B = 8E-4 \text{ torr}$
 $S_C = 1780 \text{ l/s}$
 $Q_m = 2.6 \text{ torr-liters/sec}$

Conductance is calculated by VSD (Vacuum System Design, version 2.2-2) using the same configuration as case 1A above. The vessel is assumed to contain air. The gas load, due to inleakage, is assumed to be $1.1E-06$ as in the previous analysis. A comparison of the results to those of case 1A using VACTRAN is given in Table 2 below.

TABLE 2
Pump Down Analysis Results

<u>Case Description</u>	<u>Pump Down Time</u>	
	<u>VACTRAN</u>	<u>VSD</u>
Air: DK200 + 2-STP2000	2 hr-40 min	2 hr-49 min

CONCLUSION

A review of Table 1 reveals that for all cases the proposed vacuum system will be able to pump down the vessel within the required time of 24 hours. The use of a larger rotary piston pump (DU0250) improves the pump down time by 35 minutes and therefore should be considered. The 6-inch duct for the roughing line is optimal, however, because all cases are well below the 24 hour time frame, the 4-inch duct is sufficient. The use of the single turbomolecular pump during pump down is sufficient. A pump down with helium in the vessel and a helium inleakage delays the time to achieve the base pressure marginally and is acceptable.

A review of the results in Table 2 reveals that the two programs, VACTRAN and VSD, are in agreement. Therefore, the results obtained from VACTRAN are valid and reasonable.

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GES TEST SITE

Figure 2. GES Test Site Vacuum Vessel

Figure 3. GES Test Site Vacuum

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Figure 4. Rotary Piston Pump

Figure 5. Roots Blower Pump; section through a single-stage roots pump; (1) inlet, (2) rotors, (3) housing, (4) Pump chamber (swept volume), (5) outlet.

FIGURE 6
Turbomolecular Pump

Figure 7. Rough Vacuum System Configuration

Figure 8. Turbopump Plan View.

Figure 9. Turbomolecular Pump.

Figure 10. Turbopump elevation view.

Figure 11. Transmission probabilities for elbow bend.

FIGURE 12

Pump Curve - Air

VacTran Performance Curve For STP2000A.PMP

Inlet Pressure (Torr)

VacTran Performance Curve For STPHE.PMP

FIGURE 13

Pump Curve - Helium

Appendix A

Several configurations were analyzed for both air and helium, with system descriptions defined below. The system consists of one roughing pump and one or two turbomolecular pumps attached to the vessel by ducting. The roughing pump, a rotary piston, or roots blower pump, is located at station one, external to the Test Cell. The turbomolecular pumps are located at stations two and three as applicable, within the Test Cell. In all cases, gas load was assumed to be $1.1\text{E-}6$ torr-liters per sec., air, for initial pump down (air in Test Cell) and helium for follow on pump downs (with an inerted Test Cell).

Case 1 : Air, 1 ea. DK200 & 2 ea. STP2000

VacTran System Model: RUF.sys

Selected Gas = Air
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = $3.413\text{E}+04$ Liters
Vessel + Conductance Volumes = $3.427\text{E}+04$ Liters
System Start Pressure = 760.0 Torr
System Target Pressure = $1.000\text{E-}08$ Torr
System Gas Load Model = GASLOAD.GLD ($1.1\text{E-}06$ T-L/sec., air)

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at $8.00\text{E-}03$ Torr
Pump Models: 1 DK200.PMP (Table B-1 & Figure B-1)
Conductance Models: 1 RUF.CND (Figure C-1A)
 1 6INCOND.CND (Figure C-1B)
 1 8INCOND.CND (Figure C-1C)

***** STATION 2 *****

Station turns on at 0.008 Torr
Station turns off at $1.000\text{E-}08$ Torr
Pump Models: 1 STP2000A.PMP (Table B-3, Figure B-5)
Conductance Models: 1 TURBO.CND (2226 l/sec., air)

***** STATION 3 *****

Station turns on at 0.008 Torr
Station turns off at $1.000\text{E-}08$ Torr
Pump Models: 1 STP2000A.PMP (Table B-3, Figure B-5)
Conductance Models: 1 TURBO.CND (2226 l/sec., air)

Total Pumpdown Time: 2 hr-40 min (4-in. duct)
 2 hr-20 min (6-in. duct)
 2 hr-18 min (8-in. duct)

Appendix A

Case 2: Air, 1 ea. DUO250 & 2 ea. STP2000

VacTran System Model RF2.SYS
Selected Gas = Air
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = 3.413E+04 Liters
Vessel + Conductance Volumes = 3.427E+04 Liters
System Start Pressure = 760.0 Torr
System Target Pressure = 1.000E-08 Torr
System Gas Load Model = GASLOAD.GLD (1.1E-06 T-L/sec., air)

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at 8.00E-03 Torr
Pump Models: 1 DUO250A.PMP (Table B-2, Figure B-5)
Conductance Models: 1 RUF.CND (Figure C-1A)
 1 6INCOND.CND (Figure C-1B)
 1 8INCOND.CND (Figure C-1C)

***** STATION 2 *****

Station turns on at 0.008 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STP2000A.PMP (Table B-3, Figure B-5)
Conductance Models: 1 TURBO.CND (2226 l/sec., air)

***** STATION 3 *****

Station turns on at 0.008 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STP2000A.PMP (Table B-3, Figure B-5)
Conductance Models: 1 TURBO.CND (2226 l/sec., air)

Total Pumpdown Time: 2 hr-05 min (4-in. duct)
 1 hr-45 min (6-in. duct)
 1 hr-41 min (8-in. duct)

Appendix A

Case 3: Air, 1 ea. DK200 & 1 ea. STP2000

VacTran System Model RF3.SYS
Selected Gas = Air
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = 3.413E+04 Liters
Vessel + Conductance Volumes = 3.422E+04 Liters
System Start Pressure = 760.0 Torr
System Target Pressure = 1.000E-08 Torr
System Gas Load Model = GASLOAD.GLD (1.1E-06 T-L/sec., air)

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at 8.00E-03 Torr
Pump Models: 1 DK200.PMP (Table B-1, Figure B-1)
Conductance Models: 1 RUF.CND (Figure C-1A)
 1 6INCOND.CND (Figure C-1B)
 1 8INCOND.CND (Figure C-1C)

***** STATION 2 *****

Station turns on at 0.008 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STP2000A.PMP (Table B-3, Figure B-5)
Conductance Models: 1 TURBO.CND (2226 l/sec., air)

Total Pumpdown Time: 2 hr-45 min (4-in. duct)
 2 hr-24 min (6-in. duct)
 2 hr-20 min (8-in. duct)

Appendix A

Case 4: Air, 1 ea. Stokes Dry Pump 6210 & 2 ea. STP2000

VacTran System Model STOKES.SYS
Selected Gas = Air
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = 3.000E+04 Liters

Vessel + Conductance Volumes = 3.014E+04 Liters
System Start Pressure = 760.0 Torr
System Target Pressure = 1.000E-08 Torr
System Gas Load Model = GASLOAD.GLD

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at 0.008 Torr
Pump Models: 1 STOKES.PMP (Table B-5, Figure B-8)
Conductance Models: 1 RUF.CND (Figure C-1A)
 1 6INCOND.CND (Figure C-1B)
 1 8INCOND.CND (Figure C-1C)

***** STATION 2 *****

Station turns on at 0.008 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STP2000A.PMP (Table B-3, Figure B-5)
Conductance Models: 1 TURBO.CND (2226 l/sec., air)

***** STATION 3 *****

Station turns on at 0.008 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STP2000A.PMP (Table B-3, Figure B-5)
Conductance Models: 1 TURBO.CND (2226 l/sec., air)

Total Pumpdown Time: 2 hr-20 min (4-in. duct)
 2 hr-03 min (6-in. duct)
 1 hr-59 min (8-in. duct)

Appendix A

Case 5: Helium, 1 ea. DK200 & 2 ea. STP2000

VacTran System Model HE.SYS
Selected Gas = Helium
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = 3.413E+04 Liters
Vessel + Conductance Volumes = 3.427E+04 Liters
System Start Pressure = 760.0 Torr
System Target Pressure = 1.000E-08 Torr
System Gas Load Model = GASLOAD.GLD (1.1E-06 T-L/sec., He)

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at 4.00E-03 Torr
Pump Models: 1 DK200.PMP (Table B-1, Figure B-1)
Conductance Models: 1 RUF.CND (Figure C-2A)
1 6INCOND.CND (Figure C-2B)
1 8INCOND.CND (Figure C-2C)

***** STATION 2 *****

Station turns on at 0.004 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STPHE.PMP (Table B-4, Figure B-6)
Conductance Models: 1 TURBOHE.CND (5889 l/sec., helium)

***** STATION 3 *****

Station turns on at 0.004 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STPHE.PMP (Table B-4, Figure B-6)
Conductance Models: 1 TURBOHE.CND (5889 l/sec., helium)

Total Pumpdown Time: 2 hr-44 min (4-in. duct)
2 hr-25 min (6-in. duct)
2 hr-22 min (8-in. duct)

Appendix A

Case 6: Helium, 1 ea. DU0250 & 2 ea. STP2000

VacTran System Model HE2.SYS
Selected Gas = Helium
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = 3.413E+04 Liters
Vessel + Conductance Volumes = 3.427E+04 Liters
System Start Pressure = 760.0 Torr
System Target Pressure = 1.000E-08 Torr
System Gas Load Model = GASLOAD.GLD (1.1E-06 T-L/sec., He)

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at 4.00E-03 Torr
Pump Models: 1 DU0250A.PMP (Table B-2, Figure B-3)
Conductance Models: 1 RUF.CND (Figure C-2A)
1 6INCOND.CND (Figure C-2B)
1 8INCOND.CND (Figure C-2C)

***** STATION 2 *****

Station turns on at 0.004 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STPHE.PMP (Table B-4, Figure B-6)
Conductance Models: 1 TURBOHE.CND (5886 l/sec., helium)

***** STATION 3 *****

Station turns on at 0.004 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STPHE.PMP (Table B-4, Figure B-6)
Conductance Models: 1 TURBOHE.CND (5886 l/sec., helium)

Total Pumpdown Time: 2 hr-08 min (4-in. duct)
1 hr-50 min (6-in. duct)
1 hr-46 min (8-in. duct)

Appendix A

Case 7: Helium, 1 ea. DK200 & 1 ea. STP2000

VacTran System Model HE4.SYS
Selected Gas = Helium
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = 3.413E+04 Liters
Vessel + Conductance Volumes = 3.422E+04 Liters
System Start Pressure = 760.0 Torr
System Target Pressure = 1.000E-08 Torr
System Gas Load Model = GASLOAD.GLD (1.1E-06 T-L/sec., He)

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at 4.00E-03 Torr
Pump Models: 1 DK200.PMP (Table B-1, Figure B-1)
Conductance Models: 1 RUF.CND (Figure C-2A)
 1 6INCOND.CND (Figure C-2B)
 1 8INCOND.CND (Figure C-2C)

***** STATION 2 *****

Station turns on at 0.004 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STPHE.PMP (Table B-4, Figure B-6)
Conductance Models: 1 TURBOHE.CND (5886 l/sec., helium)

Total Pumpdown Time: 2 hr-46 min (4-in. duct)
 2 hr-28 min (6-in. duct)
 2 hr-25 min (8-in. duct)

Appendix A

Case 8: Helium, 1 ea. Stokes Dry Pump 6210 & 2 ea. STP2000

VacTran System Model STOKESHE.SYS
Selected Gas = Helium
Current Temperature = 298.0 Kelvin
Vacuum Vessel Volume = 3.000E+04 Liters

Vessel + Conductance Volumes = 3.028E+04 Liters
System Start Pressure = 760.0 Torr
System Target Pressure = 1.000E-08 Torr
System Gas Load Model = GASLOAD.GLD

***** STATION 1 *****

Station turns on at 760.0 Torr
Station turns off at 0.008 Torr
Pump Models: 1 STOKES.PMP (Table B-5, Figure B-8)
Conductance Models: 1 RUF.CND (Figure C-2A)
 1 6INCOND.CND (Figure C-2B)
 1 8INCOND.CND (Figure C-2C)

***** STATION 2 *****

Station turns on at 0.008 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STPHE.PMP (Table B-4, Figure B-6)
Conductance Models: 1 TURBOHE.CND (5886 l/sec., helium)

***** STATION 3 *****

Station turns on at 0.008 Torr
Station turns off at 1.000E-08 Torr
Pump Models: 1 STPHE.PMP (Table B-4, Figure B-6)
Conductance Models: 1 TURBOHE.CND (5886 l/sec., helium)

Total Pumpdown Time: 2 hr-14 min (4-in. duct)
 2 hr (6-in. duct)
 1 hr-58 min (8-in. duct)

Appendix B

Pumps were compared on the bases of pump speed vs inlet pressure as shown below. In the case of the rotary piston and roots blower pumps, the same pump curve was used for both air and helium. Separate curves were plotted for the turbomolecular pumps.

ROTARY PISTON PUMPS

Pump: Leybold DK200

VacTran Pump Model DK200.PMP (Table B-1, Figure B-1)

Manufacturer's graph (Figure B-2)

Maximum Pump Speed = 115.2 Cu Feet/Minute

Maximum Pump Pressure = 760.0 Torr

Minimum Pump Pressure = 1.000E-05 Torr

Pump: Balzers DUO250A

VacTran Pump Model DUO250A.PMP (Table B-2, Figure B-3)

Manufacturer's graph (figure B-4)

Maximum Pump Speed = 276.9 Cu Meters/Hour

Maximum Pump Pressure = 760.0 Torr

Minimum Pump Pressure = 2.000E-04 Torr

TURBOMOLECULAR PUMP

AIR:

Pump: Seiko STP2000

VacTran Pump Model STP2000A.PMP (Table B-3, Figure B-5)

Manufacturer's graph (Figure B-7)

Maximum Pump Speed = 1920 Liters/Second

Maximum Pump Pressure = 0.01 Torr

Minimum Pump Pressure = 1.000E-10 Torr

HELIUM:

Pump: Seiko STP2000

VacTran Pump Model STPHE.PMP (Table B-4, Figure B-6)

Manufacturer's graph (Figure B-7)

Maximum Pump Speed = 1780 Liters/Second

Maximum Pump Pressure = 0.006 Torr

Minimum Pump Pressure = 1.000E-10 Torr

ROOTS BLOWER PUMP

Pump: Stokes Dry Pump '6210
VacTran Pump Model STOKES.PMP (Table B-5, Figure B-8)
Manufacturer's graph (Figure B-9)

Maximum Pump Speed = 56.63 Liters/Second
Maximum Pump Pressure = 760.0 Torr
Minimum Pump Pressure = 0.001 Torr

Appendix B

TABLE B-1
Pump Speed vs Inlet Pressure for
Leybold DK200

Gas: Air/Helium Inlet Pressure (Torr)	Speed (Cu Feet/Minute)
7.60E+02	1.15E+02
5.00E+02	1.14E+02
2.00E+00	1.14E+02
1.00E+02	1.13E+02
1.00E+01	1.11E+02
1.00E+00	1.08E+02
1.00E-00	1.02E+02
8.00E-02	1.02E+02
6.00E-02	1.01E+02
4.00E-02	9.99E+01
2.00E-02	9.70E+01
1.00E-02	9.36E+01
8.00E-03	9.20E+01
6.00E-03	9.10E+01
4.00E-03	8.80E+01
2.00E-03	8.30E+01
1.00E-03	7.67E+01
8.00E-04	7.40E+01
6.00E-04	7.10E+01
4.00E-04	6.60E+01
2.00E-04	5.70E+01
1.00E-04	4.48E+01
8.00E-05	4.10E+01
6.00E-05	3.50E+01
4.00E-05	2.50E+01
2.00E-05	7.00E+00
1.00E-05	1.00E-01

TABLE B-2
Pump Speed vs Inlet Pressure for
Balzers DU0250A

Gas: Air/Helium Inlet Pressure (Torr)	Speed (Cu Meters/Minute)
7.60E+02	2.76E+02
5.00E+02	2.76E+02
2.00E+02	1.75E+02
1.00E+02	2.73E+02
1.00E+01	2.68E+02
1.00E+00	2.56E+02
1.00E-01	2.34E+02
8.00E-02	2.32E+02
6.00E-02	2.29E+02
4.00E-02	2.22E+02
2.00E-02	2.10E+02
1.00E-02	1.97E+02
8.00E-03	1.91E+02
6.00E-03	1.85E+02
4.00E-03	1.73E+02
2.00E-03	1.52E+02
1.00E-03	1.27E+02
8.00E-04	1.17E+02
6.00E-04	1.05E+02
4.00E-04	8.49E+01
2.00E-04	4.58E+01

Appendix B

TABLE B-3
Pump Speed vs Inlet Pressure for
STP-2000

Gas: Air Inlet Pressure (Torr)	Speed (Liters/Second)
1.00E-02	1.00E-01
8.00E-03	9.40E+01
6.00E-03	4.38E+02
4.00E-03	6.88E+02
2.00E-03	1.12E+03
1.00E-03	1.54E+03
8.00E-04	1.65E+03
6.00E-04	1.73E+03
4.00E-04	1.83E+03
2.00E-04	1.92E+03
1.00E-04	1.92E+03
4.00E-05	1.92E+03
4.00E-06	1.92E+03
1.00E-06	1.92E+03
1.00E-10	1.92E+03

TABLE B-4
Pump Speed vs Inlet Pressure for
STP-2000

Gas: Helium Inlet Pressure (Torr)	Speed (Liter/Second)
6.00E-03	1.00E-01
4.00E-03	3.13E+02
2.00E-03	7.82E+02
1.00E-03	1.25E+03
8.00E-04	1.38E+03
6.00E-04	1.53E+03
4.00E-04	1.64E+03
2.00E-04	1.76E+03
1.00E-04	1.78E+03
4.00E-05	1.78E+03
4.00E-06	1.78E+03
1.00E-06	1.78E+03
1.00E-10	1.78E+03

TABLE B-5
Pump vs Inlet Pressure for Stokes Dry
Pump 6210

Gas: Air/Helium Inlet Pressure (Torr)	Speed (Liters/Second)
7.60E+02	5.56E+01
3.00E+01	5.56E+01
2.00E+01	5.61E+01
1.00E+01	5.66E+01
4.00E-01	5.61E+01
2.00E-01	5.52E+01
1.00E-01	5.38E+01
6.00E-02	5.19E+01
4.00E-02	5.04E+01
3.00E-02	4.86E+01
2.00E-02	3.96E+01
1.00E-02	2.54E+01
1.00E-03	4.71E+00

Pump Speed
(Cu Feet/Minute)

DK200 Pump Curve - Air/Helium

FIGURE B-2
DK200 MANUFACTURERS PUMP CURVE - AIR/HELIUM

Performance Curves

DK100, DK200

FIGURE B-3

DU0250A Pump Curve - Air/Helium

VacTran Performance Curve For DU0250A.PMP

FIGURE B-4
DUO250 MANUFACTURERS PUMP CURVE - AIR/HELIUM

Two-stage pumps

FIGURE B-5

STP2000 Pump Curve - Air

VacTran Performance Curve For STP2000A.PMP

FIGURE B-6

STP2000 Pump Curve - Helium

VacTran Performance Curve For STPHE.PMP

Orto Vacuum model STP-2000 1 (11/63)

STP-2000

5 10^{-3}

5 10^{-2}

5 10^{-1}

5 10^0 (Pa)

15/2 Inerts Filtration

FIGURE B-7

Pump Speed
(Cu Feet/Minute)

୧-୫ ସମାପ୍ତ

STOKES[®] VACUUM

FIGURE B-9

Stokes 6210 Manufacturers Pump Curve

Air/Helium

DRY PUMP

PERFORMANCE CURVES

Appendix C

Conductance for the rotary piston pumps was based on total length of ducting from the pump to the vessel and all included bends and elbows. (Figure 7)
The same conductance model was used for both the DK200 and the Balzers DUO250A. The parameters used are given below.

VacTran Conductance Model RUF.CND

Selected Gas = Air/Helium (Figures C-1A & C-2A, respectively)

Current Temperature = 298.0 Kelvin

Conductance Start Pressure = 760.0 Torr

Conductance Target Pressure = 1.000E-08 Torr

1) Standard Elbow :

Diameter = 9.525 Centimeters Angle = 90.0 degrees

Elbow Volume = 0.2138 Liters

2) Standard Elbow :

Diameter = 9.525 Centimeters Angle = 45.0 degrees

Elbow Volume = 0.4275 Liters

3) Pipe Bend :

Bend Radius = 55.0 Diameter = 9.525 Centimeters Angle = 55.0 degrees

Bend Volume = 1.042 Liters

4) Cylindrical Pipe :

Diameter = 9.525 Length = 528.8 Centimeters

Pipe Volume = 37.68 Liters

VacTran Conductance Model 6INCOND.CND

Selected Gas = Air/Helium (Figures C-1B & C-2B, respectively)

Current Temperature = 298.0 Kelvin

Conductance Start Pressure = 760.0 Torr

Conductance Target Pressure = 1.000E-08 Torr

1) Standard Elbow :

Diameter = 14.6 Centimeters Angle = 90.0 degrees

Elbow Volume = 0.5026 Liters

2) Standard Elbow :

Diameter = 14.6 Centimeters Angle = 45.0 degrees

Elbow Volume = 1.005 Liters

3) Cylindrical Pipe :

Diameter = 14.6 Length = 528.8 Centimeters

Pipe Volume = 88.59 Liters

4) Pipe Bend :

Bend Radius = 55.0 Diameter = 14.6 Centimeters Angle = 55.0 degrees

Bend Volume = 3.522 Liters

Appendix C

VacTran Conductance Model 8INCOND

Selected Gas = Air/Helium (Figures C-1C & C-2C, respectively)

Current Temperature = 298.0 Kelvin

Conductance Start Pressure = 760.0 Torr

Conductance Target Pressure = 1.000E-08 Torr

1) Standard Elbow :

Diameter = 20.32 Centimeters Angle = 90.0 degrees

Elbow Volume = 0.9729 Liters

2) Standard Elbow :

Diameter = 20.32 Centimeters Angle = 45.0 degrees

Elbow Volume = 1.946 Liters

3) Cylindrical Pipe :

Diameter = 20.32 Length = 528.8 Centimeters

Pipe Volume = 171.5 Liters

4) Pipe Bend :

Bend Radius = 55.0 Diameter = 20.32 Centimeters Angle = 55.0 degrees

Bend Volume = 9.488 Liters

Conductance for the turbomolecular pumps was assumed constant at:

- 2,226 liters/sec for air
- 5,889 liters/sec for helium

FIGURE C-1A

Rough Pump Conductance - Air
4-inch duct

VacTran Conductance Curve For RUF.CND

FIGURE C-1B
 Rough Pump Conductance - Air
 6-inch duct

VacTran Conductance Curve For 6INCOND.CND

FIGURE C-1C

Rough Pump Conductance - Air
8-inch duct

VacTran Conductance Curve For 8INCOND.CND

FIGURE C-2A
 Rough Pump Conductance - Helium
 4-inch duct

VacTran Conductance Curve For HE.CND

FIGURE C-2B

Rough Pump Conductance - Helium
6-inch duct

VacTran Conductance Curve For 6INCOND.CND

FIGURE C-2C

Rough Pump Conductance - Helium
8-inch duct

VacTran Conductance Curve For 8INCOND.CND

Appendix D

At equilibrium, the permeation rate is given as

$$q = \frac{K_p PA}{d} \quad (\text{O'Hanlon, 130})$$

where: d = wall thickness (1.37 cm)

P = pressure difference across wall,
for hydrogen

$P = P_{\text{atmosphere}} - P_{\text{vessel}}$

$P_{\text{atmosphere}} = 3.825\text{E-}4$ torr (O'Hanlon, 4)

$P_{\text{vessel}} = 1\text{E-}8$ torr, design

K_p = permeability constant (cm^2/sec)

A = inside surface area ($7.8\text{E+}5$ cm^2)

$$K_p = DS' \quad (\text{O'Hanlon, 130})$$

where: $S' = 1$ (solid solubility at steady-state)

D = diffusion constant

$$D = D_0 \exp(-E_d/RT) \quad (\text{Kass \& Andrzejewski: Perkins})$$

where: $D_0 = .012$ cm^2/sec (for 300 series stainless steel)

$E_d = 13,100$ cal/g-mol (for 300 series stainless steel)

$R = 1.987$ cal/g-mol-K

T = temperature (K)

for 25°C

$$D = (.012 \text{ cm}^2/\text{sec}) \exp[(-13,100 \text{ cal/g-mol}) / (1.987 \text{ cal/g-mol-K} * 298 \text{ K})]$$

$$D = 2.96\text{E-}12 \text{ cm}^2/\text{sec}$$

$$q = [(2.958\text{E-}12 \text{ cm}^2/\text{sec})(3.825\text{E-}4 \text{ torr} - 1\text{E-}8 \text{ torr}) / 1.37 \text{ cm}] 7.8\text{E+}5 \text{ cm}^2$$

$$q = 6.44\text{E-}10 \text{ torr-liters/sec}$$

for 93°C

$$D = (.012 \text{ cm}^2/\text{sec}) \exp[(-13,100 \text{ cal/g-mol}) / (1.987 \text{ cal/g-mol-K} * 366 \text{ K})]$$

$$D = 1.80\text{E-}10 \text{ cm}^2/\text{sec}$$

$$q = [(1.8\text{E-}10 \text{ cm}^2/\text{sec})(3.825\text{E-}4 \text{ torr} - 1\text{E-}8 \text{ torr}) / 1.37 \text{ cm}] 7.8\text{E+}5 \text{ cm}^2$$

$$q = 3.92\text{E-}8 \text{ torr-liters/sec}$$

Vacuum System Analysis
Denise S Rohrdanz
July 19, 1990

for 149°C

$$D = (.012 \text{ cm}^2/\text{sec}) \exp[(-13,100 \text{ cal/g-mol}) / (1.987 \text{ cal/g-mol-K} * 422\text{K})]$$

$$D = 2.04\text{E-}9 \text{ cm}^2/\text{sec}$$

$$q = [(2.04\text{E-}9 \text{ cm}^2/\text{sec})(3.825\text{E-}4 \text{ torr} - 1\text{E-}8 \text{ torr}) / 1.37 \text{ cm}] 7.8\text{E+}5 \text{ cm}^2$$

$$q = 4.67\text{E-}7 \text{ torr-liters/sec}$$

RUF.SYS

FIGURE E-1A
Case 1A Pump Down Curve - Air
4-inch duct

FIGURE E-1B
Case 1B Pump Down Curve - Air
6-inch duct

Pump Down Curve for RUF.SYS

53

Pressure

(mmHg)

Gas Load Contribution —
System with no gas load - - -

Time (Minutes)

FIGURE E-1C
Case 1C Pump Down Curve - Air
8-inch duct

Pump Down Curve for RF2.SYS

FIGURE E-2A
Case 2A Pump Down Curve - Air
4-inch duct

AF2.SYS

FIGURE E-2B
Case 2B Pump Down Curve - Air
6-inch duct

FIGURE E-2C
Case 2C Pump Down Curve - Air
8-inch duct

FIGURE E-3A

Case 3A Pump Down Curve - Air
4-inch duct

Pump Down Curve for

RF3.SYS

58
Pressure
(mmHg)

Gas Load Contribution ---
System with no gas load —

Time (Minutes)

FIGURE E-3B
Case 3B Pump Down Curve - Air
6-inch duct

Pump Down Curve for

RF3.SYS

FIGURE E-3C
Case 3C Pump Down Curve - Air
8-inch duct

FIGURE E-4A
Case 4A Pump Down Curve - Air
4-inch duct

FIGURE E-4B
Case 4B Pump Down Curve - Air
6-inch duct

Pressure

Pump Down Curve for STOKES.SYS

FIGURE E-4C
Case 4C Pump Down Curve - Air
8-inch duct

FIGURE E-5A
Case 5A Pump Down Curve - Helium
4-inch duct

FIGURE E-5B

Case 5B Pump Down Curve - Helium
6-inch duct

Pump Down Curve for HE.SYS

Pump Down Curve for HE.SYS

FIGURE E-5C
Case 5C Pump Down Curve - Helium
8-inch duct

FIGURE E-6A
Case 6A Pump Down Curve - Helium
4-inch duct

Pump Down Curve for HE2.SYS

FIGURE E-6B

Case 6B Pump Down Curve - Helium
6-inch duct

HE2.SYS

FIGURE E-6C
Case 6C Pump Down Curve - Helium
8-inch duct

Pump Down Curve for

HE4.SYS

FIGURE E-7A
Case 7A Pump Down Curve - Helium
4-inch duct

0 0 1 1 1 3 3 3 7

Pump Down Curve for

HE4.SYS

Pressure
(Torr)

70

Gas Load Contribution — — —
System with no gas load — — —

Time (Minutes)

FIGURE E-7B
Case 7B Pump Down Curve - Helium
6-inch duct

FIGURE E-7C
Case 7C Pump Down Curve - Helium
8-inch duct

Pump Down Curve for STOKES.SYS

FIGURE E-8A
Case 8A Pump Down Curve - Helium
4-inch duct

Pump Down Curve for STOKES.SYS

FIGURE E-8B
Case 8B Pump Down Curve - Helium
6-inch duct

FIGURE E-8C
Case 8C Pump Down Curve - Helium
8-inch duct

VACUUM SYSTEM DESIGN

Baseline Configuration

[Tab]-to Review

[Enter]-Accept Schematic

[Esc]-Backup

COMMERCIAL TURBOMOLECULAR PUMP DATA

MANUFAC.	MODEL	DIA-CM	GAS TYPE	SPEED-L/S
SEIKO	STP2000	24.89	NITROGEN	1,920
SEIKO	STP2000	24.89	* OXYGEN	1,796
SEIKO	STP2000	24.89	WATER	1,920

* A Pumping Speed Has Been Estimated For Those Selected Gases
For Which No Pump Data Was Available
For Improved Accuracy, Input Missing Speeds With UTIL Program.

[Enter]-Continue

[Esc]-Backup

COMMERCIAL MECHANICAL PUMP DATA

MANUFAC.	MODEL	DIA-CM	GAS TYPE	SPEED-L/S	CFM
BALZERS	DU0060A	3.99	NITROGEN	18.30	38.78
BALZERS	DU0060A	3.99	OXYGEN	18.30	38.78
BALZERS	DU0060A	3.99	WATER	18.30	38.78

All Mechanical Pump Reference Data, (Except The Base Pressure),
Is The Same For All Gas Types. Gas Flow Dependency On The Gas
Type Commences When You Start Component Addition.

[Enter]-Continue

[Esc]-Backup

COMMERCIAL MECHANICAL PUMP DATA

MANUFAC.	MODEL	DIA-CM	GAS TYPE	SPEED-L/S	CFM
LEYBOLD	DK200	7.62	NITROGEN	54.70	115.91
LEYBOLD	DK200	7.62	OXYGEN	54.70	115.91
LEYBOLD	DK200	7.62	WATER	54.70	115.91

All Mechanical Pump Reference Data, (Except The Base Pressure),
Is The Same For All Gas Types. Gas Flow Dependency On The Gas
Type Commences When You Start Component Addition.

[Enter]-Continue

[Esc]-Backup

FORELINE VAC. SYST T= 366 K		COMPONENT ADDITION (in CM)	
No.	DESCRIPTION	DIAMETER	LENGTH
1	DUD060A	3.99	
2	Circular Tube	6.03	383.46
3	Tube with Bend	6.03	11.99
4	Tube with Bend	6.03	23.94
5	Straight thru Valve	6.03	14.99
6	Gage Location	6.03	
7	System Mult. = 2	8.53	
8	Line Terminus		
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			

Press Any Key To Continue

HIGH VACUUM SYSTEM T= 366 K		COMPONENT ADDITION (in CM)	
No.	DESCRIPTION	DIAMETER	LENGTH
1	STP2000	24.89	
2	Circular Tube	26.35	76.50
3	Straight thru Valve	26.35	14.00
4	Gage Location	26.35	
5	System Mult. = 2	37.26	
6	Line Terminus		
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			

Press Any Key To Continue

EVACUATION SYSTEM T= 366 K		COMPONENT ADDITION (in CM)	
No.	DESCRIPTION	DIAMETER	LENGTH
1	DK200	7.62	
2	Circular Tube	9.52	528.80
3	Tube with Bend	9.52	23.94
4	Tube with Bend	9.52	23.94
5	Tube with Bend	9.52	14.63
6	Gage Location	9.52	
7	Line Terminus		
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			

Press Any Key To Continue

SYSTEM PUMPDOWN STATISTICS

Input Total System Volume In Liters	3.41E+04
Longest Evacuation Line In Viscous Flow For P >	0.121 TORR
Longest Evacuation Line In Molecular Flow For P <	0.002 TORR
Minimum Transfer Pressure For Evacuation Pump Is:	0.000 TORR
Maximum Transfer Pressure For High Vacuum Pump Is:	0.100 TORR
Pressure Where Evacuation Speed = Hi Vac Speed Is:	

SYSTEM TIME CONSTANT IN SECONDS/DECADE

For Evacuation Pump At 0.100 TORR Is:	2.30E+03 Sec/D
For Evacuation Pump At 0.010 TORR Is:	4.73E+03 Sec/D
For HighVacuum Pump At 0.100 TORR Is:	1.10E+02 Sec/D
For HighVacuum Pump At 0.010 TORR Is:	5.18E+01 Sec/D

Select The Pressure To Transfer To High Vacuum	.008
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ENTER CHAMBER GAS COMPOSITION IN %

1 - NITROGEN	Composition = 79
2 - OXYGEN	Composition = 20
3 - WATER	Composition = 1

Page 1		SELECTED MATERIAL OUTGASSING	
MATERIAL IDENTIFICATION	GAS TYPE	UNIT	MULT
CONSTANT LEAK (/1E-7 air)	NITROGEN	1.00E+01	
CONSTANT LEAK (/1E-7 air)	OXYGEN	1.00E+01	
ST.STL baked(cm2)	NITROGEN	1.05E+06	
ST.STL baked(cm2)	WATER	1.05E+06	
ST.STL baked(cm2)	OXYGEN	1.05E+06	

[Enter]-Next Page

PUMPDO

NITROGEN

VOL=34,130.00 LITERS

PRESSURE

78

F1-Shift

F2-Print

F3-Read

F4-Data

F5-Gas

[Enter]-Continue

No.	TIME	PUMPDOWN P	OUTGAS P	TOTAL PRES	OUTGASSING
	MINUTES	TORR	TORR	TORR	.T-L/S
1	3.08E+00	4.47E+02	0.00E+00	4.47E+02	
2	3.56E+00	4.22E+02	0.00E+00	4.22E+02	
3	4.11E+00	3.99E+02	0.00E+00	3.99E+02	
4	4.74E+00	3.77E+02	0.00E+00	3.77E+02	
5	5.48E+00	3.55E+02	0.00E+00	3.55E+02	
6	6.33E+00	3.25E+02	0.00E+00	3.25E+02	
7	7.30E+00	2.98E+02	0.00E+00	2.98E+02	
8	8.44E+00	2.67E+02	0.00E+00	2.67E+02	
9	9.74E+00	2.37E+02	0.00E+00	2.37E+02	
10	1.12E+01	2.04E+02	0.00E+00	2.04E+02	
11	1.30E+01	1.73E+02	0.00E+00	1.73E+02	
12	1.50E+01	1.43E+02	0.00E+00	1.43E+02	
13	1.73E+01	1.15E+02	0.00E+00	1.15E+02	
14	2.00E+01	8.93E+01	0.00E+00	8.93E+01	
15	2.31E+01	6.68E+01	0.00E+00	6.68E+01	
16	2.67E+01	4.77E+01	0.00E+00	4.77E+01	
17	3.08E+01	3.24E+01	0.00E+00	3.24E+01	

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[Esc]-Exit

No.	TIME	PUMPDOWN P	OUTGAS P	TOTAL PRES	OUTGASSING
	MINUTES	TORR	TORR	TORR	.T-L/S
18	3.56E+01	2.07E+01	0.00E+00	2.07E+01	
19	4.11E+01	1.24E+01	0.00E+00	1.24E+01	
20	4.74E+01	6.92E+00	0.00E+00	6.92E+00	
21	5.48E+01	3.54E+00	0.00E+00	3.54E+00	
22	6.33E+01	1.65E+00	0.00E+00	1.65E+00	
23	7.30E+01	7.08E-01	0.00E+00	7.08E-01	
24	8.44E+01	2.83E-01	0.00E+00	2.83E-01	
25	9.74E+01	1.12E-01	0.00E+00	1.12E-01	
26	1.12E+02	4.64E-02	0.00E+00	4.64E-02	
27	1.30E+02	2.11E-02	0.00E+00	2.11E-02	
28	1.50E+02	1.04E-02	0.00E+00	1.04E-02	
29	1.71E+02	2.23E-03	0.00E+00	2.23E-03	
30	2.00E+02	0.00E+00	0.00E+00	0.00E+00	
31	2.31E+02	0.00E+00	0.00E+00	0.00E+00	
32	2.67E+02	0.00E+00	0.00E+00	0.00E+00	
33	3.08E+02	0.00E+00	0.00E+00	0.00E+00	
34	3.56E+02	0.00E+00	0.00E+00	0.00E+00	

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[Esc]-Exit

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NOTES

44-38861-1A

F2-Print

F3-Read

F4-Data

55-51

[Enter]-Continue

No.	TIME	PUMPDOWN P	OUTGAS P	TOTAL PRES	OUTGASSING
	MINUTES	TORR	TORR	TORR	.T-L/S
1	3.08E+00	1.13E+02	0.00E+00	1.13E+02	
2	3.56E+00	1.07E+02	0.00E+00	1.07E+02	
3	4.11E+00	1.01E+02	0.00E+00	1.01E+02	
4	4.74E+00	9.56E+01	0.00E+00	9.56E+01	
5	5.48E+00	8.98E+01	0.00E+00	8.98E+01	
6	6.33E+00	8.23E+01	0.00E+00	8.23E+01	
7	7.30E+00	7.53E+01	0.00E+00	7.53E+01	
8	8.44E+00	6.75E+01	0.00E+00	6.75E+01	
9	9.74E+00	5.99E+01	0.00E+00	5.99E+01	
10	1.12E+01	5.17E+01	0.00E+00	5.17E+01	
11	1.30E+01	4.39E+01	0.00E+00	4.39E+01	
12	1.50E+01	3.63E+01	0.00E+00	3.63E+01	
13	1.73E+01	2.91E+01	0.00E+00	2.91E+01	
14	2.00E+01	2.26E+01	0.00E+00	2.26E+01	
15	2.31E+01	1.69E+01	0.00E+00	1.69E+01	
16	2.67E+01	1.21E+01	0.00E+00	1.21E+01	
17	3.08E+01	8.19E+00	0.00E+00	8.19E+00	

[Enter]-Next Page

[Esc]-Exit

No.	TIME	PUMPDOWN P	OUTGAS P	TOTAL PRES	OUTGASSING
	MINUTES	TORR	TORR	TORR	.T-L/S
18	3.56E+01	5.25E+00	0.00E+00	5.25E+00	
19	4.11E+01	3.15E+00	0.00E+00	3.15E+00	
20	4.74E+01	1.75E+00	0.00E+00	1.75E+00	
21	5.48E+01	8.95E-01	0.00E+00	8.95E-01	
22	6.33E+01	4.19E-01	0.00E+00	4.19E-01	
23	7.30E+01	1.79E-01	0.00E+00	1.79E-01	
24	8.44E+01	7.18E-02	0.00E+00	7.18E-02	
25	9.74E+01	2.83E-02	0.00E+00	2.83E-02	
26	1.12E+02	1.18E-02	0.00E+00	1.18E-02	
27	1.30E+02	5.35E-03	0.00E+00	5.35E-03	
28	1.50E+02	2.64E-03	0.00E+00	2.64E-03	
29	1.71E+02	5.65E-09	0.00E+00	5.65E-09	
30	2.00E+02	0.00E+00	0.00E+00	0.00E+00	
31	2.31E+02	0.00E+00	0.00E+00	0.00E+00	
32	2.67E+02	0.00E+00	0.00E+00	0.00E+00	
33	3.08E+02	0.00E+00	0.00E+00	0.00E+00	
34	3.56E+02	0.00E+00	0.00E+00	0.00E+00	

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[Esc]-Exit

0 0 1 1 1 PDOWN 0 0 0

WATER

VOL=34,130.00 LITERS

PRESSURE - TORR

LOG TIME - MIN

F1-Shift F2-Print F3-Read F4-Data F5-Gas [Enter]-Continue

No.	TIME	PUMPDOWN P	OUTGAS P	TOTAL PRES	OUTGASSING
	MINUTES	TORR	TORR	TORR	.T-L/S
1	3.08E+00	5.66E+00	0.00E+00	5.66E+00	
2	3.56E+00	5.35E+00	0.00E+00	5.35E+00	
3	4.11E+00	5.05E+00	0.00E+00	5.05E+00	
4	4.74E+00	4.78E+00	0.00E+00	4.78E+00	
5	5.48E+00	4.49E+00	0.00E+00	4.49E+00	
6	6.33E+00	4.11E+00	0.00E+00	4.11E+00	
7	7.30E+00	3.77E+00	0.00E+00	3.77E+00	
8	8.44E+00	3.37E+00	0.00E+00	3.37E+00	
9	9.74E+00	3.00E+00	0.00E+00	3.00E+00	
10	1.12E+01	2.59E+00	0.00E+00	2.59E+00	
11	1.30E+01	2.19E+00	0.00E+00	2.19E+00	
12	1.50E+01	1.82E+00	0.00E+00	1.82E+00	
13	1.73E+01	1.46E+00	0.00E+00	1.46E+00	
14	2.00E+01	1.13E+00	0.00E+00	1.13E+00	
15	2.31E+01	8.46E-01	0.00E+00	8.46E-01	
16	2.67E+01	6.04E-01	0.00E+00	6.04E-01	
17	3.08E+01	4.10E-01	0.00E+00	4.10E-01	

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[Esc]-Exit

No.	TIME	PUMPDOWN P	OUTGAS P	TOTAL PRES	OUTGASSING
	MINUTES	TORR	TORR	TORR	.T-L/S
18	3.56E+01	2.62E-01	0.00E+00	2.62E-01	
19	4.11E+01	1.58E-01	0.00E+00	1.58E-01	
20	4.74E+01	8.76E-02	0.00E+00	8.76E-02	
21	5.48E+01	4.48E-02	0.00E+00	4.48E-02	
22	6.33E+01	2.09E-02	0.00E+00	2.09E-02	
23	7.30E+01	8.96E-03	0.00E+00	8.96E-03	
24	8.44E+01	3.59E-03	0.00E+00	3.59E-03	
25	9.74E+01	1.41E-03	0.00E+00	1.41E-03	
26	1.12E+02	5.88E-04	0.00E+00	5.88E-04	
27	1.30E+02	2.68E-04	0.00E+00	2.68E-04	
28	1.50E+02	1.32E-04	0.00E+00	1.32E-04	
29	1.71E+02	2.83E-10	0.00E+00	2.83E-10	
30	2.00E+02	0.00E+00	0.00E+00	0.00E+00	
31	2.31E+02	0.00E+00	0.00E+00	0.00E+00	
32	2.67E+02	0.00E+00	0.00E+00	0.00E+00	
33	3.08E+02	0.00E+00	0.00E+00	0.00E+00	
34	3.56E+02	0.00E+00	0.00E+00	0.00E+00	

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[Esc]-Exit

DATE

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3 / 24 / 94

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