WSRC-TR-98-00445

Performance of Vacuum Pumps to be Used in Tritium Extraction Facility

by

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DOE Contract No. **DE-AC09-96SR18500**

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KEYWORDS:
Vacuum pump

RETENTION:
PERMANENT

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ABSTRACT

It has been proposed to produce tritium in Light Water Nuclear Power Reactors by installing and irradiating lithium aluminate rods. After irradiation, the rod cladding would be punctured, the rods heated and the tritium extracted in a vacuum furnace. Vacuum pumps containing oil are undesirable because the oil would become contaminated with tritium. In support of this concept, the Thermal Fluids Laboratory (TFL) tested three types of oil-free vacuum pumps. The goal of this test was to measure pump operating characteristics for three different types of vacuum pumps for three different gases and a wider range of conditions than for the vendor data. Test results will be used by Engineering Development Section for incorporation in a computer model of the pump train.

The pumps were tested with the gases helium, hydrogen and deuterium for flows ranging from 2 to 700 sccm (standard cubic centimeters per minute). The roughing pumps were metal bellows pumps discharging to pressures of either 1.0 or 2.5 atm. For the range of gas flows tested, their performance can best be characterized as providing a nearly constant compression ratio of about 20:1. Performance was independent of the gas being pumped. Normetex scroll pumps provided the intermediate stage of pumping. The pump speed approximately matched vendor literature. However, the present work concluded that a plot of scroll pump inlet pressure versus standard gas flow is a more convenient way to represent and correlate the data. The relationship between scroll pump inlet pressure and standard gas flow is the same for all three gases and both outlet pressures.

High vacuum was provided by an Edwards turbomolecular pump, which was determined to have two regimes of operation, the flow limited regime and the backing pump limited regime. In the flow limited regime the high vacuum achieved is a function of gas flow but not of the capacity of the backing pumps. In this regime, the same vacuums were achieved with both helium and deuterium. Less vacuum was achieved with hydrogen. Another way to state the same result is that the pump had lower pump speeds for hydrogen than for helium or deuterium. In the backing pump limited regime the high vacuum achieved is independent of the flow but a strong function of the backing pressure. Flow and pressure relationships were quantified for the two regimes.

CONTENTS

1. INTRODUCTION

1.1 Background

It has been proposed to produce tritium in Light Water Nuclear Power Reactors by installing and irradiating lithium/aluminum rods. After irradiation, the rod cladding would be punctured, the rods heated and the tritium extracted in a vacuum furnace. Vacuum pumps containing oil are undesirable because the oil would become contaminated with tritium. In support of this concept, the Thermal Fluids Laboratory (TFL) tested three types of oil-free vacuum pumps. The current tests are mentioned in two memoranda [1] [2]. The goal of this baseline task is to measure pump operating characteristics for three different types of vacuum pumps. Test results will be used by Engineering Development Section for incorporation in a computer model of the pump train. No Task Technical Request (TTR) was written for this task. However, the signatures of the researchers, the customer and the Cognizant Quality Function on the Task Technical and QA Plan [3] demonstrate concurrence with requirements and deliverables specified for the task.

1.2. Previous work

Sharpe [4] tested a Model PV-12 Normetex scroll pump backed by a Model MB-601 metal bellows pump with the gases helium and air. Restivo, et al. [5] measured the inlet pressure for the same model metal bellows pump for flows up to 125,000 sccm (standard cubic centimeters per minute) for the gases hydrogen and nitrogen and for outlet pressures ranging from 1.0 to 2.5 atm.

1.3. Principles of Operation for the Three Types of Vacuum Pumps

The metal bellows pump has a stainless steel bellows that is compressed and expanded at a fixed rate. Gas passes through check valves at the inlet and outlet connections to the bellows. At low gas flows, the pump is expected to provide a constant compression ratio. At high flows the pressure inside the bellows does not equilibrate with the upstream and downstream pressures and the compression ratio decreases.

The Normetex scroll pump [4] has two spirals cut into metal plates. One of the plates is fixed while the other is moved in an orbital motion. Gas is trapped and pumped from the outside to the center. There are no seals between the metal plates, just tight clearances.

The turbomolecular pump has a turbine with many rows of blades that is rotated at 35,000 rpm giving a blade velocity of approximately 400 m/s. Gas molecules impact the moving turbine blades and are propelled from the inlet side of the pump to the outlet side. Turbomolecular pumps are designed to operate best in the molecular flow regime that is characterized by pressures less than roughly 0.1 torr. In this regime individual gas molecules are more likely to collide with solid walls than with other gas molecules and the concept of gas viscosity is irrelevant. This type of pump is most effective when the blade velocity is about the same as the average thermal velocity of the gas molecules. Performance degrades when the thermal velocity is significantly higher than the blade velocity [6]. Average thermal velocity is inversely proportional to the square root of molecular weight for the gas. At 20°C the average thermal velocities for hydrogen, helium, deuterium, tritium and nitrogen are 1762 m/s, 1246 m/s, 1246 m/s, 1017 m/s and 471 m/s, respectively [7]. Therefore, in the molecular flow regime, the pump is expected to operate most effectively with nitrogen and least effectively with hydrogen. Performance is expected to be the same with helium and deuterium and slightly better with tritium. For higher pressures there is a transition from the molecular flow regime to the viscous flow regime and viscous drag becomes increasingly important. Pumping performance degrades rapidly as pressure increases into the viscous flow regime.

2. EXPERIMENTAL WORK

2.1 Experimental Equipment

The equipment layout showing five vacuum pumps is shown in Figure 1. The two roughing pumps, Model MB-601 metal bellows pumps manufactured by Met Bell, are connected in parallel. A pressure regulator and an exhaust to outside the building are located downstream of the bellows pumps. Upstream of the bellows pumps is an intermediate stage of pumping, two Model PV-12 scroll pumps manufactured by the Normetex Co., also connected in parallel. The final stage of pumping, a model STPH600C turbomolecular pump by Edwards, is connected to the inlet of the scroll pumps. A valve was installed in the line between the turbo pump and the scroll pumps that could be positioned either fully open or partially closed to vary the backpressure on the turbo pump. A 4" diameter vacuum chamber was connected to the turbo pump. Gas was metered from a gas cylinder to the chamber using one of two gas rotameters, Brooks models R2-15-AAA and R2-15-A with glass and sapphire balls, respectively. The model R2-15-AAA rotameter was used for flows less than 80 sccm, 140 sccm, and 120 sccm, for the gases helium, hydrogen and deuterium, respectively. The model R2-15-A rotameter was used for higher flows. Throttle valves were connected to the outlets of the rotameters. The usual practice is to connect a throttle valve to the inlet of a rotameter. However, it was desired to decrease the pressure from 5 psig to vacuum across the valve. A pressure regulator controlled the inlet pressure to the rotameters at 5 psig. The accuracy of the model R2-15-AAA rotameter was 2 sccm, 4 sccm and 3 sccm, for helium, hydrogen and deuterium, respectively. The accuracy of the model R2-15-A rotameter was 20 sccm, 40 sccm and 30 sccm, for helium, hydrogen and deuterium, respectively.

There were seven pressure transducers as shown in Table 1 and Figure 1. Two flammable gas sensors were installed near the equipment because both hydrogen and deuterium are flammable. The flammable gas detector was set to alarm at 50% of the lower explosive limit (LEL). The LEL for hydrogen is 4% by volume. The detector never read higher than background level during the tests. Seven Type J thermocouples were connected to the hardware according to Table 2. The thermocouple accuracy is 2 °C. The term M&TE in Tables 1 and 2 refers to Measuring and Test Equipment.

Table 1 Pressure Transducers

Identifier	M&TE number	Range	Uncertainty	Manufacturer	Location
P1	3-2201	50 mtorr	0.0002 torr	Edwards	Vacuum chamber
P2	3-2169	1 torr	0.0002 torr	Edwards	Vacuum chamber
P3	3-2285	10 torr	0.03 torr	Edwards	Outlet of turbo pump before valve
P4	3-2436	10 torr	0.01 torr	MKS	Inlet of scroll pumps after valve
P5	3-2167	100 torr	0.1 torr	Edwards	Outlet of scroll pumps
P6	298	25 psig	0.1 psi	Heise	Outlet of bellows pumps
P7	na	200" H_2O	10" H_2O	Noshock	Inlet to rotameters.

Table 2 Thermocouples

Identifier	M&TE number	Location
T1	1076	outlet of bellows pump
T2	1051	gas inlet
T3	1057	scroll pump outlet
T4	1064	turbo pump inlet
T5	1062	ambient
T6	1023	turbo pump outlet
T7	na	body of turbo pump

2.2 Abbreviated Test Procedure

After construction was complete, the equipment and piping were leak tested. Leaks were detected and repaired. The flammable gas detectors were calibrated using a gas sample containing 2% hydrogen by volume in air (50% LEL). Gas rotameters were calibrated by filling a volumetric flask with water, inverting the flask with its mouth suspended in a basin of water, bubbling gas from the rotameter inside the flask and measuring the time to displace the water in the flask down to the calibration mark.

After preparations were complete, the vacuum pumps were energized and the heaters on the turbomolecular pump were energized to drive off gases and moisture. The pressure transducers were energized to warm up. After the pressure readings had stabilized with no gas introduction, the pressure gages were zeroed. This zeroing process takes advantage of the vendor information from Edwards and Normetex that the inlet of the turbo pump, P1 and P2, will reach 10^{-12} torr with no gas flow and the inlet of the scroll pump, P3 and P4, will reach 10^{-2} torr. The pressure of 10^{-12} torr is far below the range of pressure measurements made with transducers P1 and P2. The pressure of 10^{-2} torr was added to the raw pressures recorded for P3 and P4. According to the pressure gage vendor, changing the orientation of a vacuum pressure transducer may significantly change its zero adjustment. The orientation of some transducers was different in the pretest calibration and the test. However, because of frequent zero checking this fact had no effect on the accuracy of the data.

For data runs, a gas rotameter was chosen and a gas flow was set. The pressure regulator at the outlet of the bellows pump was set to either atmospheric pressure or 1900 torr (2.5 atm). The pressure regulator did not function reliably with only the gas flow going through it so that additional air was fed into the line just upstream of the regulator. After steady state had been achieved, after about five minutes, the rotameter identifier, the rotameter reading, seven pressures and seven temperatures were recorded in Laboratory Notebook 98-00085. A detailed procedure was used to conduct the test [8].

2.3 Test Variables

The pumps were tested with helium, hydrogen and deuterium. Metal bellows pump outlet pressures of 1.0 atm. and 2.5 atm were tested. Gas flows ranged from 2 sccm to 700 sccm. For this report standard conditions are 20°C and 760 torr. The valve between the turbomolecular pump and the scroll pumps was either fully open or partially closed.

3. RESULTS OF TESTS

Tabular data for runs with helium, hydrogen and deuterium are listed in Tables 3, 4 and 5, respectively. Temperature readings are not listed in the tables but typical values of T1, T2, T3, T4, T5, T6 and T7 were 24°, 23°, 25°, 23°, 20°, 29° and 60°C, respectively.

Pressure transducers P1 and P2 both measured the pressure of the vacuum chamber and agreed well with each other as shown in Figure 2 which plots all three gases. In the following graphs pressure transducer P2 was used exclusively because the transducers were found to have equal accuracy and transducer P2 had a wider range. Pressure transducer P3 was upstream of the valve and should always read the same or higher pressure than the downstream pressure transducer P4. Figure 3, which plots all three gases, shows this relationship to be true.

Data for the metal bellows pumps are plotted in Figures 4 and 5. For the range of flows tested and three gases, compression ratio is nearly constant with flow and is independent of choice of gas. For a discharge pressure of 2.5 atm, compression ratio ranges from about 23 for low flows to 20 for the highest flows tested. Compression ratios are about 20% lower for an outlet pressure of 1 atm. Figure 5 shows the hydrogen data from Figure 4 and the hydrogen data obtained previously by Restivo [5] for higher gas flows and inlet pressures in range from 300 to 760 torr. At high gas flows the compression ratio decreases markedly. While there is a large gap in the data between the highest flow in the current work and the lowest flow in the Restivo work, the trends are consistent.

Data for the scroll pumps are shown in Figures 6 through 10. Figures 6 through 8 show pump speed as a function of pump inlet pressure for the gases helium, hydrogen and deuterium. Pump speed is the volumetric flow of gas pumped based on conditions at the inlet of the pump. Pump speed was computed by multiplying the standard flow by 760 torr and dividing by the pump inlet pressure, P4, expressed in torr. Figure 6 compares pump speeds measured by the vendor, Sharpe for helium and this work for helium and both outlet pressures. No gas or outlet pressure conditions were specified for the vendor curve. Agreement between the four data sets is good for inlet pressures less than 1 torr. For inlet pressures between 1 torr and 300 torr, the present data and the Sharpe data are significantly higher than the vendor data. The difference between the vendor data and the present data and Sharpe data may have been caused by a different choice of roughing pumps. The vendor may have used a lower capacity roughing pump than the metal bellows pumps used by Sharpe and the present work. High inlet pressures to the scroll pumps correspond to high mass flows. The vendor's roughing pump may not have been able to accommodate the high mass flows. As a result, pressure at the outlet of the scroll pump increased and limited scroll pump performance. Figures 7 and 8 show pump speeds for hydrogen and deuterium. Data for the scroll pumps with hydrogen and a metal bellows pump outlet pressure of 2.5 atm were lost because insufficient time was allowed for steady state to develop. Measured pump speed agreed with the vendor's literature for inlet pressures up to 0.7 torr. Measured pump speeds were significantly higher than vendor's speeds for higher inlet pressures, probably for the same reason that Sharpe measured higher pump speeds.

Figure 9 plots scroll pump flow as a function of scroll pump inlet pressure and is an alternate method of representing the same data that were plotted in Figures 6 through 8. All five data sets fall on the same curve, described by the following equations, where flow, F, and inlet pressure, P_4, have the units sccm and torr.

$$F = 274\, P_4^{1.435} \qquad \text{for } P_4 < 1.3 \text{ torr} \qquad (1)$$

$$F = 312\, P_4^{0.952} \qquad \text{for } P_4 > 1.3 \text{ torr} \qquad (2)$$

Therefore, the relationship between scroll pump flow and inlet pressure seems to be independent of gas and bellows pump outlet pressure for the range of conditions tested. The scroll pump outlet pressure is about one-twentieth of the bellows pump outlet pressure. Therefore, the relationship between scroll pump flow and inlet pressure also seems to be independent of scroll pump outlet pressure. Equations 1 and 2 are easier to use than the curves in Figures 6 through 8.

Figure 10 plots scroll pump compression ratio as a function of scroll pump flow for all three gases. Compression ratio appears to be independent of gas, although depends on outlet pressure of the scroll pump, P_5. The equation for compression ratio, R, for bellows pump outlet pressures, P_6, of 1 atm and 2.5 atm follow.

$$R = 2150 / F^{0.7} \qquad \text{bellows pump outlet pressure} = 1 \text{ atm (scroll pump outlet pressure} \sim 40 \text{ torr)} \qquad (3)$$

$$R = 4000 / F^{0.7} \qquad \text{bellows pump outlet pressure} = 2.5 \text{ atm (scroll pump outlet pressure} \sim 85 \text{ torr)} \qquad (4)$$

Data for the turbo pump are shown in Figure 11 through 15. Figures 11 through 13 show inlet pressure for the three gases as a function of pump backing pressure with gas flow as a parameter. Backing pressure is the pressure downstream of the pump. The trends are clearest in Figure 11 for helium. For a particular flow, runs with the throttle valve fully open are the points closest to the left side of the graph. Incrementally closing the valve generates points moving first horizontally to the right, the flow limited regime, and then up the steep part of the curve, the backing pump limited regime. The vacuum achieved by the turbomolecular pump for the flow limited regime is a function of flow only. Figure 14 plots the high vacuum, P2, versus the gas flow for flow limited regime and for all three gases. The data points fall around lines with the following equations.

$P_2 = 3.7 \times 10^{-4}\ F$ helium and deuterium

$P_2 = 5.5 \times 10^{-4}\ F$ tritium

Figure 15 replots the data for the flow limited regime as pump speed versus inlet pressure to the pump. The data points were for a fully open valve downstream of the turbomolecular pump. Vendor data for hydrogen are also plotted. Measured pump speeds for helium, molecular weight = 4, and deuterium, molecular weight = 4, are nearly the same. Measured pump speeds for hydrogen, molecular weight = 2, are less by a factor of about two. Both of these observations are consistent with the discussion of turbomolecular pumps and the molecular flow regime in Section 1.3 of this report. By extension, the pump speed for tritium, molecular weight = 6, is expected to be greater than for helium or deuterium. Measured and vendor pump speeds for hydrogen agree reasonably well.

The high vacuum created by the turbomolecular pump for the backing pump limited regime is a strong function of backing pressure and is independent of flow. Figure 16 shows the relationship between high vacuum and backing pressure for the backing pump limited regime. The equations for the three gases follow.

helium $P_3 = 3.3\ P_2^{0.124}$

hydrogen $P_3 = 2.0\ P_2^{0.240}$

deuterium $P_3 = 2.25\ P_2^{0.153}$

These equations should be used in the following way. For a given P_2 use the equation to calculate to backing pump limited value of P_3. If the actual value of P_3 is less than the pump limited value then the pump is operating in the flow limited regime. Otherwise, the pump is operating in the backing pump limited regime.

4. CONCLUSIONS

1. The goal of measuring the characteristics of the three types of vacuum pumps for three different gases was met. All task activities specified in the Task Technical and QA Plan were satisfied.
2. For the range of flows tested, the metal bellows pump provides a compression ratio of about 20 and that is independent of the gas that is being pumped. The compression

ratio was about 20% higher for the atmospheric pressure outlet condition than for the 2.5 atm pressure outlet condition.

3. The pump speeds measured with all three gases for the Normetex scroll pump are approximately the same as vendor literature.
4. The relationship between scroll pump inlet pressure and standard gas flow is the same for all three gases and both outlet pressures. This is a more convenient way to correlate the data than pump speed.
5. For a given standard flow and backing pressure, the turbomolecular pump achieves the highest vacuums for deuterium and the lowest for hydrogen. This was expected because hydrogen is lightest. By extension, the turbomolecular pump is expected to be more effective with tritium than with helium or hydrogen.
6. The turbomolecular pump operation has two regimes. In the flow limited regime, the high vacuum achieved by the pump is a function of gas flow but is unaffected by backing pressure. In the backing pump limited regime the high vacuum achieved is a function of backing pressure but is unaffected by gas flow. Equations were provided to determine the operating regime of the pump for different gases.
7. The orientation of a torr range pressure transducer can significantly affect its zero.

5. ACKNOWLEDGMENTS

Mike Armstrong and Jerry Corbett constructed the test facility and conducted testing. Vern Bush connected the instruments.

6. REFERENCES

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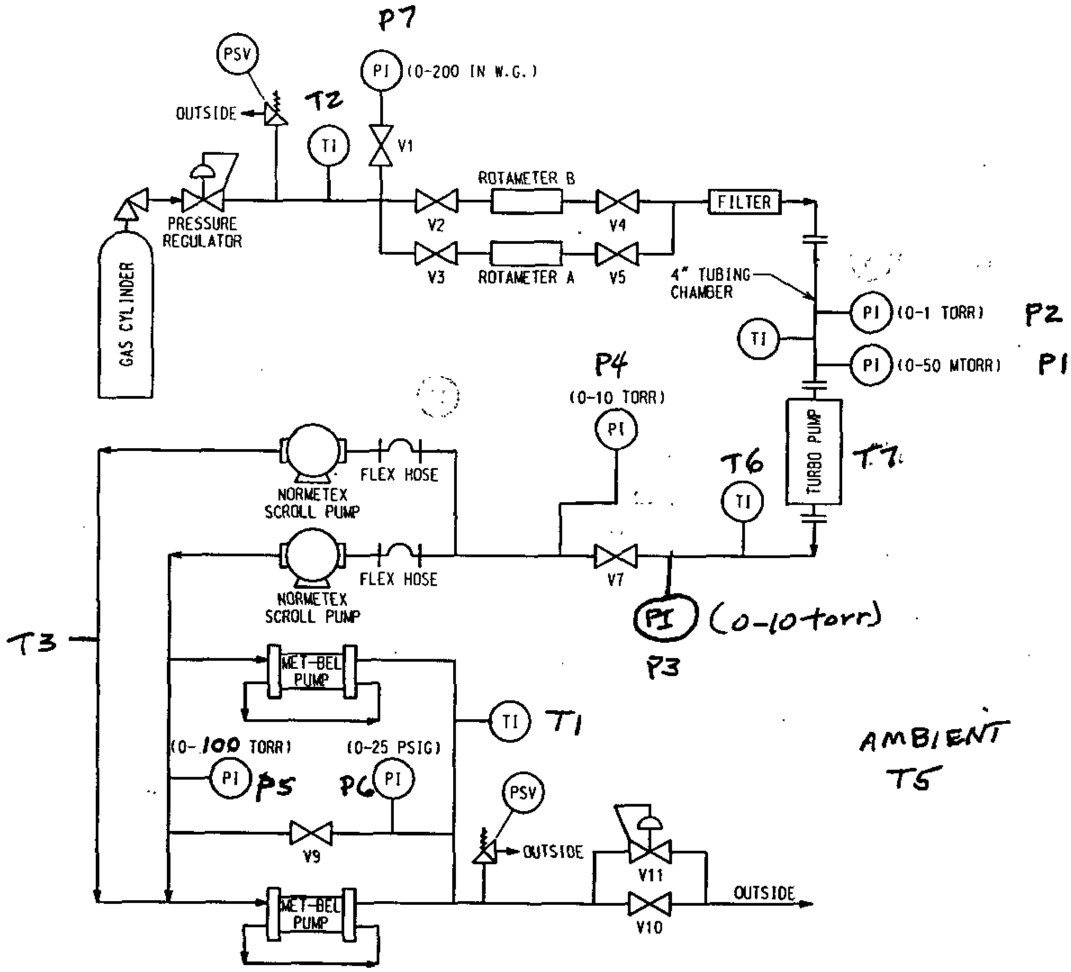

FIGURE 1
PIPING SCHEMATIC FOR TEST SETUP

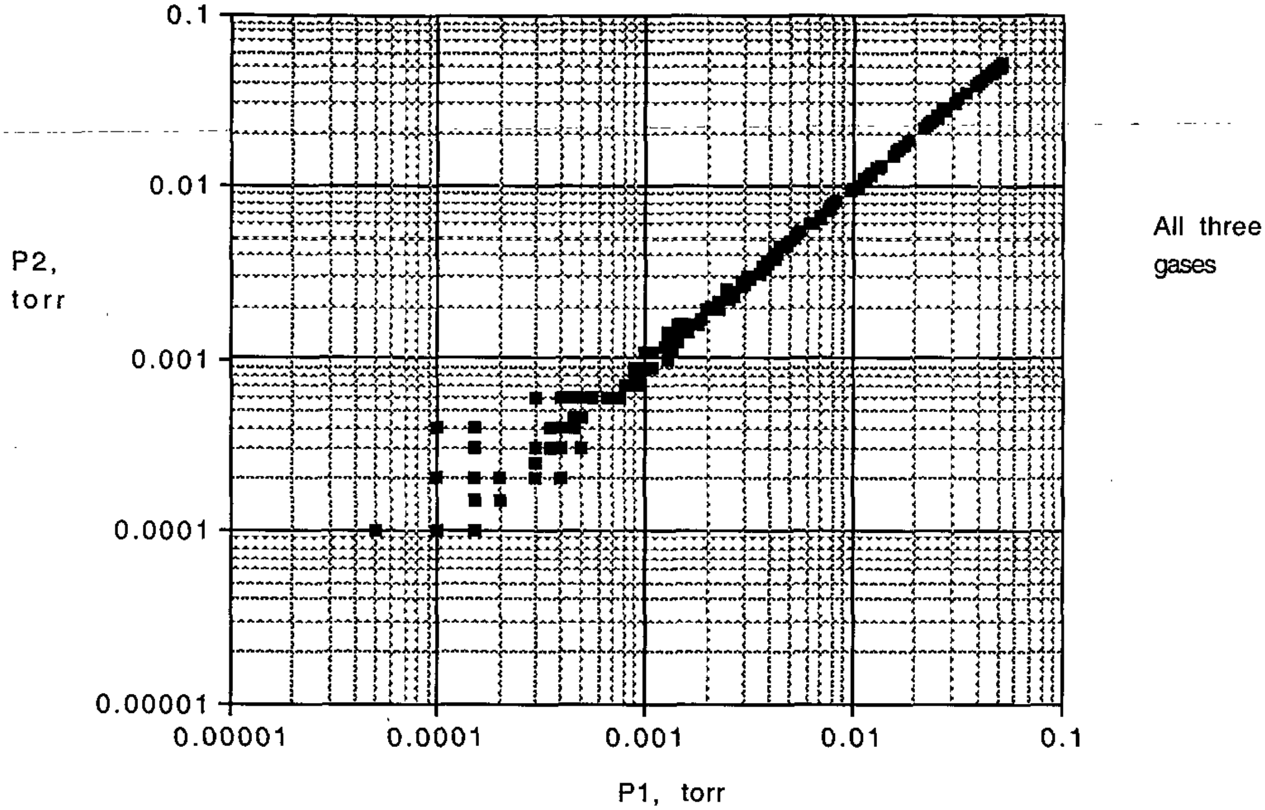

Figure 2 Comparison of Two Pressure Gages on Turbomolecular Pump Chamber

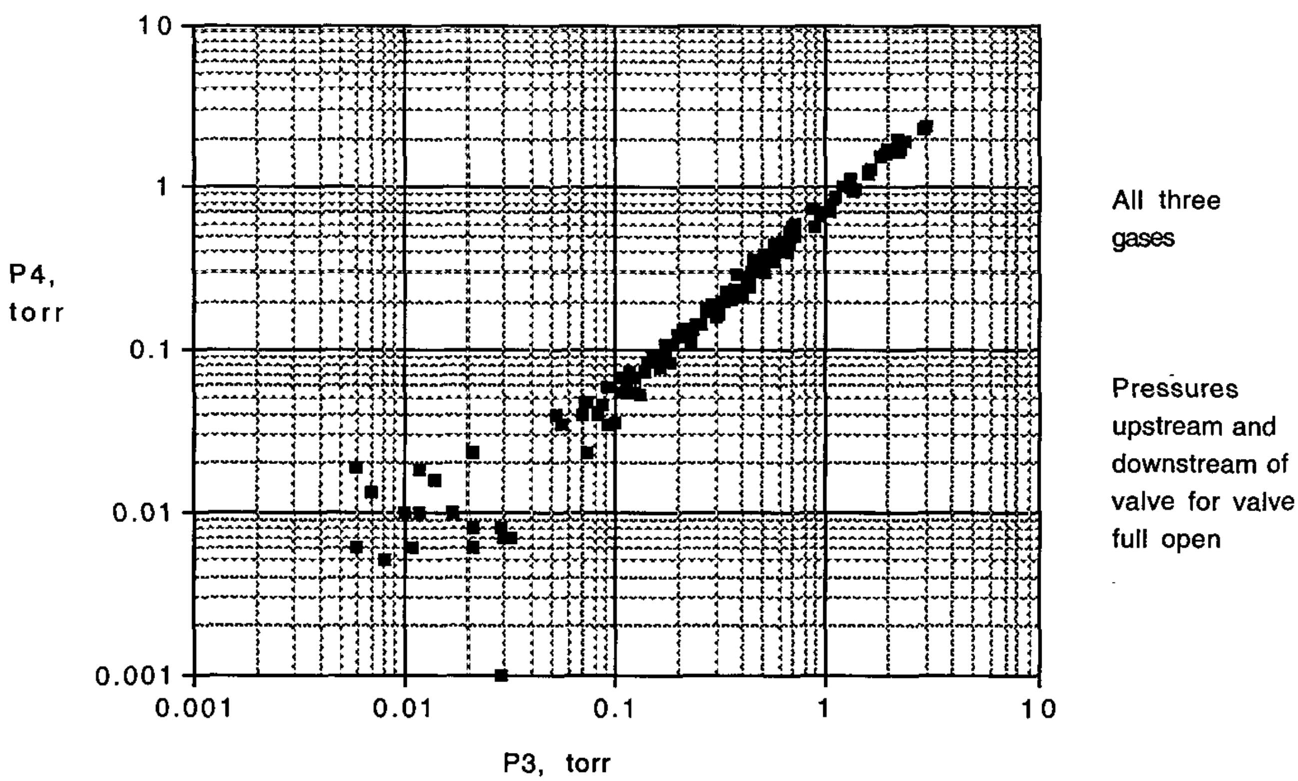

Figure 3 Comparison of Pressures Upstream and Downstream of Valve

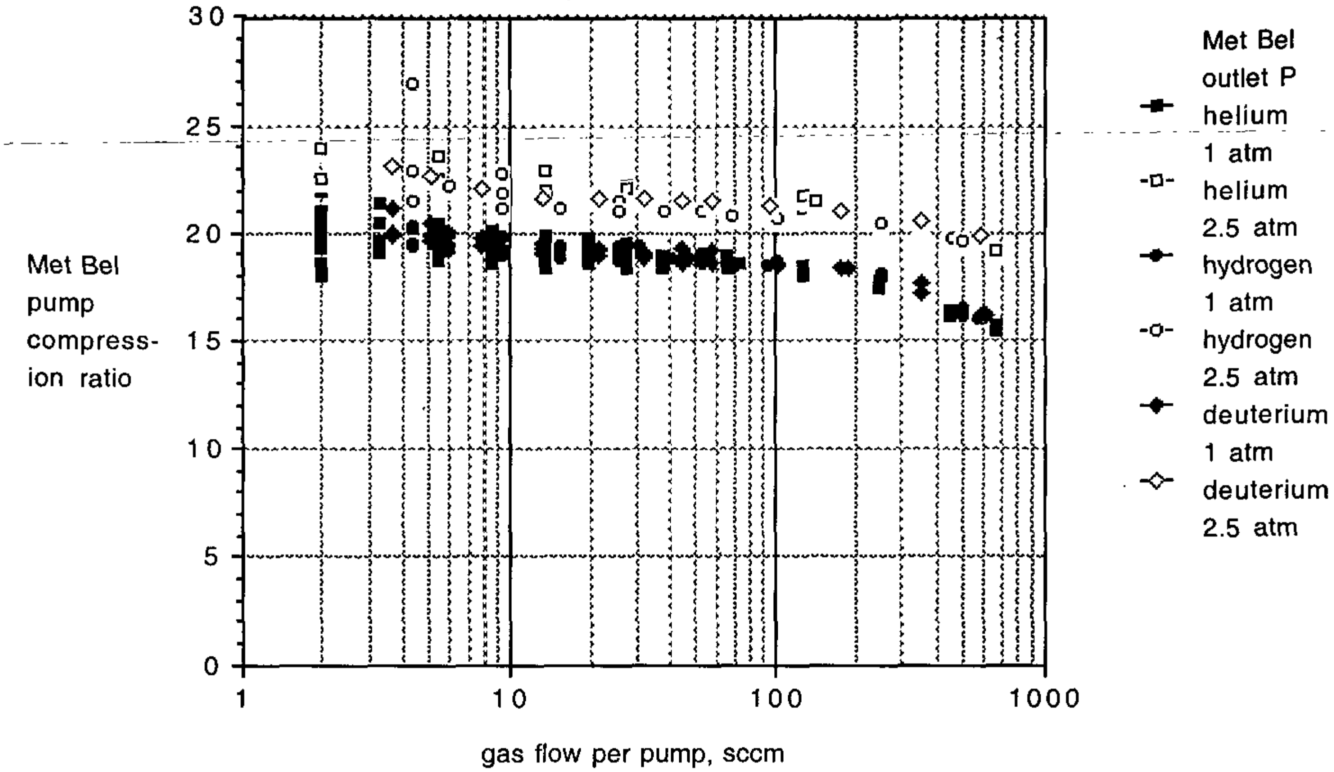

Figure 4 Compression Ratio for Met Bel Pump

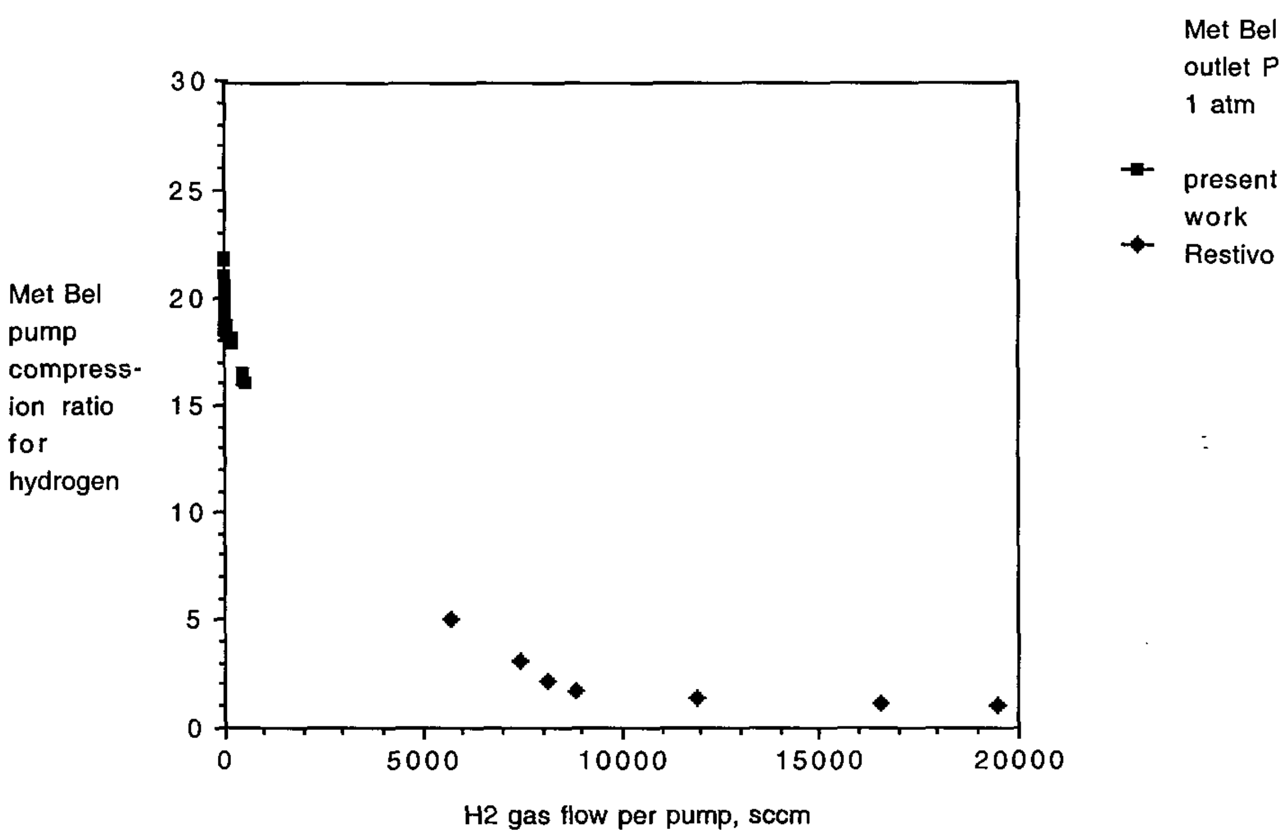

Figure 5 Compression Ratio for Met Bel Pump with Hydrogen

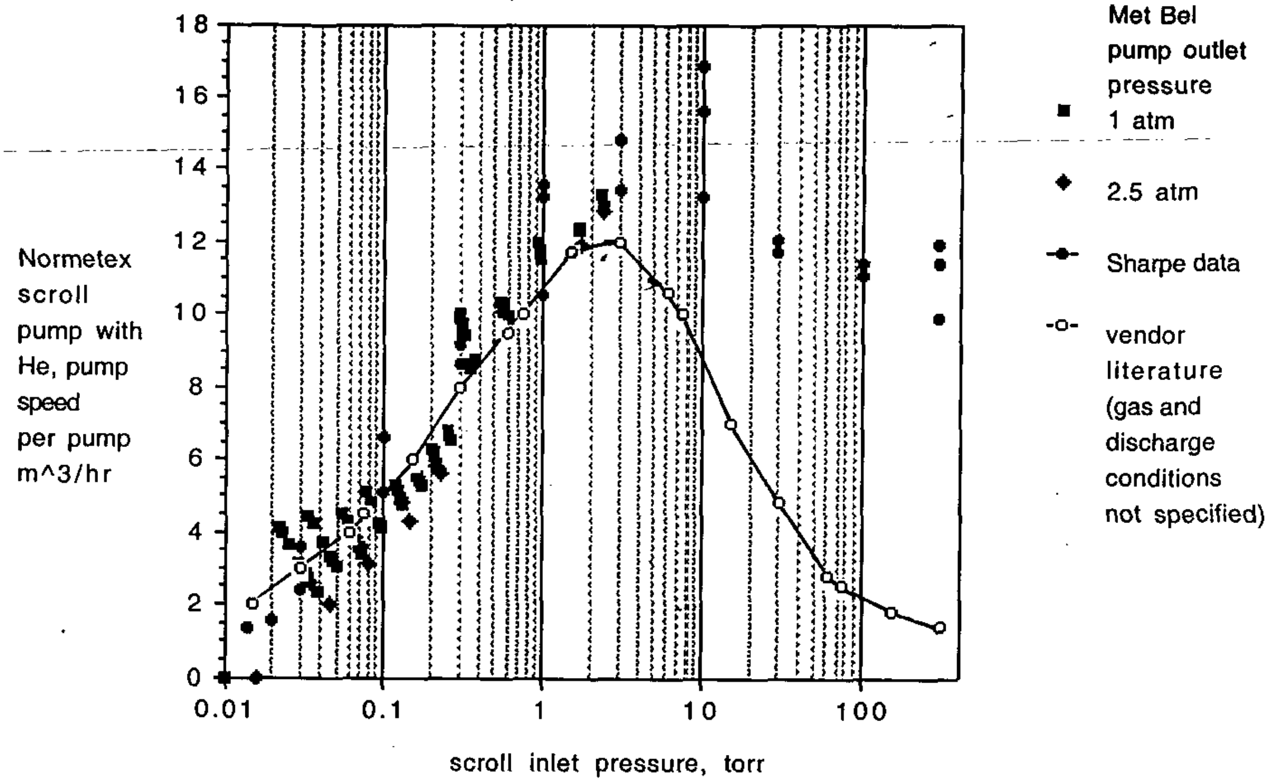

Figure 6 Pump Speed for Normetex Scroll Pump and Helium

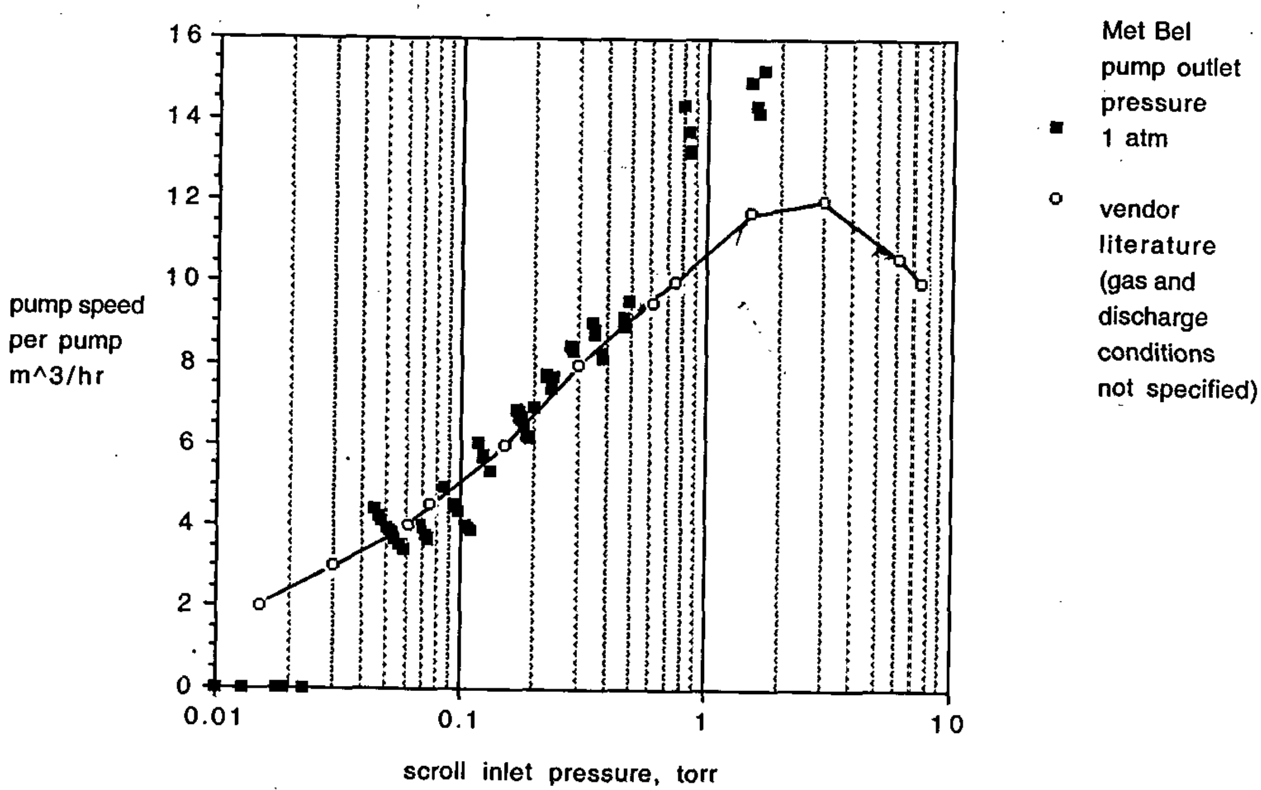

Figure 7 Pump Speed for Normetex Scroll Pump and Hydrogen

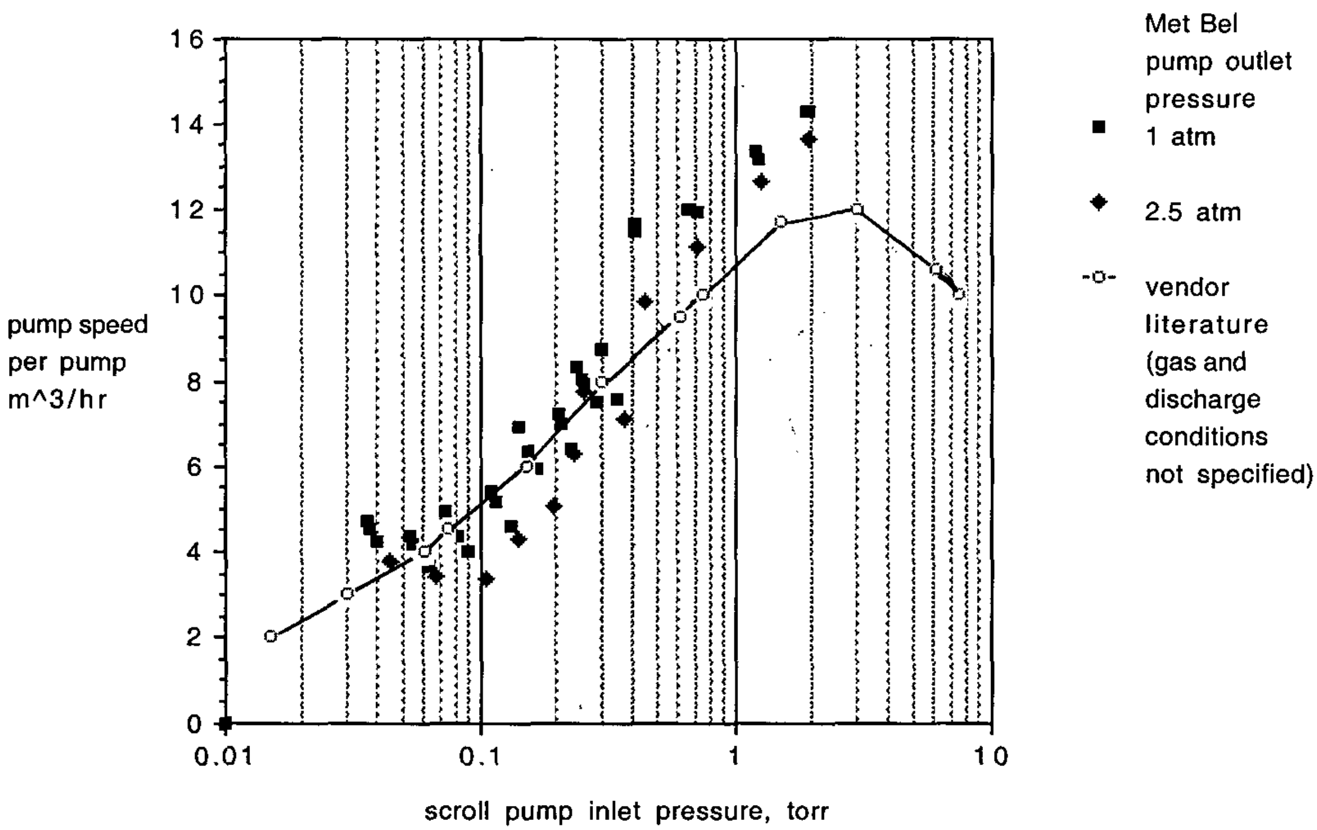

Figure 8 Pump Speed for Normetex Scroll Pump and Deuterium

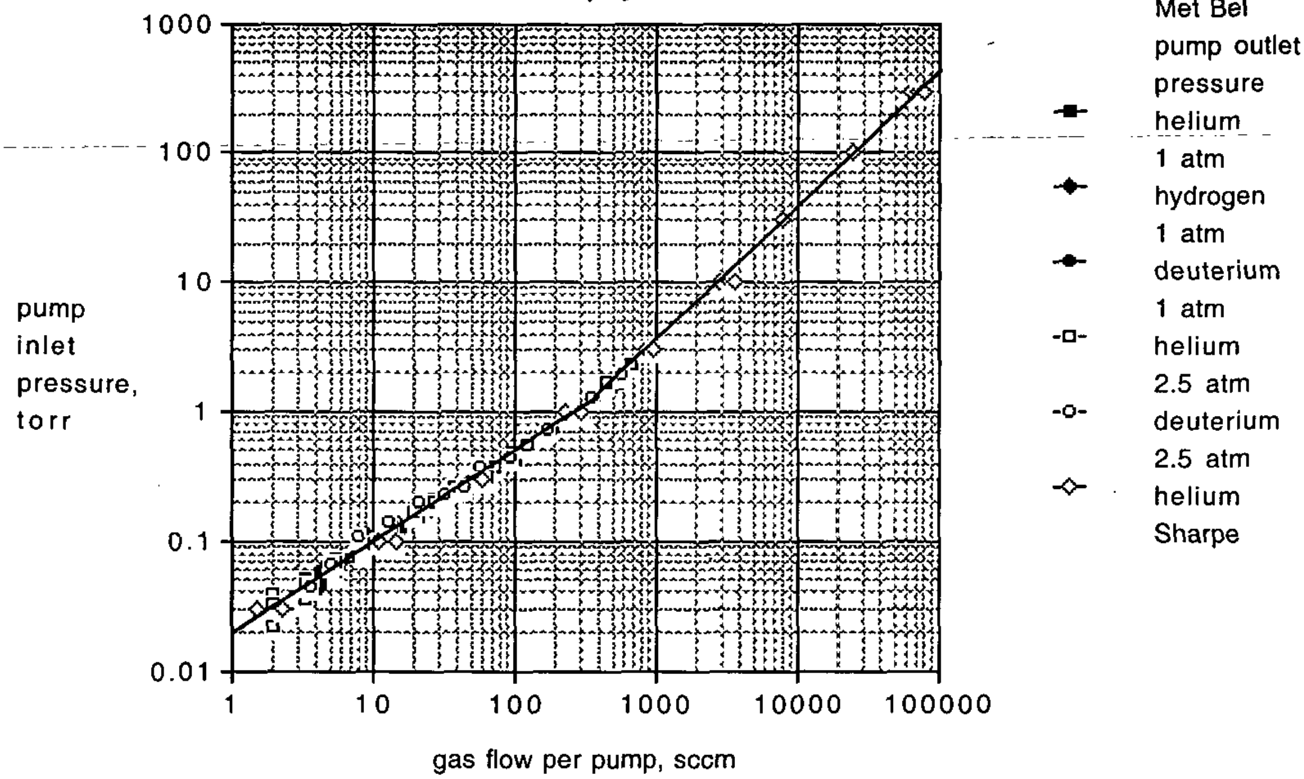

Figure 9 Normetex Scroll Pump Inlet Pressure

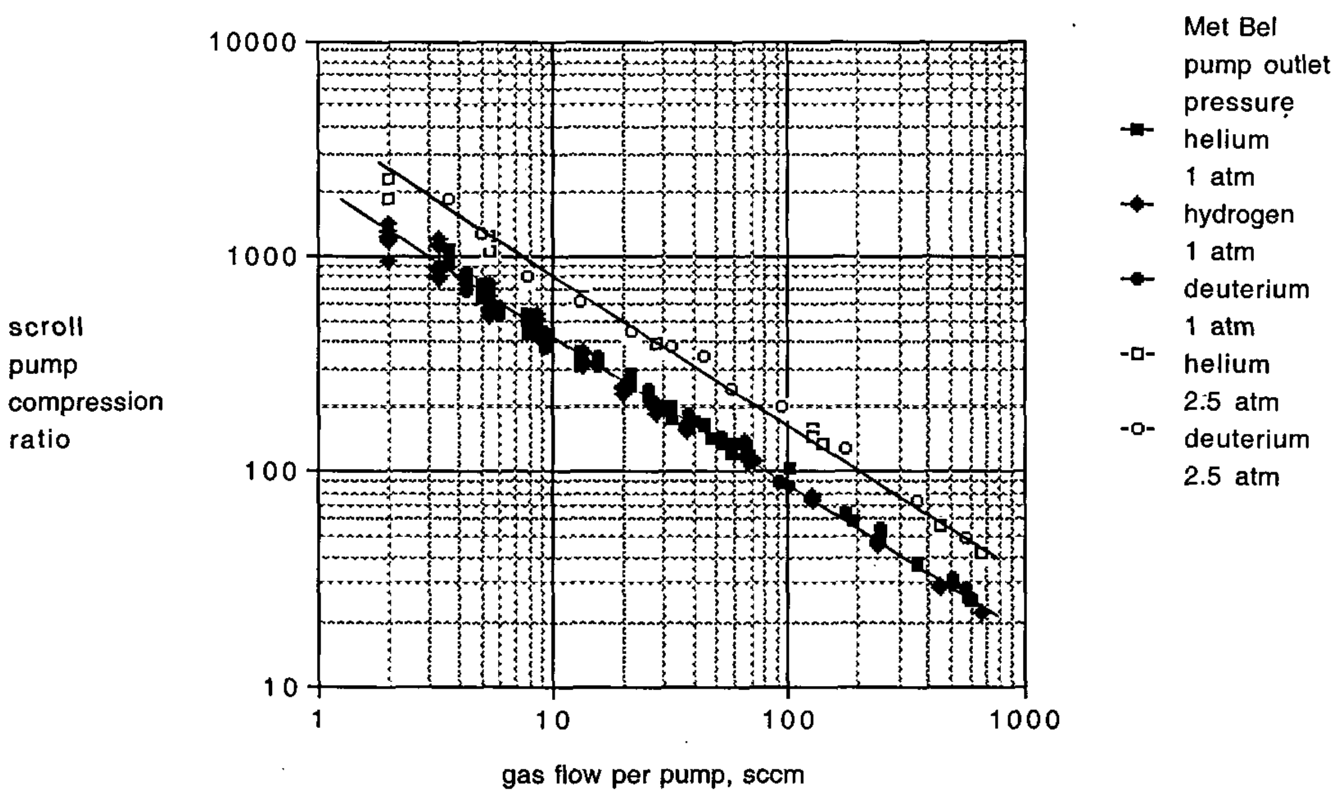

Figure 10 Normetex Scroll Pump Inlet Pressure

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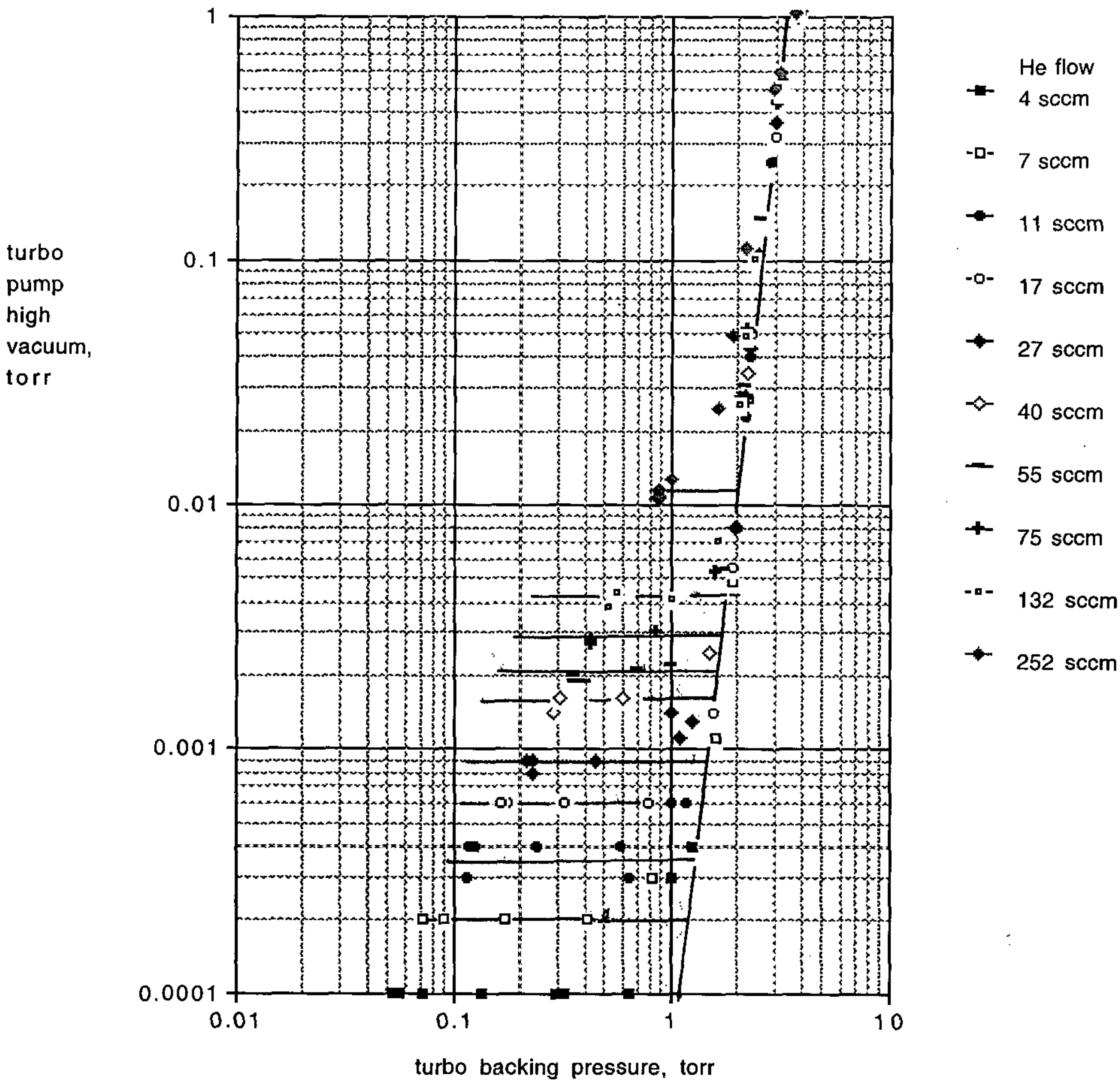

Figure 11

Pressure Relationship for Turbomolecular Pump and Helium

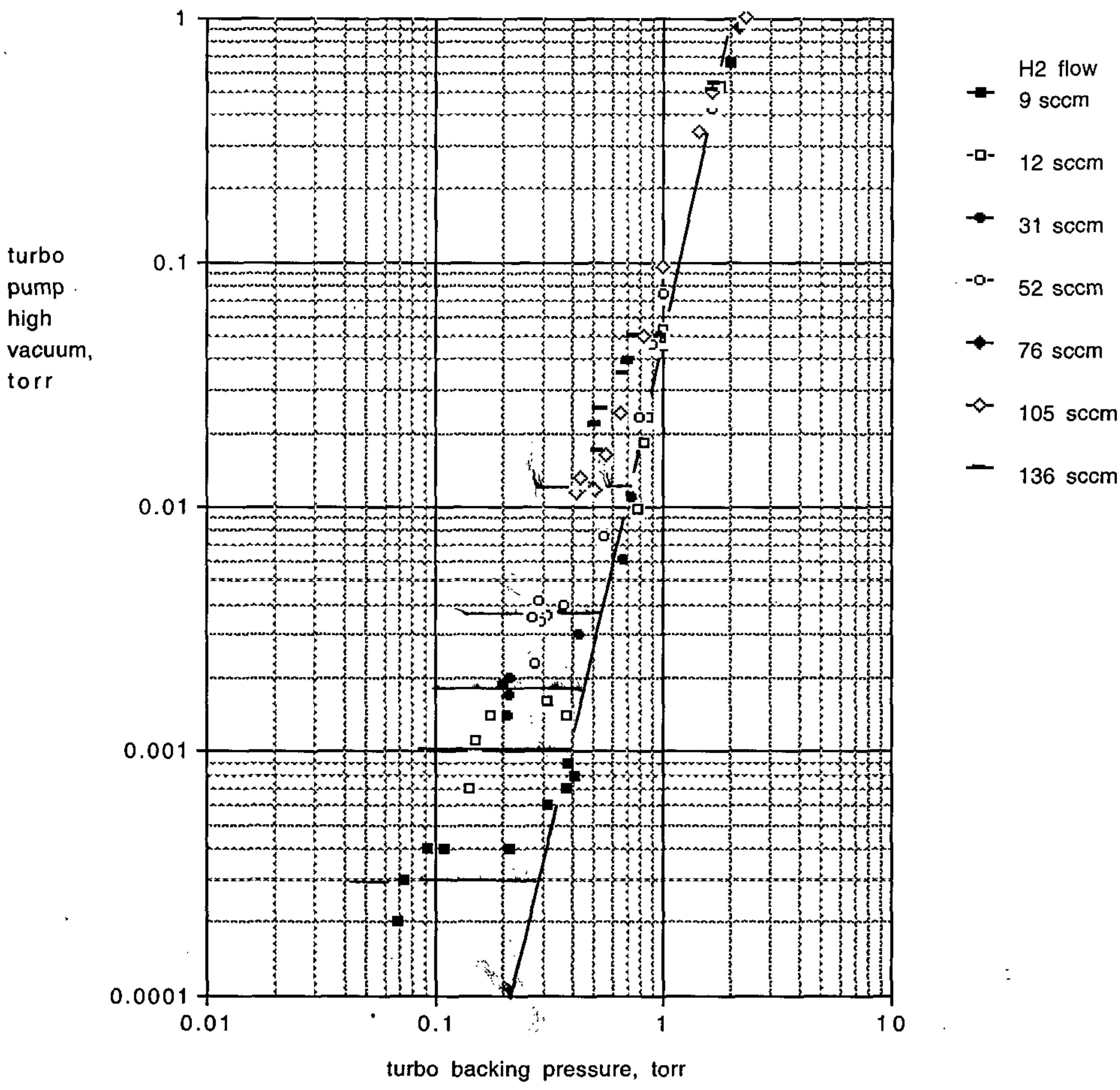

Figure 12

Pressure Relationship for Turbomolecular Pump and Hydrogen

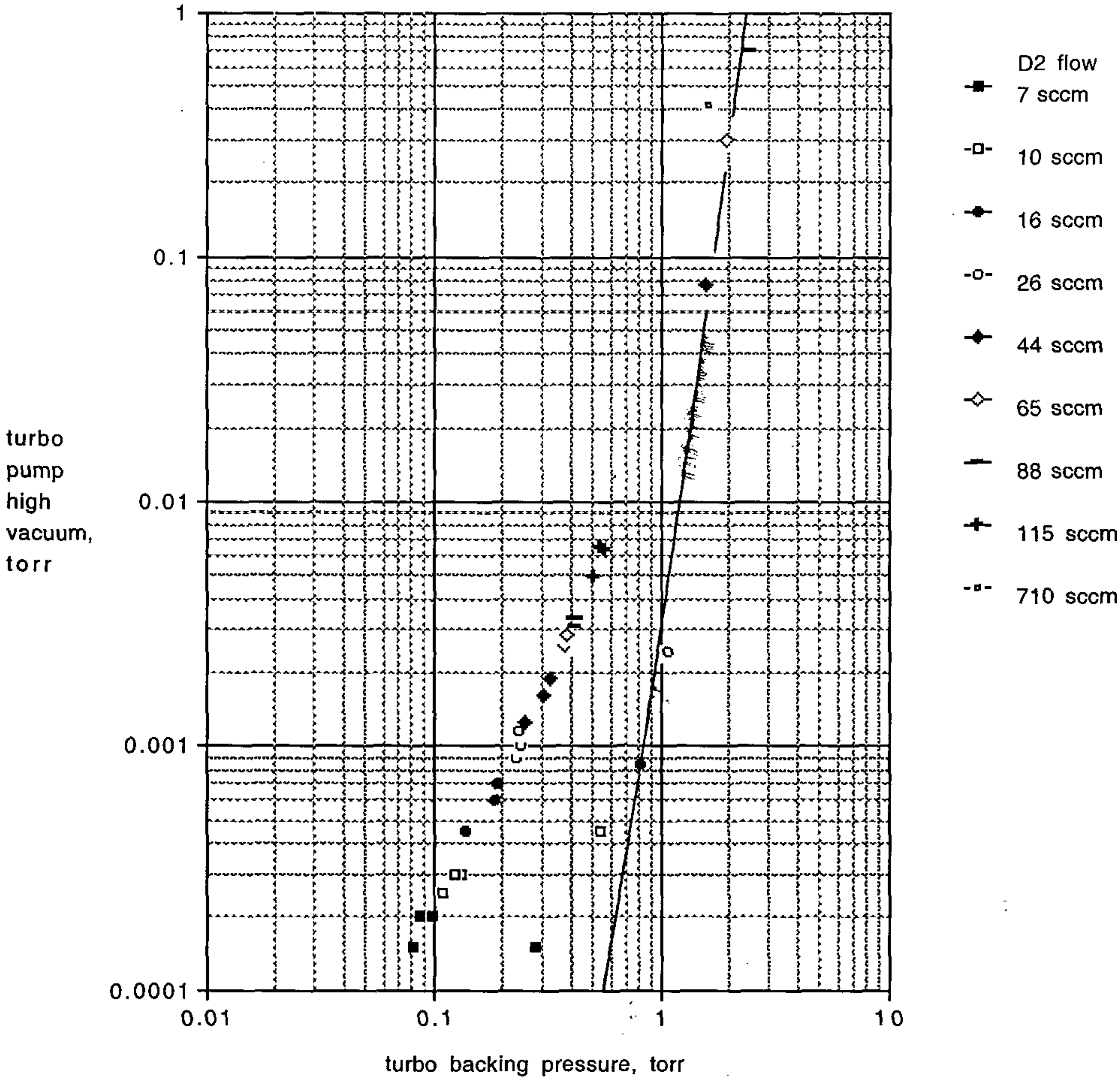

Figure 13

Pressure Relationship for Turbomolecular Pump and Deuterium

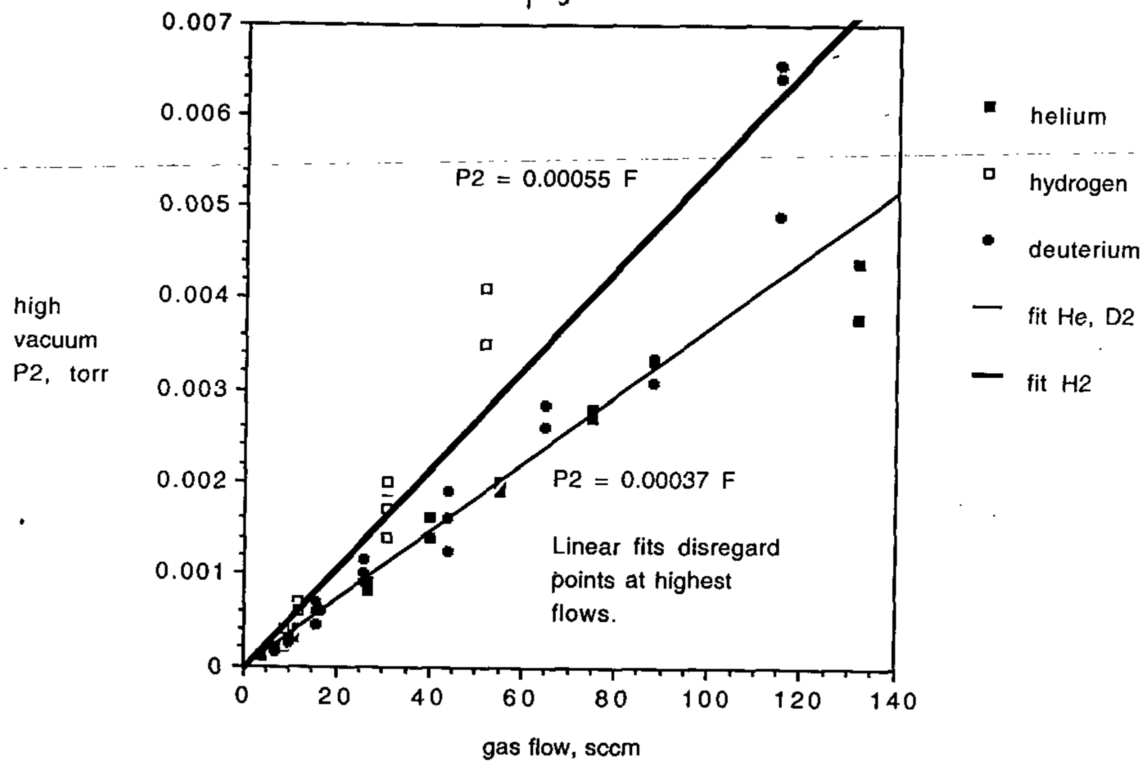

Figure 14 Vacuum Pulled by Turbomolecular Pump in Flow Limited Regime

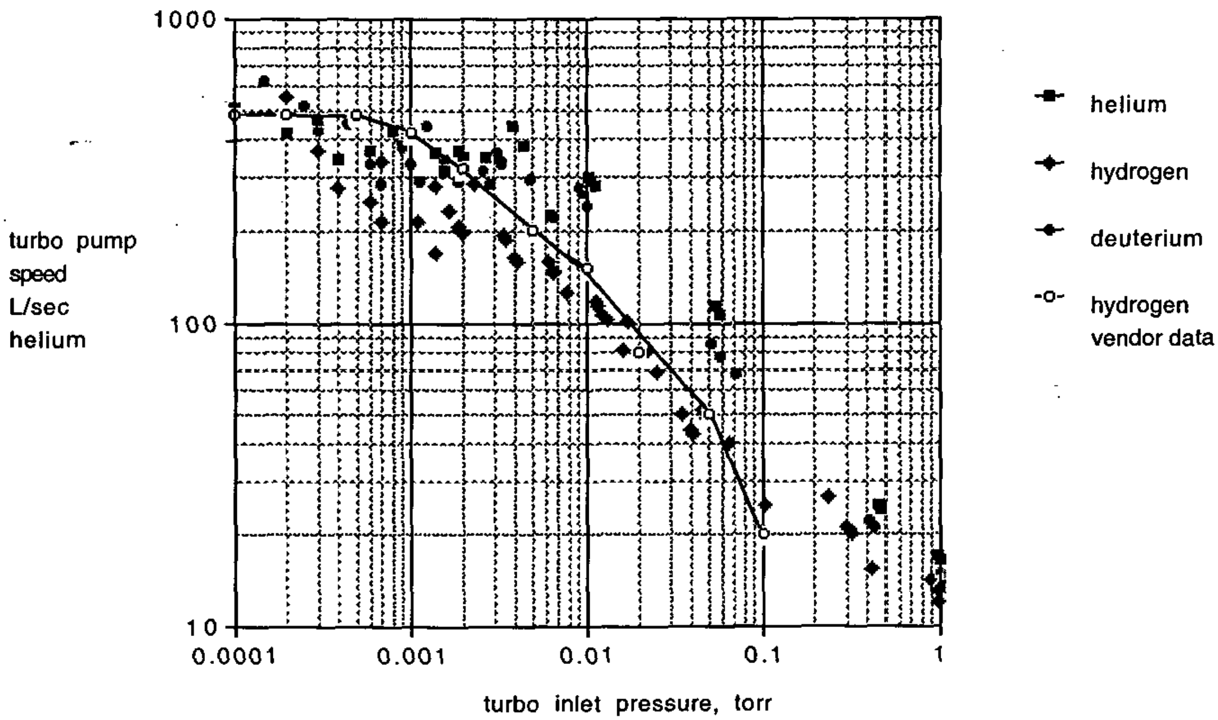

Figure 15 Pump Speed for Turbomolecular Pump in the Flow Limited Regime

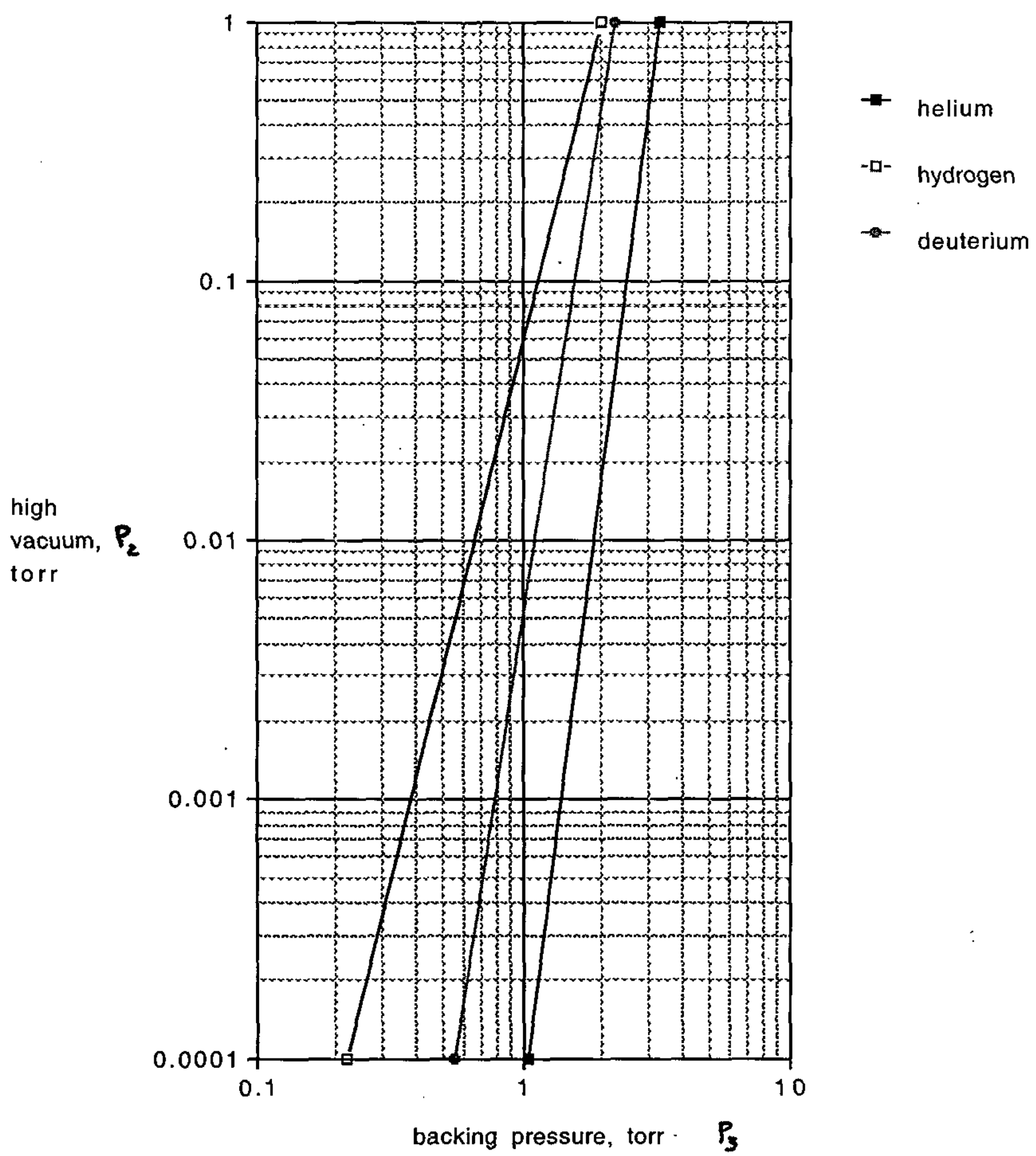

Figure 16 Vacuum Pulled By Turbomolecular Pump for Backing Pump Limited Regime

Table 3 Helium Data

date	time	Helium flow sccm	P1 turbo pump inlet torr	P2 turbo pump inlet torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bellows out psig	P7 rota meter in psig
911	1301	0.0	0	0	-0.01	0.01	36.2	0.32	0.72
911	1309	4.0	0.00015	0.0001	0.053	0.039	37	0.32	5.02
911	1342	6.7	0.00015	0.0002	0.072	0.048	38	0.32	4.98
911	1346	10.9	0.00035	0.0004	0.119	0.073	38.8	0.32	4.98
911	1348	17.4	0.00055	0.0006	0.176	0.093	39.4	0.32	4.98
911	1352	27.2	0.00095	0.0009	0.217	0.129	39.7	0.32	4.98
911	1354	39.7	0.0015	0.0014	0.287	0.171	39.3	0.32	4.98
911	1357	55.4	0.0022	0.0019	0.361	0.216	39.9	0.32	4.98
911	1359	75.1	0.003	0.0027	0.433	0.263	40.9	0.32	4.98
911	1408	132.0	0.00485	0.0044	0.568	0.353	41.1	0.32	4.98
911	1412	252.0	0.0121	0.0114	0.877	0.571	42	0.32	4.98
911	1414	488.0	#NA	0.0546	1.355	0.943	44.6	0.32	4.98
911	1422	905.1	#NA	0.4603	2.216	1.677	48.2	0.32	4.98
911	1426	1336.6	#NA	0.9905	2.903	2.295	50.2	0.32	4.98
911	1450	4.0	0.00005	0.0001	0.295	0.029	37.7	0.32	4.98
911	1455	10.9	0.00035	0.0003	0.644	0.063	38.4	0.32	4.98
911	1457	27.2	0.0013	0.0013	1.266	0.125	39.4	0.32	4.98
911	1500	55.4	0.02525	0.0252	2.168	0.215	40	0.32	4.98
911	1513	145.2	#NA	1.0216	3.767	0.378	41.9	0.32	4.98
911	1645	0.0	0	0	0.014	0.016	74	21.99	0.00
911	1650	4.0	0.0001	0.0001	0.056	0.035	79.4	21.97	4.98
911	1653	10.9	0.0003	0.0003	0.116	0.065	80.5	21.96	4.98
911	1655	27.2	0.0009	0.0008	0.231	0.129	82.9	21.96	4.98
911	1657	55.4	0.0021	0.0019	0.378	0.219	85.5	21.96	4.98
911	1703	252.0	0.0113	0.0106	0.884	0.57	90	22.05	4.98
911	1707	905.1	#NA	0.4765	2.27	1.727	96	21.85	4.98
911	1711	1336.6	#NA	1.0264	2.978	2.37	98.6	21.95	4.98
912	808	0.0	0	0	0.032	0.007	34.4	0.33	0.43
912	821	4.0	#NA	0.3156	2.953	0.025	35.4	0.33	4.98
912	827	6.7	#NA	0.3068	2.97	0.041	36.4	0.33	4.98
912	835	10.9	#NA	0.251	2.899	0.059	38	0.33	4.98
912	840	17.4	#NA	0.3175	2.996	0.082	38.7	0.33	4.98
912	844	27.2	#NA	0.363	3.039	0.12	39.1	0.33	4.98
912	851	39.7	#NA	0.446	3.124	0.163	40	0.34	4.98
912	855	55.4	#NA	0.4451	3.11	0.205	40.7	0.34	4.98
912	859	75.1	#NA	0.4366	3.083	0.254	41.1	0.35	4.98
912	909	132.0	#NA	0.4931	3.13	0.349	41.1	0.35	4.98
912	914	252.0	#NA	0.5816	3.177	0.555	42.3	0.39	4.98
912	918	488.0	#NA	0.711	3.198	0.93	44.3	0.43	4.98
912	922	905.1	#NA	0.832	3.02	1.664	48.4	0.62	4.98
912	926	1336.6	#NA	1.0443	3.019	2.345	51.3	0.87	4.98
914	820	0.0	0	0	0.036	0.005	34.5	0.32	4.98
914	904	4.0	0.0004	0.0003	1.009	0.046	84.2	21.93	4.98

Table 3 Helium Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
911	1301	1	#ERR	0.000	#-INF	3620.0	21.5	-1.00
911	1309	1	506	2.334	530.0	948.7	21.0	1.36
911	1342	1	421	3.161	360.0	791.7	20.4	1.50
911	1346	1	346	3.415	297.5	531.5	20.0	1.63
911	1348	1	367	4.267	293.3	423.7	19.7	1.89
911	1352	1	383	4.814	241.1	307.8	19.6	1.68
911	1354	1	359	5.288	205.0	229.8	19.8	1.68
911	1357	1	369	5.846	190.0	184.7	19.5	1.67
911	1359	1	352	6.511	160.4	155.5	19.0	1.65
911	1408	1	380	8.526	129.1	116.4	18.9	1.61
911	1412	1	280	10.062	76.9	73.6	18.5	1.54
911	1414	1	113	11.799	24.8	47.3	17.4	1.44
911	1422	1	25	12.306	4.8	28.7	16.1	1.32
911	1426	1	17	13.278	2.9	21.9	15.5	1.26
911	1450	0	506	3.139	2950.0	1300.0	20.6	10.17
911	1455	0	462	3.957	2146.7	609.5	20.2	10.22
911	1457	0	265	4.968	973.8	315.2	19.7	10.13
911	1500	0	28	5.873	86.0	186.0	19.4	10.08
911	1513	0	2	8.757	3.7	110.8	18.5	9.97
911	1645	1	#ERR	0.000	#+INF	4625.0	25.6	0.88
911	1650	1	506	2.601	560.0	2268.6	23.9	1.60
911	1653	1	462	3.835	386.7	1238.5	23.5	1.78
911	1655	1	431	4.814	288.8	642.6	22.9	1.79
911	1657	1	369	5.766	198.9	390.4	22.2	1.73
911	1703	1	301	10.080	83.4	157.9	21.1	1.55
911	1707	1	24	11.950	4.8	55.6	19.7	1.31
911	1711	1	16	12.858	2.9	41.6	19.2	1.26
912	808	1	#ERR	0.000	#+INF	4914.3	22.6	4.57
912	821	0	0	3.641	9.4	1416.0	22.0	118.12
912	827	0	0	3.701	9.7	887.8	21.3	72.44
912	835	0	0	4.225	11.5	644.1	20.4	49.14
912	840	0	0	4.840	9.4	472.0	20.1	36.54
912	844	0	0	5.175	8.4	325.8	19.9	25.33
912	851	0	1	5.548	7.0	245.4	19.4	19.17
912	855	0	2	6.160	7.0	198.5	19.1	15.17
912	859	0	2	6.742	7.1	161.8	18.9	12.14
912	909	0	3	8.623	6.3	117.8	18.9	8.97
912	914	0	5	10.352	5.5	76.2	18.4	5.72
912	918	0	9	11.964	4.5	47.6	17.7	3.44
912	922	0	14	12.402	3.6	29.1	16.4	1.81
912	926	0	16	12.995	2.9	21.9	15.7	1.29
914	820	0	#ERR	0.000	#+INF	6900.0	22.5	7.20
914	904	0	169	1.979	3363.3	1830.4	22.5	21.93

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Table 3 Helium Data

date	time	Helium flow sccm	P1 turbo pump inlet torr	P2 turbo pump inlet torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bel-lows out psig	P7 rota meter in psig
9/14/99	911 15:38	10.9	0.00075	0.0006	1.009	0.08	84.2	21.98	4.98
914	915	27.2	0.0016	0.0014	1.011	0.144	86.3	21.98	4.98
914	919	55.4	0.00255	0.0022	1.013	0.226	87.3	22	4.98
914	928	252.0	0.0135	0.0127	1.011	0.601	87.5	22.01	4.98
914	931	281.9	0.016	0.0152	1.015	0.651	88.1	21.98	4.98
915	953	0.0	0	0	0.03	0.007	37.8	0.31	4.98
915	1003	55.4	0.00225	0.0019	0.399	0.208	40.9	0.32	4.98
915	1007	55.4	0.0022	0.0019	0.404	0.217	86	21.94	4.98
915	1026	0.0	0	0	0.029	0.008	38	0.31	0.58
1102	1218	0.0	-0.0002	0	0.029	0.001	39.3	0.24	#NA
1102	1231	4.0	-0.00005	0.0001	0.073	0.023	42.9	0.24	4.98
1102	1235	4.0	-0.00005	0.0001	0.136	0.023	42.9	0.24	4.98
1102	1239	4.0	-0.00005	0.0001	0.323	0.023	42.8	0.24	4.98
1102	1243	4.0	0	0.0001	0.64	0.023	42.4	0.24	4.98
1102	1247	4.0	0.00015	0.0004	1.272	0.022	41.5	0.24	4.98
1102	1256	4.0	#NA	0.4917	3.165	0.022	40.1	0.24	4.98
1102	1304	6.7	0.0001	0.0002	0.091	0.034	40.5	0.24	4.98
1102	1307	6.7	0.0001	0.0002	0.172	0.034	40.4	0.24	4.98
1102	1310	6.7	0.0001	0.0002	0.416	0.034	40.3	0.24	4.98
1102	1315	6.7	0.00015	0.0003	0.823	0.036	40.3	0.24	4.98
1102	1319	6.7	0.001	0.0011	1.629	0.036	40.6	0.25	4.98
1102	1334	6.7	#NA	1.0649	3.905	0.036	40.4	0.24	4.98
1102	1336	10.9	0.0001	0.0004	0.126	0.055	41.2	0.24	4.98
1102	1341	10.9	0.00015	0.0004	0.243	0.058	41.2	0.24	4.98
1102	1344	10.9	0.00015	0.0004	0.59	0.058	41.2	0.24	4.98
1102	1348	10.9	0.0003	0.0006	1.17	0.058	41.2	0.25	4.98
1102	1352	10.9	0.04005	0.0401	2.331	0.058	41.1	0.24	4.98
1102	1358	10.9	#NA	1.0388	3.863	0.058	40.9	0.24	4.98
1102	1402	17.4	0.0004	0.0006	0.165	0.078	41.7	0.25	4.98
1102	1406	17.4	0.00045	0.0006	0.32	0.082	41.3	0.25	4.98
1102	1409	17.4	0.0005	0.0006	0.785	0.082	41.4	0.25	4.98
1102	1414	17.4	0.0013	0.0014	1.564	0.082	41.7	0.25	4.98
1102	1420	17.4	#NA	0.4616	3.109	0.082	41.5	0.25	4.98
1102	1425	17.4	#NA	1.0349	3.849	0.082	41.4	0.25	4.98
1102	1428	27.2	0.0009	0.0009	0.231	0.118	42	0.25	4.98
1102	1432	27.2	0.0009	0.0009	0.453	0.117	42.1	0.25	4.98
1102	1439	27.2	0.0011	0.0011	1.118	0.117	42	0.25	4.98
1102	1448	27.2	0.02765	0.0277	2.223	0.118	41.3	0.25	4.98
1102	1453	27.2	#NA	0.5129	3.171	0.118	41.1	0.25	4.98
1102	1457	27.2	#NA	1.0507	3.86	0.118	41.1	0.25	4.98
1102	1500	39.7	0.00145	0.0016	0.309	0.167	41.2	0.25	4.98
1102	1503	39.7	0.00145	0.0016	0.608	0.167	41.4	0.25	4.98
1102	1506	39.7	0.00245	0.0025	1.508	0.167	41.6	0.25	4.98
1102	1509	39.7	0.03455	0.0347	2.239	0.167	41.4	0.25	4.98
1102	1513	39.7	#NA	0.1017	2.476	0.167	40.9	0.25	4.98
1102	1516	39.7	#NA	0.508	3.155	0.167	41	0.25	4.98
1102	1522	39.7	#NA	0.9952	3.784	0.167	41	0.25	4.98
1102	1525	55.4	0.0022	0.002	0.36	0.202	41.2	0.25	4.98

Table 3 Helium Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
9/14/99	91 115:38	0	231	3.116	1681.7	1052.5	22.5	12.61
914	915	0	246	4.313	722.1	599.3	22.0	7.02
914	919	0	319	5.588	460.5	386.3	21.7	4.48
914	928	0	251	9.560	79.6	145.6	21.7	1.68
914	931	0	235	9.872	66.8	135.3	21.5	1.56
915	953	1	#ERR	0.000	#+INF	5400.0	20.5	4.29
915	1003	1	369	6.071	210.0	196.6	19.0	1.92
915	1007	1	369	5.819	212.6	396.3	22.0	1.86
915	1026	1	#ERR	0.000	#+INF	4750.0	20.4	3.63
1102	1218	1	#ERR	0.000	#+INF	39300.0	19.7	29.00
1102	1231	1	506	3.958	730.0	1865.2	18.0	3.17
1102	1235	0	506	3.958	1360.0	1865.2	18.0	5.91
1102	1239	0	506	3.958	3230.0	1860.9	18.0	14.04
1102	1243	0	506	3.958	6400.0	1843.5	18.2	27.83
1102	1247	0	126	4.138	3180.0	1886.4	18.6	57.82
1102	1256	0	0	4.138	6.4	1822.7	19.3	143.86
1102	1304	1	421	4.463	455.0	1191.2	19.1	2.68
1102	1307	0	421	4.463	860.0	1188.2	19.1	5.06
1102	1310	0	421	4.463	2080.0	1185.3	19.2	12.24
1102	1315	0	281	4.215	2743.3	1119.4	19.2	22.86
1102	1319	0	77	4.215	1480.9	1127.8	19.0	45.25
1102	1334	0	0	4.215	3.7	1122.2	19.1	108.47
1102	1336	1	346	4.533	315.0	749.1	18.7	2.29
1102	1341	0	346	4.298	607.5	710.3	18.7	4.19
1102	1344	0	346	4.298	1475.0	710.3	18.7	10.17
1102	1348	0	231	4.298	1950.0	710.3	18.8	20.17
1102	1352	0	3	4.298	58.1	708.6	18.8	40.19
1102	1358	0	0	4.298	3.7	705.2	18.9	66.60
1102	1402	1	367	5.088	275.0	534.6	18.5	2.12
1102	1406	0	367	4.840	533.3	503.7	18.7	3.90
1102	1409	0	367	4.840	1308.3	504.9	18.7	9.57
1102	1414	0	157	4.840	1117.1	508.5	18.5	19.07
1102	1420	0	0	4.840	6.7	506.1	18.6	37.91
1102	1425	0	0	4.840	3.7	504.9	18.7	46.94
1102	1428	1	383	5.263	256.7	355.9	18.4	1.96
1102	1432	0	383	5.308	503.3	359.8	18.4	3.87
1102	1439	0	314	5.308	1016.4	359.0	18.4	9.56
1102	1448	0	12	5.263	80.3	350.0	18.7	18.84
1102	1453	0	0	5.263	6.2	348.3	18.8	26.87
1102	1457	0	0	5.263	3.7	348.3	18.8	32.71
1102	1500	1	314	5.415	193.1	246.7	18.8	1.85
1102	1503	0	314	5.415	380.0	247.9	18.7	3.64
1102	1506	0	201	5.415	603.2	249.1	18.6	9.03
1102	1509	0	14	5.415	64.5	247.9	18.7	13.41
1102	1513	0	5	5.415	24.3	244.9	18.9	14.83
1102	1516	0	0	5.415	6.2	245.5	18.9	18.89
1102	1522	0	0	5.415	3.8	245.5	18.9	22.66
1102	1525	1	351	6.251	180.0	204.0	18.8	1.78

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Table 3 Helium Data

date	time	Helium flow sccm	P1 turbo pump inlet torr	P2 turbo pump inlet. torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bel-lows out psig	P7 rota meter in psig
2/116299	1a5216:39	55.4	0.00225	0.0021	0.708	0.202	42	0.25	4.98
1102	1530	55.4	0.00555	0.0054	1.768	0.202	41.3	0.25	4.98
1102	1536	55.4	0.03085	0.0306	2.189	0.203	41.8	0.26	4.98
1102	1538	55.4	0.0513	0.051	2.295	0.203	41.8	0.25	4.98
1102	1542	55.4	#NA	0.1481	2.566	0.203	41.7	0.26	4.98
1102	1545	55.4	#NA	0.4995	3.132	0.203	41.7	0.26	4.98
1102	1549	55.4	#NA	0.9954	3.776	0.203	41.6	0.25	4.98
1102	1553	75.1	0.0029	0.0028	0.437	0.253	41.8	0.25	4.98
1102	1557	75.1	0.00305	0.003	0.863	0.253	41.4	0.26	4.98
1102	1600	75.1	0.0054	0.0053	1.625	0.258	42.1	0.26	4.98
1102	1603	75.1	0.02725	0.0272	2.121	0.257	41.8	0.26	4.98
1102	1609	75.1	0.0521	0.0518	2.26	0.258	41.4	0.26	4.98
1102	1613	75.1	#NA	0.4972	3.109	0.258	41.3	0.25	4.98
1102	1619	75.1	#NA	1.063	3.843	0.258	41.4	0.25	4.98
1102	1621	132.0	0.00415	0.0038	0.512	0.305	41.7	0.26	4.98
1102	1624	132.0	0.00435	0.0041	1.013	0.301	41.7	0.26	4.98
1102	1626	132.0	0.0075	0.0072	1.642	0.309	41.4	0.27	4.98
1102	1629	132.0	0.02575	0.0255	2.055	0.311	41.4	0.26	4.98
1102	1633	132.0	0.05	0.0495	2.21	0.313	41.5	0.27	4.98
1102	1635	132.0	#NA	0.101	2.394	0.314	41.6	0.26	4.98
1102	1639	132.0	#NA	0.508	3.104	0.317	42	0.26	4.98
1102	1645	132.0	#NA	1.0561	3.821	0.319	41.8	0.26	4.98
1102	1700	0.0	0	0.0001	-0.004	0.005	38.1	0.25	4.98
1103	825	0.0	0	0	0.01	0.01	34.6	0.31	4.98
1103	839	252.0	0.01165	0.0109	0.879	0.562	42.8	0.36	4.98
1103	842	252.0	0.0252	0.0248	1.66	0.557	43.3	0.35	4.98
1103	845	252.0	0.0495	0.0489	1.921	0.555	42.2	0.35	4.98
1103	847	252.0	#NA	0.1128	2.207	0.555	42.3	0.35	4.98
1103	855	252.0	#NA	0.5008	2.975	0.56	43	0.34	4.98
1103	858	252.0	#NA	1.025	3.699	0.569	43.1	0.35	4.98
1103	901	488.0	#NA	0.0585	1.378	0.957	44	0.4	4.98
1103	904	488.0	#NA	0.0997	1.764	0.961	44	0.4	4.98
1103	907	488.0	#NA	0.4997	2.802	0.962	43.8	0.39	4.98
1103	910	488.0	#NA	1.0002	3.545	0.963	44	0.39	4.98
1103	922	4.0	0.0045	0.0045	1.97	0.033	39	0.31	4.98
1103	925	4.0	0.02815	0.028	2.283	0.033	39	0.31	4.98
1103	930	4.0	0.05035	0.0501	2.389	0.033	39.1	0.31	4.98
1103	933	4.0	#NA	0.1052	2.549	0.032	39.2	0.31	4.98
1103	939	4.0	#NA	1.0215	3.85	0.032	38.8	0.31	4.98
1103	944	6.7	0.00505	0.0048	1.951	0.05	40	0.31	4.98
1103	949	6.7	0.0274	0.0271	2.265	0.046	39.7	0.31	4.98
1103	955	6.7	0.05075	0.0502	2.376	0.046	39.9	0.31	4.98
1103	1000	6.7	#NA	0.0991	2.524	0.046	39.7	0.31	4.98
1103	1005	6.7	#NA	0.5234	3.211	0.046	39.5	0.31	4.98
1103	1009	10.9	0.00815	0.008	2.03	0.07	40.1	0.31	4.98
1103	1012	10.9	0.0228	0.0226	2.22	0.071	40.3	0.31	4.98
1103	1017	10.9	#NA	0.1035	2.524	0.071	40.2	0.31	4.98
1103	1020	10.9	#NA	0.5398	3.226	0.07	40.3	0.32	4.98

Table 3 Helium Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
2/16/99	15:25:39	0	334	6.251	337.1	207.9	18.4	3.50
1102	1530	0	130	6.251	327.4	204.5	18.7	8.75
1102	1536	0	23	6.221	71.5	205.9	18.5	10.78
1102	1538	0	14	6.221	45.0	205.9	18.5	11.31
1102	1542	0	5	6.221	17.3	205.4	18.5	12.64
1102	1545	0	1	6.221	6.3	205.4	18.5	15.43
1102	1549	0	0	6.221	3.8	204.9	18.6	18.60
1102	1553	0	340	6.769	156.1	165.2	18.5	1.73
1102	1557	0	317	6.769	287.7	163.6	18.7	3.41
1102	1600	0	180	6.638	306.6	163.2	18.4	6.30
1102	1603	0	35	6.664	78.0	162.6	18.5	8.25
1102	1609	0	18	6.638	43.6	160.5	18.7	8.76
1102	1613	0	2	6.638	6.3	160.1	18.7	12.05
1102	1619	0	0	6.638	3.6	160.5	18.7	14.90
1102	1621	1	440	9.868	-134.7	136.7	18.5	1.68
1102	1624	0	408	9.999	247.1	138.5	18.5	3.37
1102	1626	0	232	9.740	228.1	134.0	18.7	5.31
1102	1629	0	66	9.677	80.6	133.1	18.7	6.61
1102	1633	0	34	9.615	44.6	132.6	18.6	7.06
1102	1635	0	17	9.585	23.7	132.5	18.6	7.62
1102	1639	0	3	9.494	6.1	132.5	18.4	9.79
1102	1645	0	2	9.434	3.6	131.0	18.5	11.98
1102	1700	1	0	0.000	-40.0	7620.0	20.3	-0.80
1103	825	1	#ERR	0.000	#+INF	3460.0	22.4	1.00
1103	839	1	293	10.223	80.6	76.2	18.2	1.56
1103	842	0	129	10.315	66.9	77.7	18.0	2.98
1103	845	0	65	10.352	39.3	76.0	18.4	3.46
1103	847	0	28	10.352	19.6	76.2	18.4	3.98
1103	855	0	6	10.260	5.9	76.8	18.1	5.31
1103	858	0	3	10.098	3.6	75.7	18.1	6.50
1103	901	1	106	11.626	23.6	46.0	17.7	1.44
1103	904	0	62	11.578	17.7	45.8	17.7	1.84
1103	907	0	12	11.566	5.6	45.5	17.8	2.91
1103	910	0	6	11.554	3.5	45.7	17.7	3.68
1103	922	0	11	2.758	437.8	1181.8	19.9	59.70
1103	925	0	2	2.758	81.5	1181.8	19.9	69.18
1103	930	0	1	2.758	47.7	1184.8	19.8	72.39
1103	933	0	0	2.845	24.2	1225.0	19.8	79.66
1103	939	0	0	2.845	3.8	1212.5	20.0	120.31
1103	944	0	18	3.035	406.5	800.0	19.4	39.02
1103	949	0	3	3.299	83.6	863.0	19.5	49.24
1103	955	0	2	3.299	47.3	867.4	19.4	51.65
1103	1000	0	0	3.299	25.5	863.0	19.5	54.87
1103	1005	0	0	3.299	6.1	858.7	19.6	69.80
1103	1009	0	17	3.561	253.8	572.9	19.4	29.00
1103	1012	0	6	3.511	98.2	567.6	19.3	31.27
1103	1017	0	1	3.511	24.4	566.2	19.3	35.55
1103	1020	0	0	3.561	6.0	575.7	19.3	46.09

Table 3 · Helium Data

date	time	Helium flow sccm	P1 turbo pump inlet torr	P2 turbo pump inlet torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bel-lows out psig	P7 rota meter in psig
2/16/99 [illegible]	[illegible]:39	17.4	0.00565	0.0055	1.936	0.096	40.5	0.31	4.98
1103	1040	17.4	0.0322	0.032	2.263	0.095	40.3	0.31	4.98
1103	1044	17.4	0.0504	0.05	2.347	0.096	40.6	0.31	4.98
1103	1047	17.4	#NA	0.1046	2.51	0.095	40.2	0.31	4.98
1103	1052	27.2	0.0083	0.0081	1.981	0.127	40.8	0.32	4.98
1103	105	27.2	0.0436	0.0433	2.306	0.127	40.8	0.32	4.98
1103	1100	27.2	#NA	0.1064	2.501	0.131	40.6	0.31	4.98

Table 3 Helium Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
2/16/99	10:35:39	0	40	4.134	352.0	421.9	19.2	20.17
1103	1040	0	7	4.177	70.7	424.2	19.3	23.82
1103	1044	0	4	4.134	46.9	422.9	19.1	24.45
1103	1047	0	2	4.177	24.0	423.2	19.3	26.42
1103	1052	0	43	4.890	244.6	321.3	19.0	15.60
1103	105	0	8	4.890	53.3	321.3	19.0	18.16
1103	1100	0	3	4.741	23.5	309.9	19.1	19.09

2/18/99 at 7:38

Table 4 Hydrogen Data

date	time	Hydrogen flow sccm	P1 turbo pump inlet torr	P2 turbo pump inlet torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bel-lows out psig	P7 rota meter in psig
912	1030	0.0	0.00015	0	0.021	0.008	35.8	0.32	0.00
912	1053	136.3	0.0175	0.0171	0.525	0.345	42	0.38	4.98
912	1059	185.0	0.0457	0.0452	0.672	0.464	42.2	0.38	4.98
912	1103	502.4	#NA	0.2382	1.06	0.799	43.7	0.41	4.98
912	1110	1003.3	#NA	0.898	1.847	1.535	48.7	0.5	4.98
912	1120	1142.5	#NA	1.0715	2.03	1.715	49.2	0.52	4.98
912	1223	0.0	0.00015	0	0.012	0.01	35.8	0.32	0.00
912	1234	8.7	0.0004	0.0002	0.069	0.039	70.4	22.01	4.98
912	1237	18.7	0.0009	0.0007	0.143	0.083	82.8	21.79	4.98
912	1240	51.7	0.0027	0.0023	0.274	0.176	88.2	21.98	4.98
912	1244	105.2	0.01215	0.0118	0.512	0.39	91.8	21.96	4.98
912	1259	502.4	#NA	0.3175	1.206	1	94	21.98	4.98
912	1303	922.5	#NA	0.974	1.972	1.734	96	21.99	4.98
912	1310	8.7	0.00095	0.0007	0.383	0.047	38.2	0.32	4.98
912	1314	18.7	0.0101	0.0098	0.787	0.087	39.4	0.32	4.98
912	1326	51.7	#NA	0.4282	1.641	0.174	40.6	0.33	4.98
912	1332	82.1	#NA	0.9977	2.325	0.243	41.2	0.34	4.98
912	1415	8.7	#NA	0.6563	2.013	0.045	38.4	0.33	4.98
912	1422	8.7	0.00045	0.0004	0.213	0.078	82.9	21.99	4.98
912	1426	11.9	0.0008	0.0007	0.29	0.102	85.4	22	4.98
912	1429	18.7	0.00145	0.0014	0.38	0.135	87.1	21.99	4.98
912	1441	31.2	0.0063	0.0061	0.671	0.233	89.4	21.98	4.98
912	1447	50.8	0.0285	0.283	0.881	0.301	90.6	2197	4.98
912	1451	76.7	#NA	0.1016	1.1	0.37	91.5	21.99	4.98
912	1459	105.2	#NA	0.3411	1.446	0.497	90.2	22.01	4.98
912	1503	136.3	#NA	0.5418	1.695	0.574	91.1	22.03	4.98
912	1517	185.0	#NA	0.9	2.109	0.71	90.5	21.98	4.98
912	1534	8.7	0.0004	0.0004	0.11	0.056	38.3	0.33	4.98
912	1536	11.9	0.00065	0.0006	0.112	0.073	38.8	0.32	4.98
912	1540	8.7	0.00065	0.0006	0.312	0.054	38.3	0.32	4.98
912	1544	11.9	0.00095	0.0008	0.309	0.072	39	0.32	4.98
912	1547	18.7	0.00165	0.0016	0.31	0.106	39.3	0.33	4.98
912	1549	51.7	0.0039	0.0036	0.311	0.183	40.5	0.33	4.98
912	1552	61.2	0.00465	0.0045	0.307	0.201	40.1	0.34	4.98
912	1557	8.7	0.04545	0.0452	1.006	0.056	38.2	0.32	4.98
912	1606	11.5	0.05115	0.0509	1.017	0.067	38.7	0.33	4.98
912	1612	18.7	#NA	0.0535	1.008	0.098	39.2	0.33	4.98
912	1616	51.7	#NA	0.0736	1.017	0.183	40	0.35	4.98
912	1619	105.2	#NA	0.0963	1.009	0.288	40.9	0.36	4.98
912	1628	502.4	#NA	0.2848	1.074	0.838	43.2	0.4	4.98
912	1636	185.0	#NA	0.1488	1.01	0.474	42	0.34	4.98
915	1140	0.0	0	0	0.0108	0.006	35.6	0.31	0.79

Table 4 Hydrogen Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
912	1030	1	#ERR	0.00	#+INF	4475.0	21.7	2.63
912	1053	1	101	9.01	30.7	121.7	18.6	1.52
912	1059	1	52	9.09	14.9	90.9	18.5	1.45
912	1103	1	27	14.34	4.5	54.7	17.9	1.33
912	1110	1	14	14.90	2.1	31.7	16.1	1.20
912	1120	1	14	15.19	1.9	28.7	16.0	1.18
912	1223	1	#ERR	0.00	#+INF	3580.0	21.7	1.20
912	1234	1	549	5.07	345.0	1805.1	27.0	1.77
912	1237	1	339	5.14	204.3	997.6	22.8	1.72
912	1240	1	285	6.70	119.1	501.1	21.5	1.56
912	1244	1	113	6.15	43.4	235.4	20.6	1.31
912	1259	1	20	11.45	3.8	94.0	20.2	1.21
912	1303	1	12	12.13	2.0	55.4	19.8	1.14
912	1310	0	157	4.21	547.1	812.8	20.3	8.15
912	1314	0	24	4.91	80.3	452.9	19.7	9.05
912	1326	0	2	6.78	3.8	233.3	19.1	9.43
912	1332	0	1	7.71	2.3	169.5	18.9	9.57
912	1415	0	0	4.39	3.1	853.3	20.2	44.73
912	1422	0	275	2.53	532.5	1062.8	22.9	2.73
912	1426	0	215	2.66	414.3	837.3	22.2	2.84
912	1429	0	169	3.16	271.4	645.2	21.8	2.81
912	1441	0	65	3.06	110.0	383.7	21.2	2.88
912	1447	0	2	3.85	3.1	301.0	1262.1	2.93
912	1451	0	10	4.72	10.8	247.3	20.7	2.97
912	1459	0	4	4.83	4.2	181.5	21.0	2.91
912	1503	0	3	5.42	3.1	158.7	20.8	2.95
912	1517	0	3	5.94	2.3	127.5	21.0	2.97
912	1534	0	275	3.53	275.0	683.9	20.3	1.96
912	1536	0	251	3.71	186.7	531.5	20.0	1.53
912	1540	0	183	3.66	520.0	709.3	20.3	5.78
912	1544	0	188	3.77	386.3	541.7	19.9	4.29
912	1547	0	148	4.03	193.8	370.8	19.8	2.92
912	1549	0	182	6.44	86.4	221.3	19.2	1.70
912	1552	0	172	6.94	68.2	199.5	19.4	1.53
912	1557	0	2	3.53	22.3	682.1	20.3	17.96
912	1606	0	3	3.92	20.0	577.6	20.1	15.18
912	1612	0	4	4.36	18.8	400.0	19.8	10.29
912	1616	0	9	6.44	13.8	218.6	19.5	5.56
912	1619	0	14	8.33	10.5	142.0	19.0	3.50
912	1628	0	22	13.67	3.8	51.6	18.1	1.28
912	1636	0	16	8.90	6.8	88.6	18.5	2.13
915	1140	1	#ERR	0.00	#+INF	5933.3	21.8	1.80

Table 4 Hydrogen Data

date	time	Hydrogen flow sccm	P1 turbo pump inlet torr	P2 turbo pump inlet torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bel-lows out psig	P7 rota meter in psig
9/15/99	1227	31.2	0.0016	0.0014	0.209	0.118	40	0.32	4.98
915	1238	31.2	0.00185	0.0017	0.214	0.125	40.1	0.32	4.98
915	1257	51.7	0.00365	0.0034	0.292	0.178	40	0.32	4.98
915	1301	51.7	0.0042	0.004	0.373	0.289	90.2	22	4.98
915	1306	76.7	0.00805	0.0078	0.463	0.357	90.2	22	4.98
915	1309	76.7	0.0069	0.0066	0.372	0.237	41.3	0.32	4.98
915	1312	105.2	0.0129	0.0125	0.46	0.303	41.3	0.34	4.98
915	1316	105.2	0.0168	0.0165	0.565	0.44	90.4	21.98	4.98
915	1322	136.3	0.035	0.0348	0.671	0.532	90.5	21.9	4.98
915	1335	136.3	0.0393	0.0389	0.701	0.574	91	21.98	4.98
915	1341	136.3	0.0409	0.0405	0.713	0.589	91	21.98	4.98
915	1402	204.6	#NA	0.0647	0.703	0.489	41.7	0.35	4.98
915	1408	204.6	#NA	0.1039	0.873	0.72	91.5	21.99	4.98
915	1412	502.4	#NA	0.4148	1.322	1.124	92.5	21.95	4.98
915	1415	502.4	#NA	0.3028	1.111	0.865	43.3	0.38	4.98
915	1425	1003.3	#NA	0.9862	1.912	1.618	48.3	0.47	4.98
915	1428	1003.3	#NA	#NA	2.213	1.968	95.9	21.78	4.98
915	1431	136.3	0.0258	0.0252	0.549	0.381	42	0.32	4.98
915	1437	0.0	0.00015	0	0.021	0.023	38.1	0.31	0.72
922	1401	0.0	0.0001	0	0.006	0.006	37.2	0.27	0.72
922	1413	136.3	0.02195	0.0215	0.514	0.351	42	0.3	4.98
922	1417	105.2	0.0119	0.0114	0.426	0.284	41.8	0.29	4.98
922	1420	76.7	0.0069	0.0065	0.35	0.227	41.7	0.28	4.98
922	1424	51.7	0.00385	0.0035	0.27	0.172	41.3	0.28	4.98
922	1427	31.2	0.0021	0.0019	0.199	0.124	40	0.27	4.98
922	1430	18.7	0.00135	0.0011	0.152	0.094	40.2	0.27	4.98
922	1433	11.9	0.0008	0.0007	0.108	0.068	40.1	0.27	4.98
922	1436	8.7	0.0005	0.0003	0.073	0.048	39.8	0.27	4.98
922	1440	136.3	0.02225	0.0218	0.516	0.356	42	0.3	4.98
922	1443	0.0	0.0001	0	0.012	0.018	39.6	0.27	0.72
922	1453	0.0	0.00005	0	0.007	0.013	38.3	0.27	0.72
922	1500	8.7	0.00105	0.0009	0.384	0.047	39.7	0.27	4.98
922	1508	18.7	0.02355	0.0233	0.864	0.096	40.6	0.28	4.98
922	1515	51.7	#NA	0.4887	1.664	0.175	41	0.28	4.98
922	1518	51.7	#NA	0.492	1.668	0.175	41.2	0.29	4.98
922	1523	51.7	#NA	0.4941	1.671	0.176	41.2	0.29	4.98
922	1537	51.7	#NA	0.4792	1.654	0.175	41.1	0.28	4.98
922	1542	51.7	#NA	0.5045	1.685	0.177	41.2	0.28	4.98
922	1555	76.1	#NA	0.9179	2.169	0.225	42	0.28	4.98
922	1610	31.2	#NA	1.0476	2.336	0.243	89.9	22.01	4.98
922	1614	18.7	#NA	0.9691	2.25	0.237	89.9	22	4.98
922	1638	8.7	#NA	0.4865	1.702	0.18	88.4	22.01	4.98
922	1643	#NA	-0.00005	0.0001	0.005	0.02	39.3	0.28	0.72
922	1653	0.0	-0.00005	0	-0.004	0.013	37.8	0.28	0.72
1103	1228	0.0	0	0	-0.003	0.01	36.9	0.31	4.98
1103	1242	8.7	0.00045	0.0004	0.093	0.058	40.1	0.31	4.98
1103	1248	8.7	0.0009	0.0008	0.412	0.052	40	0.31	4.98
1103	1253	8.7	0.0506	0.0503	1.036	0.051	40	0.31	4.98

Table 4 Hydrogen Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
915	1223	1	283	6.04	149.3	339.0	19.4	1.77
915	1238	1	233	5.70	125.9	320.8	19.4	1.71
915	1257	1	193	6.62	85.9	224.7	19.4	1.64
915	1301	1	164	4.08	93.3	312.1	21.0	1.29
915	1306	1	125	4.90	59.4	252.7	21.0	1.30
915	1309	1	147	7.38	56.4	174.3	18.8	1.57
915	1312	1	107	7.92	36.8	136.3	18.8	1.52
915	1316	1	81	5.45	34.2	205.5	21.0	1.28
915	1322	1	50	5.84	19.3	170.1	20.9	1.26
915	1335	1	44	5.42	18.0	158.5	20.8	1.22
915	1341	1	43	5.28	17.6	154.5	20.8	1.21
915	1402	1	40	9.54	10.9	85.3	18.7	1.44
915	1408	1	25	6.48	8.4	127.1	20.7	1.21
915	1412	1	15	10.19	3.2	82.3	20.5	1.18
915	1415	1	21	13.24	3.7	50.1	18.0	1.28
915	1425	1	13	14.14	1.9	29.9	16.2	1.18
915	1428	1	#NA	11.62	#NA	48.7	19.7	1.12
915	1431	1	69	8.16	21.8	110.2	18.5	1.44
915	1437	1	#ERR	0.00	#+INF	1656.5	20.4	0.91
922	1401	1	#ERR	0.00	#+INF	6200.0	20.8	1.00
922	1413	1	80	8.86	23.9	119.7	18.5	1.46
922	1417	1	117	8.45	37.4	147.2	18.5	1.50
922	1420	1	149	7.70	53.8	183.7	18.6	1.54
922	1424	1	187	6.86	77.1	240.1	18.8	1.57
922	1427	1	208	5.75	104.7	322.6	19.3	1.60
922	1430	1	216	4.54	138.2	427.7	19.3	1.62
922	1433	1	215	3.99	154.3	589.7	19.3	1.59
922	1436	1	366	4.12	243.3	829.2	19.4	1.52
922	1440	1	79	8.73	23.7	118.0	18.5	1.45
922	1443	1	#ERR	0.00	#+INF	2200.0	19.5	0.67
922	1453	1	#ERR	0.00	#+INF	2946.2	20.2	0.54
922	1500	0	122	4.21	426.7	844.7	19.5	8.17
922	1508	0	10	4.45	37.1	422.9	19.1	9.00
922	1515	0	1	6.74	3.4	234.3	18.9	9.51
922	1518	0	1	6.74	3.4	235.4	18.8	9.53
922	1523	0	1	6.70	3.4	234.1	18.8	9.49
922	1537	0	1	6.74	3.5	234.9	18.8	9.45
922	1542	0	1	6.66	3.3	232.8	18.8	9.52
922	1555	0	1	7.72	2.4	186.7	18.4	9.64
922	1610	0	0	2.93	2.2	370.0	21.1	9.61
922	1614	0	0	1.80	2.3	379.3	21.1	9.49
922	1638	0	0	1.10	3.5	491.1	21.5	9.46
922	1643	0	#NA	#NA	50.0	1965.0	19.7	0.25
922	1653	0	#ERR	0.00	#-INF	2907.7	20.5	-0.31
1103	1228	1	#ERR	0.00	#-INF	3690.0	21.0	-0.30
1103	1242	1	275	3.41	232.5	691.4	19.4	1.60
1103	1248	0	137	3.80	515.0	769.2	19.4	7.92
1103	1253	0	2	3.88	20.6	784.3	19.4	20.31

Table 4 Hydrogen Data

date	time	Hydrogen flow sccm	P1 turbo pump inlet torr	P2 turbo pump inlet torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bel-lows out psig	P7 rota meter in psig
[illegible]	[illegible]	8.7	#NA	0.5316	1.782	0.051	39.8	0.31	4.98
1103	1302	8.7	#NA	0.9939	2.32	0.05	39.7	0.31	4.98
1103	1307	11.9	0.00065	0.0006	0.118	0.073	40.6	0.31	4.98
1103	1310	11.9	0.00195	0.0019	0.506	0.074	40.4	0.31	4.98
1103	1313	11.9	0.0476	0.0474	1.001	0.074	40.5	0.31	4.98
1103	1317	11.9	#NA	0.4946	1.714	0.074	40.3	0.31	4.98
1103	1320	11.9	#NA	0.9994	2.306	0.074	40.1	0.31	4.98
1103	1323	18.7	0.0016	0.0014	0.176	0.109	40.7	0.31	4.98
1103	1327	18.7	0.0185	0.0183	0.834	0.11	41	0.31	4.98
1103	1334	18.7	0.04995	0.0495	0.989	0.11	40.7	0.31	4.98
1103	1338	18.7	#NA	0.5088	1.72	0.109	40.6	0.32	4.98
1103	1342	18.7	#NA	0.9932	2.288	0.109	40.9	0.31	4.98
1103	1344	31.2	0.0021	0.002	0.212	0.133	40.9	0.31	4.98
1103	1346	31.2	0.00305	0.003	0.433	0.133	40.8	0.31	4.98
1103	1349	31.2	0.0112	0.0111	0.733	0.133	41.2	0.31	4.98
1103	1352	31.2	0.05005	0.0498	0.971	0.133	40.9	0.31	4.98
1103	1356	31.2	#NA	0.4992	1.699	0.133	41	0.32	4.98
1103	1359	31.2	#NA	1.0064	2.296	0.133	40.9	0.32	4.98
1103	1401	51.7	0.0042	0.0041	0.287	0.189	41	0.32	4.98
1103	1405	51.7	0.00775	0.0076	0.558	0.19	41.1	0.32	4.98
1103	1408	51.7	0.0236	0.0234	0.796	0.19	41.4	0.32	4.98
1103	1411	51.7	0.047	0.0467	0.918	0.19	41.5	0.32	4.98
1103	1414	51.7	#NA	0.5022	1.684	0.19	41.3	0.31	4.98
1103	1419	51.7	#NA	1.0033	2.277	0.191	41.2	0.32	4.98
1103	1425	76.7	0.00635	0.0061	0.341	0.228	41.4	0.32	4.98
1103	1432	76.7	0.0162	0.016	0.674	0.228	41.4	0.31	0.72
1103	1435	76.7	0.04925	0.049	0.898	0.228	41.1	0.32	0.72
1103	1438	76.7	#NA	0.5072	1.68	0.228	41.3	0.32	4.98
1103	1442	76.7	#NA	0.993	2.257	0.228	41.2	0.32	4.98
1103	1444	105.2	0.01355	0.0131	0.443	0.305	41.6	0.32	4.98
1103	1446	105.2	0.0244	0.024	0.655	0.305	41.4	0.32	4.98
1103	1449	105.2	0.05005	0.0496	0.832	0.305	41.6	0.32	4.98
1103	1452	105.2	#NA	0.4966	1.642	0.306	41.8	0.32	4.98
1103	1454	105.2	#NA	1.0188	2.271	0.306	41.6	0.31	4.98
1103	1456	136.3	0.0255	0.0252	0.533	0.377	41.8	0.32	4.98
1103	1458	136.3	0.05	0.0498	0.755	0.379	42	0.32	4.98
1103	1500	136.3	#NA	0.5089	1.635	0.379	42.3	0.32	4.98
1103	1504	136.3	#NA	1.0687	2.312	0.38	41.9	0.32	4.98
1103	1530	185.0	0.04955	0.049	0.638	0.463	42	0.35	4.98
1103	1536	185.0	#NA	0.1347	0.971	0.472	42	0.33	4.98
1103	1540	185.0	#NA	0.4943	1.583	0.47	42	0.33	4.98
1103	1543	185.0	#NA	0.9786	2.188	0.468	42.1	0.33	4.98
1103	1547	502.4	#NA	0.3077	1.097	0.867	43	0.36	4.98
1103	1549	502.4	#NA	0.5714	1.548	0.866	43.4	0.36	4.98
1103	1552	502.4	#NA	1.0728	2.207	0.868	43.4	0.36	4.98
1103	1555	1003.3	#NA	0.9655	1.87	1.595	47.5	0.44	4.98
1103	1635	0.0	0.00005	0	0.006	0.019	38.2	0.31	4.98

Table 4 Hydrogen Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
1103	1258	0	0	3.88	3.4	780.4	19.5	34.94
1103	1302	0	0	3.95	2.3	794.0	19.5	46.40
1103	1307	1	251	3.71	196.7	556.2	19.1	1.62
1103	1310	0	79	3.66	266.3	545.9	19.2	6.84
1103	1313	0	3	3.66	21.1	547.3	19.2	13.53
1103	1317	0	0	3.66	3.5	544.6	19.3	23.16
1103	1320	0	0	3.66	2.3	541.9	19.4	31.16
1103	1323	1	169	3.92	125.7	373.4	19.1	1.61
1103	1327	0	13	3.88	45.6	372.7	18.9	7.58
1103	1334	0	5	3.88	20.0	370.0	19.1	8.99
1103	1338	0	0	3.92	3.4	372.5	19.1	15.78
1103	1342	0	0	3.92	2.3	375.2	19.0	20.99
1103	1344	1	198	5.36	106.0	307.5	19.0	1.59
1103	1346	0	132	5.36	144.3	306.8	19.0	3.26
1103	1349	0	36	5.36	66.0	309.8	18.8	5.51
1103	1352	0	8	5.36	19.5	307.5	19.0	7.30
1103	1356	0	0	5.36	3.4	308.3	18.9	12.77
1103	1359	0	0	5.36	2.3	307.5	19.0	17.26
1103	1401	1	160	6.24	70.0	216.9	18.9	1.52
1103	1405	0	86	6.21	73.4	216.3	18.9	2.94
1103	1408	0	28	6.21	34.0	217.9	18.8	4.19
1103	1411	0	14	6.21	19.7	218.4	18.7	4.83
1103	1414	0	1	6.21	3.4	217.4	18.8	8.86
1103	1419	0	0	6.17	2.3	215.7	18.8	11.92
1103	1425	1	159	7.67	55.9	181.6	18.8	1.50
1103	1432	0	61	7.67	42.1	181.6	18.7	2.96
1103	1435	0	20	7.67	18.3	180.3	18.9	3.94
1103	1438	0	2	7.67	3.3	181.1	18.8	7.37
1103	1442	0	0	7.67	2.3	180.7	18.8	9.90
1103	1444	1	102	7.86	33.8	136.4	18.7	1.45
1103	1446	0	56	7.86	27.3	135.7	18.8	2.15
1103	1449	0	27	7.86	16.8	136.4	18.7	2.73
1103	1452	0	3	7.84	3.3	136.6	18.6	5.37
1103	1454	0	1	7.84	2.2	135.9	18.7	7.42
1103	1456	1	69	8.25	21.2	110.9	18.6	1.41
1103	1458	0	35	8.20	15.2	110.8	18.5	1.99
1103	1500	0	3	8.20	3.2	111.6	18.4	4.31
1103	1504	0	2	8.18	2.2	110.3	18.5	6.08
1103	1530	1	48	9.11	13.0	90.7	18.5	1.38
1103	1536	0	17	8.94	7.2	89.0	18.5	2.06
1103	1540	0	5	8.98	3.2	89.4	18.5	3.37
1103	1543	0	2	9.01	2.2	90.0	18.5	4.68
1103	1547	1	21	13.21	3.6	49.6	18.1	1.27
1103	1549	0	11	13.23	2.7	50.1	17.9	1.79
1103	1552	0	6	13.20	2.1	50.0	17.9	2.54
1103	1555	0	13	14.34	1.9	29.8	16.5	1.17
1103	1635	1	#ERR	0.00	#+INF	2010.5	20.3	0.32

Table 5 Deuterium Data

date	time	Deuterium flow, sccm	P1 turbo pump inlet torr	P2 turbo pump inlet torr	P3 turbo pump outlt torr	P4 scroll pump inlet torr	P5 scroll pump outlt torr	P6 bel-lows out psig	P7 rota meter in psig
917	1034	43.6	0.0018	0.0016	0.305	0.157	40.3	0.31	4.98
917	1037	26.4	0.0011	0.0009	0.232	0.111	39.8	0.31	4.98
917	1040	15.9	0.0007	0.0006	0.186	0.083	39.4	0.31	4.98
917	1049	10.1	0.00035	0.0003	0.133	0.053	39.1	0.3	4.98
917	1052	7.4	0.0002	0.0002	0.099	0.036	38.7	0.29	4.98
917	1054	64.5	0.00295	0.0026	0.384	0.211	41.2	0.31	4.98
917	1057	88.5	0.00365	0.0033	0.431	0.243	40.2	0.31	4.98
917	1100	114.7	0.0053	0.0049	0.51	0.3	40.5	0.32	4.98
917	1106	205.0	0.01025	0.0097	0.655	0.407	41.9	0.33	4.98
917	1110	375.0	#NA	0.071	1.039	0.716	42.5	0.35	4.98
917	1114	710.3	#NA	0.4018	1.611	1.215	45.4	0.45	4.98
917	1118	1190.6	#NA	1.0156	2.355	1.9	48.8	0.63	4.98
917	1124	1190.6	#NA	1.0192	2.358	1.903	48.8	0.63	4.98
917	1226	0.0	0.0001	0	0.021	0.006	36.6	0.3	#NA
917	1237	7.4	0.0003	0.0002	0.087	0.045	82.2	22.04	4.98
917	1240	10.1	0.0005	0.0003	0.126	0.067	83.8	22.04	4.98
917	1244	15.9	0.00095	0.0007	0.191	0.107	86	22.03	4.98
917	1248	26.4	0.0013	0.001	0.241	0.141	87.9	22.04	4.98
917	1251	43.6	0.00225	0.0019	0.328	0.197	88.1	22.03	4.98
917	1258	64.5	0.00295	0.0026	0.383	0.234	88.1	22.02	4.98
917	1302	88.5	0.00355	0.0031	0.421	0.26	88.3	22.02	4.98
917	1306	114.7	0.00695	0.0064	0.569	0.368	88.6	22.03	4.98
917	1313	191.0	0.0107	0.01	0.666	0.443	89.5	22.04	4.98
917	1318	348.1	#NA	0.0573	1.003	0.715	90.4	22.04	4.98
917	1323	710.3	#NA	0.4252	1.651	1.284	92.5	22.04	4.98
917	1331	1161.7	#NA	1.011	2.36	1.943	95.7	22.04	4.98
917	1338	0.0	0	0	0.017	0.01	37.2	0.3	#NA
924	938	0.0	-0.00005	0.00005	0.008	0.005	39.2	0.31	4.98
924	942	7.4	0.00015	0.00015	0.082	0.04	36.8	0.31	4.98
924	944	10.1	0.0003	0.00025	0.109	0.055	38	0.31	4.98
924	947	15.9	0.00045	0.00045	0.14	0.073	39.3	0.32	4.98
924	951	26.4	0.00125	0.00115	0.235	0.132	40.2	0.32	4.98
924	954	43.6	0.00145	0.00125	0.255	0.144	40.5	0.32	4.98
924	959	64.5	0.0032	0.00285	0.385	0.229	40.8	0.33	4.98
924	1003	88.5	0.00375	0.00335	0.416	0.251	41.8	0.34	4.98
924	1007	114.7	0.00695	0.00655	0.548	0.346	41.8	0.34	4.98
924	1011	205.0	0.00985	0.00935	0.623	0.402	42	0.34	4.98
924	1015	348.1	0.0519	0.05135	0.948	0.661	42.5	0.36	4.98
924	1020	710.3	#NA	0.41635	1.602	1.229	44.4	0.46	4.98
924	1025	1219.9	#NA	1.06085	2.38	1.947	49	0.63	4.98
924	1032	7.4	0.0002	0.00015	0.281	0.037	39.1	0.31	4.98
924	1035	10.1	0.0005	0.00045	0.542	0.063	39.6	0.32	4.98

Table 5 Deuterium Data, continued

date	time	valve position 1=full open	pump speed turbopump L/sec	pump speed per scroll m^3/hr	turbo compress. ratio	scroll compress. ratio	bellows compress. ratio	pressure ratio for valve
917	1034	1	345	6.33	190.6	256.7	19.3	1.94
917	1037	1	371	5.42	257.8	358.6	19.5	2.09
917	1040	1	335	4.36	310.0	474.7	19.7	2.24
917	1049	1	427	4.35	443.3	737.7	19.8	2.51
917	1052	1	467	4.67	495.0	1075.0	20.0	2.75
917	1054	1	314	6.97	147.7	195.3	18.8	1.82
917	1057	1	340	8.30	130.6	165.4	19.3	1.77
917	1100	1	296	8.71	104.1	135.0	19.2	1.70
917	1106	1	268	11.48	67.5	102.9	18.5	1.61
917	1110	1	67	11.94	14.6	59.4	18.3	1.45
917	1114	1	22	13.33	4.0	37.4	17.3	1.33
917	1118	1	15	14.29	2.3	25.7	16.2	1.24
917	1124	1	15	14.26	2.3	25.6	16.2	1.24
917	1226	1	#ERR	0.00	#+INF	6100.0	21.2	3.50
917	1237	1	467	3.74	435.0	1826.7	23.1	1.93
917	1240	1	427	3.44	420.0	1250.7	22.7	1.88
917	1244	1	287	3.38	272.9	803.7	22.1	1.79
917	1248	1	334	4.27	241.0	623.4	21.6	1.71
917	1251	1	290	5.04	172.6	447.2	21.6	1.66
917	1258	1	314	6.29	147.3	376.5	21.5	1.64
917	1302	1	361	7.76	135.8	339.6	21.5	1.62
917	1306	1	227	7.10	88.9	240.8	21.4	1.55
917	1313	1	242	9.83	66.6	202.0	21.2	1.50
917	1318	1	77	11.10	17.5	126.4	21.0	1.40
917	1323	1	21	12.61	3.9	72.0	20.5	1.29
917	1331	1	15	13.63	2.3	49.3	19.8	1.21
917	1338	1	#ERR	0.00	#+INF	3720.0	20.8	1.70
924	938	1	0	0.00	160.0	7840.0	19.8	1.60
924	942	1	623	4.20	546.7	920.0	21.1	2.05
924	944	1	512	4.19	436.0	690.9	20.4	1.98
924	947	1	447	4.96	311.1	538.4	19.8	1.92
924	951	1	291	4.56	204.3	304.5	19.3	1.78
924	954	1	441	6.90	204.0	281.3	19.2	1.77
924	959	1	287	6.42	135.1	178.2	19.0	1.68
924	1003	1	334	8.04	124.2	166.5	18.6	1.66
924	1007	1	222	7.56	83.7	120.8	18.6	1.58
924	1011	1	278	11.63	66.6	104.5	18.5	1.55
924	1015	1	86	12.01	18.5	64.3	18.3	1.43
924	1020	1	22	13.18	3.8	36.1	17.7	1.30
924	1025	1	15	14.29	2.2	25.2	16.2	1.22
924	1032	0	623	4.55	1873.3	1056.8	19.8	7.59
924	1035	0	285	3.66	1204.4	628.6	19.6	8.60

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