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CHARACTERIZATION OF A TURBOMOLECULAR-PUMPED MAGNETIC SECTOR MASS SPECTROMETER

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ABSTRACT

A Perkin Elmer MGA-1200, turbomolecular-pumped, magnetic sector, multiple gas analyzer mass spectrometer with modified inlet for fast response was characterized for the analysis of hydrogen, helium, oxygen and argon in nitrogen and helium background gases. This instrument was specially modified for the Vanderberg AFB SLC-6 Hydrogen Disposal Test Program, as a part of the Hydrogen Sampling System (H2S2). Linearity, precision, drift, detection limits and accuracy among other analytical parameters for each of the background gas were studied to evaluate the performance of the instrument. The results demonstrate that H2S2 mass spectrometer is a stable instrument and can be utilized for the quantitative analytical determination of hydrogen, helium, oxygen and argon in nitrogen and helium background gases.

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I- INTRODUCTION

Hazardous gases are used extensively in various phases of the space shuttle launch at the Kennedy Space Center (KSC). Presence of hydrogen (H_2), even in small amounts in unwanted areas may generate severe hazardous conditions. In order to avoid the accumulation of these gases, nitrogen (N_2) and helium (He) are used as purge gases in various shuttle compartments and in cryogenic fuel lines respectively. This results in the importance of monitoring the presence of hydrogen, oxygen and other inorganic gases in the purged environments for a safe space shuttle launch.

Gas detection system used at KSC for the space shuttle launches involves the monitoring of the hazardous gases in various purged environments. Mass spectrometers and other analytical instruments, located in the Mobile Launch Pad (MLP) are used for the analysis of these purged gases. The spectrometers, in the past, had diode ion-pumps for their high vacuum systems, and have proven to be highly reliable over numerous shuttle launches for the detection of hydrogen, oxygen, argon and helium in nitrogen purged areas. Helium purged areas could not be monitored by these systems since ion-pumps are not well suited to pumping with a nearly 100% helium background.

Recently, mass spectrometers with turbo-molecular vacuum pumps have become available which are ideal for monitoring the helium purged environments. These pumps have an advantage that they are not affected by the noble gases. Currently at KSC, turbomolecular-pumped mass spectrometers are being tested for use in monitoring helium and nitrogen purged areas and the results have been very promising.

The present investigation has focussed primarily on the evaluation of a modified version of a Perkin Elmer's magnetic sector, multiple gas analyzer mass spectrometer having a turbo-molecular pump installed for its vacuum system. Precisely, it involves the evaluation of the instrument for the analysis of hydrogen, oxygen, helium and argon in nitrogen and helium background gases.

II- MATERIALS AND METHODS

A.

1- Mass Spectrometric System

The mass spectrometer used for this work was a Perkin Elmer's MGA-1200 Multiple Gas Analyzer (H2S2) with a mass range of 2-135 atomic mass unit. The spectrometer is a magnetic sector type which utilizes a turbo-molecular pump (50 L/sec capacity) for its vacuum system, The system was not further modified for this investigation. The MGA operates with a pressure of 50 Torr at its inlet leak and is equipped with Faraday detectors for intercepting the ion beams. The block diagram of the MGA system is presented in Figure 1. Figure 2A and 2B respectively demonstrate the flow diagram of the sample delivery system and the operation of the magnetic sector mass spectrometer.

2- Calibration Gases

Matheson Gas Products compressed gas cylinders containing mixtures of various gases of interest at different levels of concentrations in nitrogen and helium were used for this study. Pure nitrogen, air and helium gases were supplied by KSC.

B. Sample Delivery System

The sample delivery system used was a 8-port rotary gas valve for selecting the correct calibration gas. Standard gas mixtures with nitrogen and helium as the background gases were connected to the rotary valve having an electronically controlled switch. The switch facilitated rapid changes between various gas mixtures. The outlet of the rotary valve was connected to a pre-calibrated sample flow controller (Linde). The outlet of the flow controller was connected to the capillary of one of the inlet ports of the instrument via a digital calibrated gas flow meter (Sierra) and a T-connector. This T-connector is important

for maintaining the sample inlet capillary at the atmospheric pressure. The total length of the tubing from the rotary outlet to the inlet capillary of the spectrometer was about six feet. Standard gas bottles were connected to the rotary valve with 2-4 feet long tubing. PVC tubing was used for all the gas transport lines. All the pressure regulators at the standard gas bottles were operated at an outlet pressure of about 15 lbs/in^2. MGA required a minimum of 0.40 SLPM sample inlet flow for the capillary having inner diameter of 0.025 inches. The flow was optimized by monitoring the oxygen channel reading of the mass spectrometer while cycling a standard gas mixture through the system. Below this setting the "clean capillary" indicator light indicates that an insufficient amount of sample is reaching the inlet capillary. A higher flow rate of upto 0.8 SLPM of gas did not affect the performance of the instrument. Unless otherwise specified, a sample flow rate of 0.48-0.52 SLPM through the system was maintained for all the analytical measurements. The gas flow requirements may vary according to the diameter of the capillary connected to the sample inlet port of the instrument.

All the measurements were taken after a delay of about 15 seconds stabilization time. This was the time required by the mass spectrometer to respond accurately to the sample change at the rotary valve at the flow rate used for the experimental work.

C. Calibration

For its characterization, the mass spectrometer was calibrated using analyzed gas mixtures from Matheson Gas Products. The instrument was calibrated with a zero gas and a standard gas mixture having known concentrations of the gases to be analyzed in their respective background gases. For the analysis in nitrogen background, the calibration standard gas mixture contained:

H_2 - 2.601%

He	-	7.006%
O_2	-	7.007%
Ar	-	1.001%

For the analysis in helium background, the calibration standard gas mixture contained:

H_2	-	2.600%
O_2	-	5.003%
Ar	-	1.000%

D. Linearity and Precision Tests

The linearity and repeatability tests for the analyte gases in nitrogen and helium background gases were performed by analyzing standard gas mixtures containing varying concentrations of the analyte gases in their respective backgrounds. The experimental setup procedure for the determination of these parameters is shown in Figure 3. The output of each analyte gas channel was recorded in a digital form through an external digital voltmeter and also on a 6-channel chart recorder as the zero gas and the standard gas mixtures were cycled through the rotary valve.

E. Drift Tests

Drifts in the output of the various gas channels of the instrument were monitored for 24 hours by cycling standard gas mixtures in nitrogen and helium background gases. The setup procedure for this study is presented in Figure 4. The standard gas mixtures used for this study are as follows:

1. Analyte gases in nitrogen background

H_2 - 2.598%
He - 5.006%
O_2 - 5.122%
Ar - 1.000%

2. Analyte gases in helium background

H_2 - 7.058%
O2 - 3.297%
Ar - 0.999%

The instrument was calibrated for the appropriate background gas (N_2 or He) with the standard mixture before the start of the test. Appropriate zero gas kept flowing through the system for most of the time except for when the instrument inlet was switched to the other inlet port for analyzing the standard gas mixture. After recording the output of the various channels on a strip chart recorder and in a digital form at certain intervals of time, the inlet was switched back to the original zero gas inlet of the instrument.

F. Detection Limits

The output of H2(0-100% range), He(0-100% range), O2(0-25% range) and Ar(0-100% range) analyte channels of the instrument were recorded on a strip chart recorder preset in milli-volts ranges by using a fast scan speed (30 cm/min) for 30 seconds when appropriate zero gas was flowing through the system.

G. Response to a Gas Pulse

H2S2 is equipped with a [illegible] inlet for a fast response to detect a sudden sample change in the zero gas flowing through the system. The purpose of this test was to see how fast the instrument can detect 90% of the gas peak from

the base value when a gas pulse of one zero gas was generated into another zero gas. The response of the instrument was recorded on a strip chart recorder. The setup procedure for this test is presented in Figure 5. Gas pulses of half a second to one second were generated from one zero gas into another zero gas through a fast-response Marotta electric valve. An auto timer to generate the timed pulses, and to control the strip chart recorder simultaneously was constructed in the laboratory.

III - RESULTS AND DISCUSSIONS

A. Linearity and Precision Tests

A1- Nitrogen Background Gas

Data obtained by analyzing a series of seven standard gas mixtures containing varying concentrations of analyte gases are presented in Table 1A. The experimental averages with background correction are the average of a set of eleven consecutive runs. The background levels of various analyte gases were obtained when pure nitrogen was cycling through the system. The relative errors in the analytical results for most of the standards for the analyte gases are in the range of 0.05-3.05% except for hydrogen on standard mixture bottle numbers 2 and 6. No obvious explanation can be offered for this deviation except to question the accuracy of the supplied standard bottle mixtures. The linear curves obtained for the various analyte gases are presented in Figures 6A-6E. The curves demonstrate a linear response of the mass spectrometer to the concentration range of the various analyte gases tested under the conditions of the experiment.

Repeatability test data are presented in a graphic form in Figures 7A-7C. The coefficient of variation for the eleven consecutive test runs is less than 2% for all the analyte gases.

The results obtained for the detection limits of the four analyte gases when pure nitrogen zero gas was cycled through the system are presented in Table 1B. The detection limits for the four analyte gases in nitrogen background gas taken as twice the standard deviation are as follows:

H_2 (0-100% range)	-	197	PPM
O_2 (0-25% range)	-	26	PPM
He (0-100% range)	-	305	PPM
Ar (0-100% range)	-	27	PPM

A2- Helium Background Gas

Table 2A demonstrates the data obtained by analyzing a series of standard gas mixtures in helium zero gas. The experimental averages with background correction are again the averages of a set of eleven consecutive runs. The background levels of various analyte gases were also obtained when pure helium was cycling through the system. The relative errors in the analytical results for various gas mixtures for the three analyte gases are in the range of 0.05-4.03% except for the two standard mixtures corresponding to bottle numbers 2 and 5. Again no explanation can be offered for this discrepancy except suggesting to check the accuracy of these standard mixtures by running fresh and reliable new standards. The linear curves obtained for the various analyte gases are presented in Figures 8A-8D. The curves demonstrate a linear response of the mass spectrometer to the concentration range of the various analyte gases tested under the prescribed conditions of the test.

The repeatability test data is presented in a graphic form in Figures 9A and 9B. The coefficient of variation of the eleven consecutive test runs is less than 1% for all the analyte gases in helium background gas.

The results obtained for the detection limits of the three analyte gases when pure helium was cycled through the system are presented in Table 2B. The detection limits for the three analyte gases taken as twice the standard deviation are as follows:

H_2 (0-100% RANGE)	-	109	PPM
O_2 (0-25% RANGE)	-	22	PPM
Ar (0-100% RANGE)	-	15	PPM

B. Drift Study

B1- Nitrogen Background Gas

During the analysis of the zero gas over a 24-hour period, all of the analyte channels demonstrated a negative drift from their initial values and fell between 138 to 300 PPM except for argon which drifted about 70 PPM.

Table 3 demonstrates the drift in the analytical readout obtained for the standard gas mixture in nitrogen with background correction. The drift study plots of the various analyte gas channels are presented in Figures 10A-10C. Most of the channels demonstrate stability with small fluctuations, about 1% from the initial value, except for argon which deviated about 4% of the initial value in the positive direction.

B2- Helium Background Gas

For the zero helium gas analysis, all the channels drifted in the negative direction from the start of the experiment. The drift in all the analyte gas channels fell in the range of 50 to 220 PPM.

Table 4 demonstrates the drift in the analytical readout of the various analyte gas channels for the standard gas mixture in helium with background corrections. The data is presented in a graphic form in Figures 11A and 11B. Hydrogen channel demonstrates a negative drift from the initial value while oxygen and argon reflect an upward trend. Hydrogen and oxygen channels drifted about 2% and argon channel drifted about 6% from their initial readout.

B3- General

The results obtained on the drift study of the various analyte gas channels of the instrument reflect that for accurate and precise analytical results, periodic background corrections are needed during the analysis of gases in nitrogen background gas. It is especially important during the analysis of the analyte gases in helium background gas.

C. Response to a Gas Pulse

Tables 5A and 5B demonstrate the results obtained for the time required by the instrument to detect 90% peak of a zero gas from the baseline when pulses of half to one second durations were genearated into another zero gas flowing through the system. The results demonstrate that H2S2 can detect 90% of the peak from the baseline, from a distance of about six feet from its T-capillary connection, a half a second pulse of nitrogen zero gas into helium zero gas flowing at a rate of 3-6 SLPM in about 0.6 to 0.7 second (Table 5A). For pulses of similar durations of helium zero gas into nitrogen zero gas flowing at the same rate, the time was found to be about 0.4 second (Table 5B). Figure 12 demonstrates a typical strip chart recording of the response time for a pulse of half a second of nitrogen zero gas genearated into helium zero gas flowing at a rate of 6 SLPM.

IV - CONCLUSIONS

1 - The linearity data demonstrate a linear response of the instrument in the concentration range tested for the analysis of oxygen, hydrogen, helium and argon in nitrogen background gas, and hydrogen, oxygen and argon in helium background gas.

2 - Optimum sample flow required for the instrument is 0.48-0.52 SLPM for the sample inlet port capillary having inner diameter of 0.025 inch. Higher flow rates of upto 0.8 SLPM did not affect the analytical readout of the instrument. The flow rate should be optimized for the individual sample inlet port capillary.

3 - The detection limits of the multiple gas analyzer mass spectrometer for the analysis of the analyte gases in nitrogen zero gas are: H_2(0-100% range)-197 PPM, O_2(0-25% range)-26 PPM, He(0-100% range)-305 PPM and Ar(0-100% range)-27 PPM. The detection limits in helium zero gas are: H_2(0-100% range)-109 PPM, O_2(0-25% range)-22 PPM and Ar(0-100% range)-15 PPM.

4 - The drift study reflects that the analyte gas channel output are much stable in nitrogen zero gas as compared to helium zero gas. For accurate and precise analytical results, periodic background correction is needed during the analysis of the analyte gases in nitrogen background gas. However, it is especially important during the analysis in helium background gas.

5 - Minimum response time required by the instrument to detect 90% of a peak of nitrogen zero gas from the baseline was found to be 0.6-0.7 second when pulses of half a second duration of nitrogen zero gas were generated into helium zero gas flowing at a rate of 3-6 SLPM. For pulses of helium zero gas of similar duration generated into nitrogen zero gas flowing at the same rate, the response time was found to be

about 0.4 second.

6 - The present study on the characterization of the Perkin Elmer's MGA-1200, turbomolecular-pumped, magnetic sector, multiple gas analyzer mass spectrometer (H2S2) demonstrates that the instrument can be utilized for the quantitative analytical determination of hydrogen, oxygen, helium and argon in nitrogen and helium background gases.

TABLES

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Table 1A

LINEARITY AND PRECISION STUDY: STATISTICAL DATA OF GASES IN N2 BKG GAS

	A	B	C	D	E	F	G
1		H2 10%	H2 100%	He	N2	O2 25%	Ar
2	BOTTLE 2						
3							
4	STD CONC	0.9850	0.9850	0.7998	96.7132	1.0000	0.5020
5							
6	EXP AVERAGE	0.8901	0.8927	0.7936	97.3364	1.0107	0.5017
7							
8	STD DEV	0.0038	0.0065	0.0163	0.0446	0.0016	0.0070
9							
10	COF OF VARIAT	0.4217	0.7244	2.0529	0.0458	0.1600	1.4040
11							
12	REL ERROR	9.6354	9.3678	0.7705	0.6443	1.0682	0.0543
13							
14	----------	----------	----------	----------	----------	----------	----------
15							
16		H2 10%	H2 100%	He	N2	O2 25%	Ar
17	BOTTLE 3						
18							
19	STD CONC	2.6040	2.6040	11.9990	72.3840	12.0110	1.0020
20							
21	EXP AVERAGE	2.6434	2.6445	12.0282	72.2445	12.0439	1.0223
22							
23	STD DEV	0.0061	0.0082	0.0133	0.0169	0.0226	0.0195
24							
25	COF OF VARIAT	0.2309	0.3101	0.1104	0.0235	0.1881	1.9034
26							
27	REL ERROR	1.5117	1.5570	0.2432	0.1927	0.2736	2.0232
28							
29	----------	----------	----------	----------	----------	----------	----------
30							
31		H2 10%	H2 100%	He	N2	O2 25%	Ar
32	BOTTLE 4						
33							
34	STD CONC	2.5980	2.5980	5.0060	86.2740	5.1220	1.0000
35							
36	EXP AVERAGE	2.6620	2.6555	4.9845	86.0273	5.1305	1.0202
37							
38	STD DEV	0.0027	0.0069	0.0069	0.0508	0.0095	0.0166
39							
40	COF OF VARIAT	0.1022	0.2579	0.1388	0.0707	0.1860	1.5255
41							
42	REL ERROR	2.4634	2.5964	1.0279	0.2960	0.1651	2.0182

Table 1A Continue

LINEARITY AND PRECISION STUDY: STATISTICAL DATA OF GASES IN N2 BKG GAS

	A	B	C	D	E	F	G
43							
44		H2 10%	H2 100%	He	N2	O2 25%	Ar
45	BOTTLE 5						
46							
47	STD CONC	2.6010	2.6010	7.0060	82.3850	7.0070	1.0010
48							
49	EXP AVERAGE	2.6472	2.6491	7.0009	82.1827	7.0255	1.0207
50							
51	STD DEV	0.0055	0.0083	0.0083	0.0205	0.0117	0.0184
52							
53	COF OF VARIAT	0.2075	0.3138	0.1187	0.0250	0.1660	1.8039
54							
55	REL ERROR	1.7755	1.8489	0.0727	0.2455	0.2634	1.9709
56							
57	.....	.....	.....	.....	.....	.....	.....
58							
59		H2 10%	H2 100%	He	N2	O2 25%	Ar
60	BOTTLE 6						
61							
62	STD CONC	8.0000	8.0000		92.0000		
63							
64	EXP AVERAGE	8.4587	8.4582		93.0427		
65							
66	STD DEV	0.0107	0.0125		0.0429		
67							
68	COF OF VARIAT	0.1270	0.1478		0.0461		
69							
70	REL ERROR	5.7341	5.7273		1.1334		
71							
72	.....	.....	.....	.....	.....	.....	.....
73							
74		H2 10%	H2 100%	He	N2	O2 25%	Ar
75	BOTTLE 7						
76							
77	STD CONC	5.1450	5.1450	5.0040	85.5430	3.2940	1.0000
78							
79	EXP AVERAGE	4.9921	4.9892	4.9000	85.4691	3.3250	0.9946
80							
81	STD DEV	0.0087	0.0060	0.0089	0.0270	0.0061	0.0167
82							
83	COF OF VARIAT	0.1734	0.1209	0.1825	0.0316	0.1842	1.6741
84							
85	REL ERROR	2.9720	3.0480	2.0783	0.0934	0.9411	0.5364
86							
87	.....	.....	.....	.....	.....	.....	.....
88							
89		H2 10%	H2 100%	He	N2	O2 25%	Ar
90	BOTTLE 9						
91							
92	STD CONC	10.0090	10.0080	10.0040	75.6870	3.3000	1.0010
93							
94	EXP AVERAGE	9.8732	9.8500	9.9007	75.5845	3.3300	0.9921
95							
96	STD DEV	0.0131	0.0352	0.0079	0.0197	0.0061	0.0181
97							
98	COF OF VARIAT	0.1327	0.3561	0.0794	0.0260	0.1839	1.8315
99							
100	REL ERROR	1.2872	1.1791	1.0103	0.1618	0.9091	1.2715

Table 1B

BACKGROUND CONCENTRATIONS IN N2 FOR DETECTION LIMIT DETERMINATION

	A	B	C	D	E	F
1			O2 25%	He	H2 100%	Ar
2						
3	n=30		CONC, PPM	CONC, PPM	CONC, PPM	CONC, PPM
4						
5			31.25	200.00	150.00	40.00
6			25.00	400.00	50.00	30.00
7			25.00	140.00	20.00	20.00
8			18.75	700.00	50.00	50.00
9			43.75	340.00	10.00	30.00
10			25.00	300.00	170.00	50.00
11			25.00	200.00	120.00	62.00
12			25.00	240.00	10.00	20.00
13			50.00	240.00	400.00	42.00
14			6.25	100.00	280.00	40.00
15			37.50	260.00	50.00	8.00
16			43.75	240.00	120.00	48.00
17			18.75	300.00	50.00	40.00
18			18.75	600.00	100.00	20.00
19			12.50	220.00	50.00	36.00
20			43.75	500.00	250.00	20.00
21			12.50	700.00	170.00	34.00
22			6.25	400.00	200.00	24.00
23			31.25	240.00	150.00	30.00
24			27.50	200.00	120.00	30.00
25			31.25	500.00	160.00	40.00
26			50.00	400.00	150.00	30.00
27			50.00	360.00	100.00	32.00
28			50.00	480.00	70.00	52.00
29			31.25	440.00	200.00	54.00
30			31.25	240.00	400.00	62.00
31			18.75	400.00	150.00	26.00
32			18.75	360.00	50.00	40.00
33			25.00	200.00	150.00	40.00
34			25.00	300.00	150.00	20.00
35						
36	EXP AVERAGE	(BKG)	28.63	340.00	136.67	35.67
37						
38	STD DEV	(S.D.)	12.77	152.50	98.73	13.27
39						
40	DETECT LIMIT	(2 S.D.)	25.54	305.00	197.46	26.54

Table 2A

LINEARITY AND PRECISION STUDY: STATISTICAL DATA OF GASES IN He BKG GAS

	A	B	C	D	E	F
1		H2 10%	H2 100%	He	O2 25%	Ar
2	BOTTLE 2					
3						
4	STD CONC	3.0140	3.0140	92.9830	3.3003	1.0000
5						
6	EXP AVERAGE	3.2092	3.2464	92.3700	2.8966	0.9789
7						
8	STD DEV	0.0076	0.0150	0.0307	0.0038	0.0066
9						
10	COF OF VARIAT	0.2381	0.4625	0.0332	0.1296	0.6721
11						
12	REL ERROR	6.4758	7.7095	0.6593	12.2325	2.1091
13						
14						
15	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
16		H2 10%	H2 100%	He	O2 25%	Ar
17	BOTTLE 3					
18						
19	STD CONC	9.9980	9.9980	90.0020		
20						
21	EXP AVERAGE	9.8432	9.9827	91.0164		
22						
23	STD DEV	0.0144	0.0200	0.0329		
24						
25	COF OF VARIAT	0.1461	0.2008	0.0362		
26						
27	REL ERROR	1.5485	0.1528	1.1270		
28						
29						
30	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
31						
32		H2 10%	H2 100%	He	O2 25%	Ar
33	BOTTLE 4					
34						
35	STD CONC	2.5980	2.5980	87.4120	9.9900	0.9990
36						
37	EXP AVERAGE	2.5230	2.5718	88.1964	9.7530	1.0079
38						
39	STD DEV	0.0105	0.0214	1.0214	0.0086	0.0060
40						
41	COF OF VARIAT	0.3956	0.8306	4.5596	0.0887	0.5960
42						
43	REL ERROR	2.8868	1.0078	0.8973	2.3728	0.8918
44						

Table 2A Continue

LINEARITY AND PRECISION STUDY: STATISTICAL DATA OF GASES IN He BKG GAS

	A	B	C	D	E	F
45	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
46						
47		H2 10%	H2 100%	He	O2 25%	Ar
48	BOTTLE 5					
49						
50	STD CONC	2.0020	2.0020	95.1987	1.9900	0.8003
51						
52	EXP AVERAGE	1.8584	1.8836	95.1609	1.9425	0.7899
53						
54	STD DEV	0.0060	0.0050	0.0365	0.0034	0.0053
55						
56	COF OF VARIAT	0.3231	0.2678	0.0383	0.1727	0.6686
57						
58	REL ERROR	7.1746	5.9123	0.0397	2.8264	1.2984
59						
60	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
61						
62		H2 10%	H2 100%	He	O2 25%	Ar
63	BOTTLE 6					
64						
65	STD CONC	2.6000	2.6000	91.3970	5.0030	1.0000
66						
67	EXP AVERAGE	2.5118	2.5473	91.1645	4.8386	0.9956
68						
69	STD DEV	0.0049	0.0185	0.0418	0.0168	0.0077
70						
71	COF OF VARIAT	0.1949	0.7258	0.0459	0.3476	0.7744
72						
73	REL ERROR	3.3916	2.0280	0.2543	3.2853	0.4364
74						
75	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
76						
77		H2 10%	H2 100%	He	O2 25%	Ar
78	BOTTLE 7					
79						
80	STD CONC	7.0580	7.0580	88.6460	3.2970	0.9990
81						
82	EXP AVERAGE	7.3423	7.4345	87.8955	3.1925	0.9845
83						
84	STD DEV	0.0091	0.0216	0.0372	0.0030	0.0074
85						
86	COF OF VARIAT	0.1239	0.2908	0.0424	0.0927	0.7483
87						
88	REL ERROR	4.0277	5.3350	0.8467	3.1695	1.4469

Table 2A Continue

LINEARITY AND PRECISION STUDY: STATISTICAL DATA OF GASES IN He BKG GAS

	A	B	C	D	E	F
89						
90						
91						
92		H2 10%	H2 100%	He	O2 25%	Ar
93	BOTTLE 8					
94						
95	STD CONC	5.0040	5.0040	90.6950	3.3010	1.0000
96						
97	EXP AVERAGE	5.0011	5.0782	90.2473	3.1961	0.9871
98						
99	STD DEV	0.0073	0.0060	0.0297	0.0034	0.0074
100						
101	COF OF VARIAT	0.1462	0.1187	0.0329	0.1070	0.7547
102						
103	REL ERROR	0.0581	1.4825	0.4937	3.1767	1.2909

Table 2B

BACKGROUND CONCENTRATIONS IN He FOR DETECTION LIMIT DETERMINATION

	A	B	C	D	E
1			O2 25%	H2 100%	Ar
2					
3	n=30		CONC,PPM	CONC,PPM	CONC,PPM
4					
5			35.00	70.00	35.00
6			30.00	90.00	8.00
7			10.00	90.00	20.00
8			35.00	20.00	10.00
9			20.00	70.00	20.00
10			12.50	190.00	15.00
11			25.00	110.00	15.00
12			42.50	140.00	18.00
13			25.00	130.00	10.00
14			2.50	60.00	15.00
15			12.50	70.00	5.00
16			2.50	100.00	5.00
17			30.00	100.00	30.00
18			12.50	170.00	32.00
19			17.50	60.00	19.00
20			45.00	170.00	16.00
21			22.50	20.00	20.00
22			10.00	160.00	29.00
23			22.50	130.00	25.00
24			20.00	60.00	20.00
25			10.00	20.00	15.00
26			25.00	170.00	15.00
27			15.00	120.00	22.00
28			35.00	200.00	20.00
29			20.00	200.00	18.00
30			15.00	60.00	18.00
31			15.00	180.00	10.00
32			15.00	100.00	15.00
33			30.00	130.00	14.00
34			10.00	160.00	20.00
35					
36	EXP AVERAGE	(BKG)	20.75	111.67	17.80
37					
38	STD DEV	(S.D.)	10.93	54.34	7.29
39					
40	DETECT LIMIT	(2 S.D.)	21.86	108.68	14.58

Table 3

DRIFT STUDY: READOUT OF THE STD GAS MIXTURE IN N2 WITH BKG CORRECTIONS

	A	B	C	D	E	F	G
1							
2		H2 10%	H2 100%	He	N2	O2 25%	Ar
3							
4	STD CONC	2.5980	2.5980	5.0060	86.2740	5.1220	1.0000
5							
6							
7	7-Jul-88	CONC	CONC	CONC	CONC	CONC	CONC
8	TIME						
9	PM 5.30	2.4900	2.4700	4.9200		5.1275	0.9930
10	7.00	2.5080	2.4900	4.9300		5.1450	0.9840
11	7.30	2.4980	2.4700	4.9300		5.1400	0.9790
12	8.00	2.5070	2.4700	4.9400		5.1450	0.9820
13	8.30	2.5160	2.4800	4.9200		5.1500	0.9840
14	8-Jul-88						
15	AM 8.00	2.4910	2.4600	4.9200		5.1450	0.9960
16	9.00	2.4930	2.4600	4.9200		5.1500	1.0120
17	10.15	2.4920	2.4600	4.9100		5.1450	1.0230
18	11.15	2.4920	2.4700	4.9000		5.1550	1.0310
19	PM 12.00	2.4970	2.4500	4.9100		5.1375	1.0340
20	1.00	2.4990	2.4600	4.9300		5.1500	1.0360
21	2.10	2.4970	2.4800	4.9100		5.1525	1.0360
22	3.15	2.4990	2.4600	4.9300		5.1550	1.0360
23	4.00	2.4960	2.4800	4.9100		5.1550	1.0320
24							
25							
26	EXP AVERAGE	2.4982	2.4686	4.9200		5.1466	1.0113
27							
28	STD DEV	0.0075	0.0110	0.0111		0.0078	0.0236
29							
30	MAX READOUT	2.5160	2.4900	4.9400		5.1550	1.0360
31							
32	MIN READOUT	2.4900	2.4500	4.9000		5.1275	0.9790
33							
34	INI READOUT	2.4900	2.4700	4.9200		5.1275	0.9930
35							
36	FIN READOUT	2.4960	2.4800	4.9100		5.1550	1.0320

Table 4

DRIFT STUDY: READOUT OF STD GAS MIXTURE IN He WITH BKG CORRECTIONS

	A	B	C	D	E	F	G
1							
2		H2 10%	H2 100%	He	N2	O2 25%	Ar
3							
4	STD CONC	7.0580	7.0580	88.6460	0.0000	3.2970	0.9990
5							
6							
7	JULY 5,88	CONC	CONC	CONC	CONC	CONC	CONC
8	TIME						
9	AM 9.45	7.0880	7.0500			3.1900	1.0360
10	10.15	7.0640	7.0200			3.1775	1.0470
11	11.00	7.0940	7.0500			3.1850	1.0060
12	11.30	7.1170	7.0700			3.1975	0.9970
13	PM 12.20	7.0670	7.0100			3.2100	0.9660
14	1.00	7.0590	7.0100			3.2025	0.9580
15	1.30	7.0670	7.0200			3.2075	0.9590
16	2.30	7.0610	7.0100			3.2125	0.9720
17	3.00	7.0420	6.9900			3.2125	0.9720
18	3.30	7.0270	6.9900			3.2150	0.9350
19	4.00	7.0260	7.0000			3.2150	0.9730
20	4.30	7.0250	6.9700			3.2175	0.9510
21	JULY 6,88						
22	AM 8.00	7.0030	6.9600			3.2450	1.0870
23	8.30	7.0010	6.9500			3.2475	1.0970
24	9.00	6.9940	6.9500			3.2500	1.1010
25	10.00	6.9970	6.9200			3.2500	1.1070
26							
27							
28	EXP AVERAGE	7.0458	6.9981			3.2147	1.0103
29							
30	STD DEV	0.0373	0.0409			0.0229	0.0600
31							
32	MAX READOUT	7.1170	7.0500			3.2500	1.1070
33							
34	MIN READOUT	6.9940	6.9200			3.1775	0.9350
35							
36	INI READOUT	7.0880	7.0500			3.1900	1.0360
37							
38	FIN READOUT	6.9970	6.9200			3.2500	1.1070

Table 5A

RESPONSE TIME, N2 GAS PULSE IN He (90% PEAK DETECTION FROM BASELINE)

	A	B	C	D
1				
2			RESPONSE TIME, SEC	
3				
4		He FLOW,	1/2 SEC.	1 SEC.
5		SLPM	PULSE	PULSE
6				
7		2.52	0.6	1.3
8				
9		3.00	0.6	1.2
10				
11		4.00	0.7	0.7
12				
13		5.00	0.7	0.7
14				
15		6.00	0.6	0.7

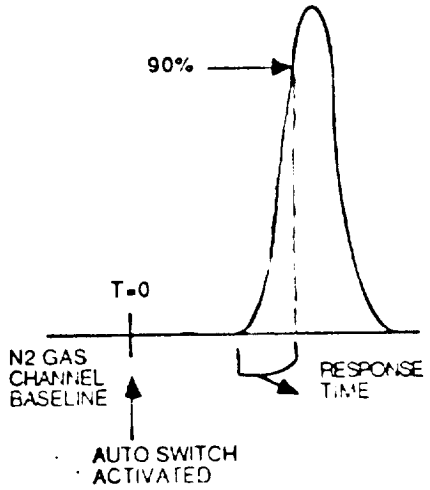
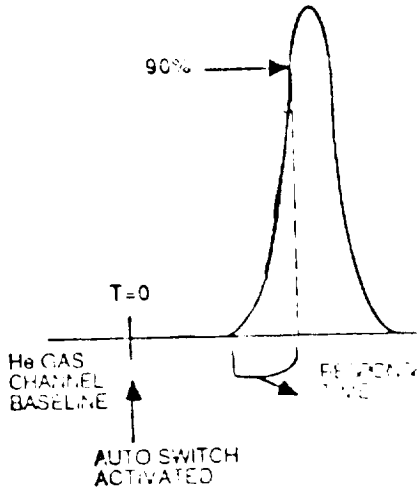


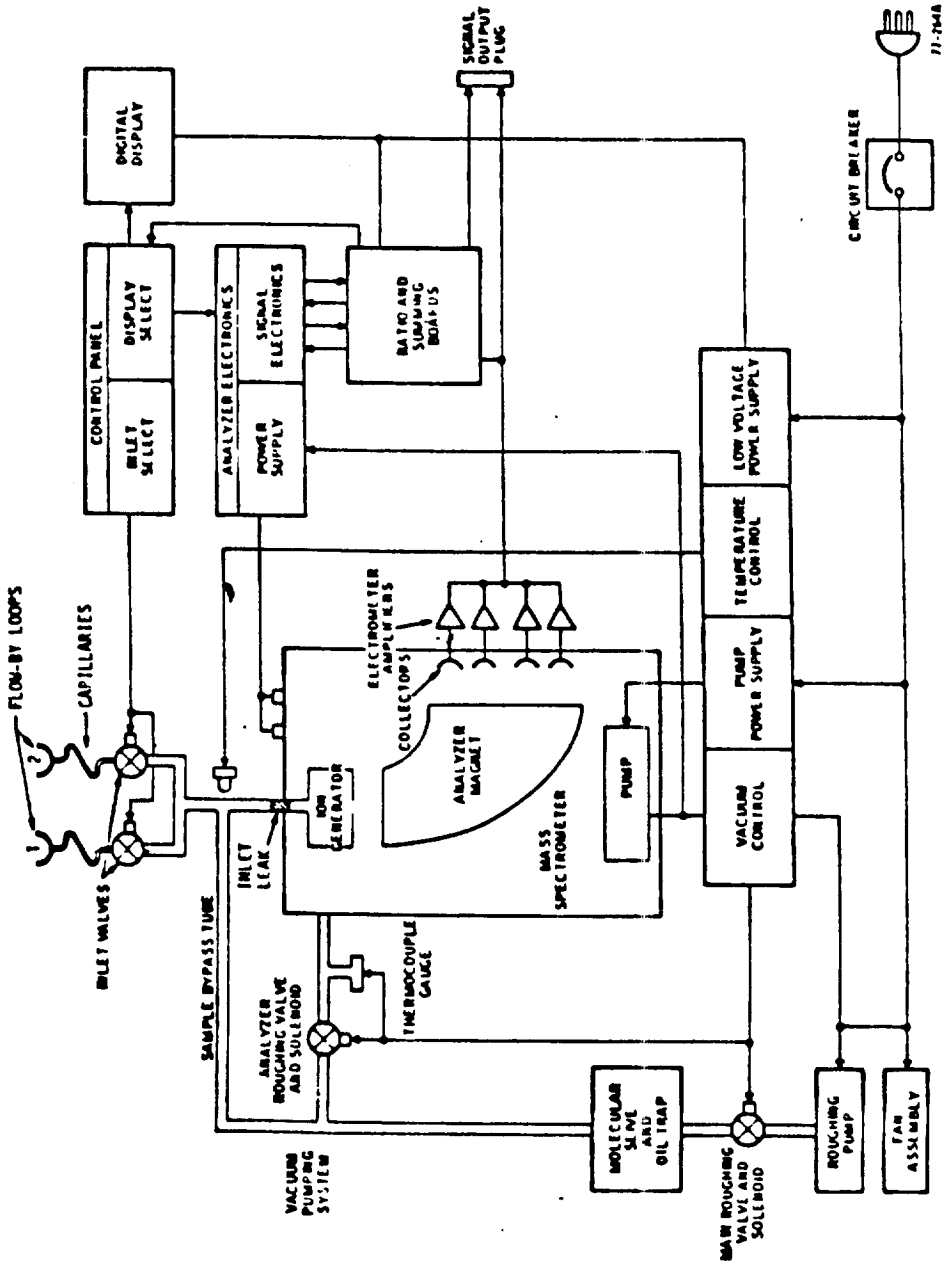
Table 5B

RESPONSE TIME, He GAS PULSE IN N2 (90% PEAK DETECTION FROM BASELINE)

	A	B	C	D
1				
2			RESPONSE TIME, SEC	
3				
4		N2 FLOW,	1/2 SEC	1 SEC
5		SLPM	PULSE	PULSE
6				
7		2.52	0.5	0.8
8				
9		3.00	0.4	0.6
10				
11		4.00	0.4	0.6
12				
13		5.00	0.4	0.4
14				
15		6.00	0.4	0.4

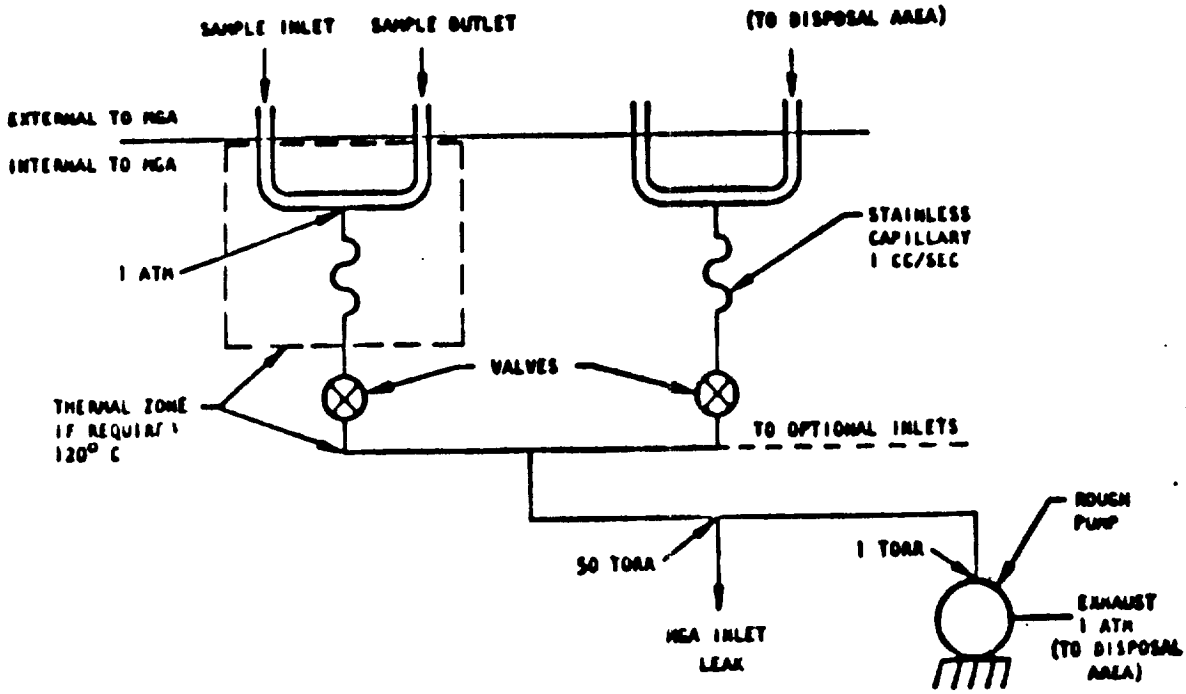


ILLUSTRATIONS



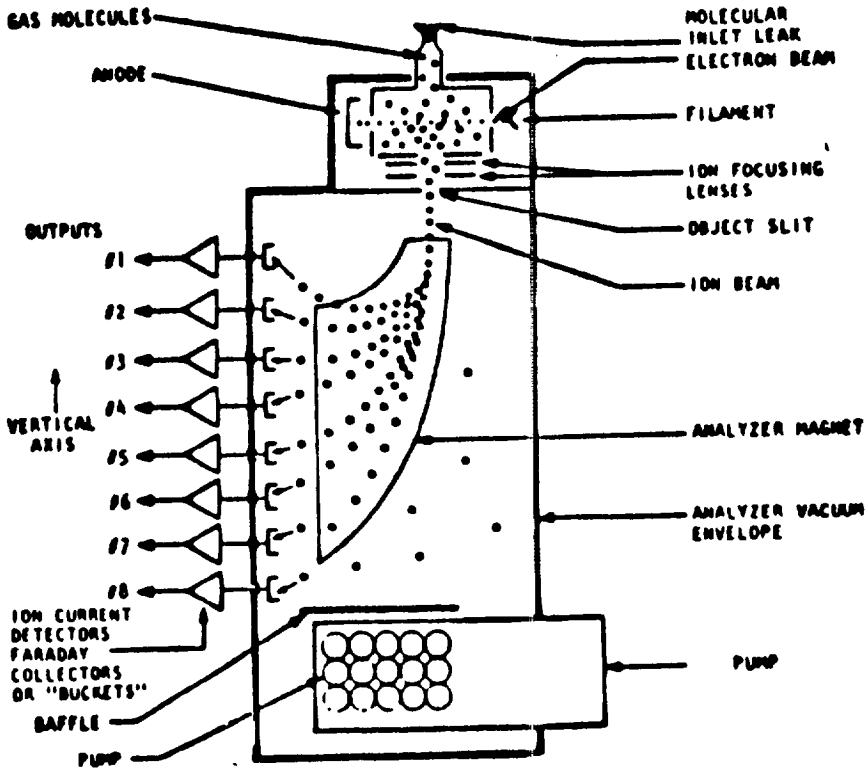
Typical MGA-1200 System Block Diagram

Figure 1



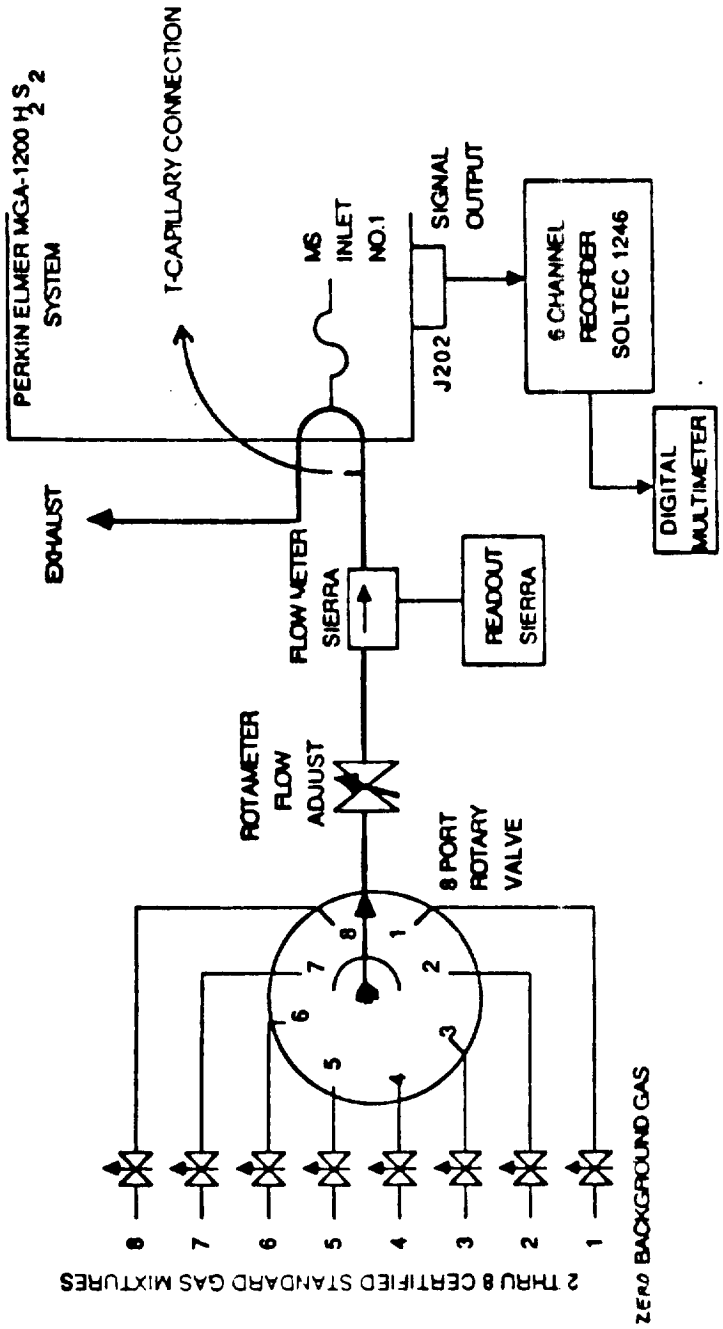
Typical MGA-1200 Inlet System

Figure 2A



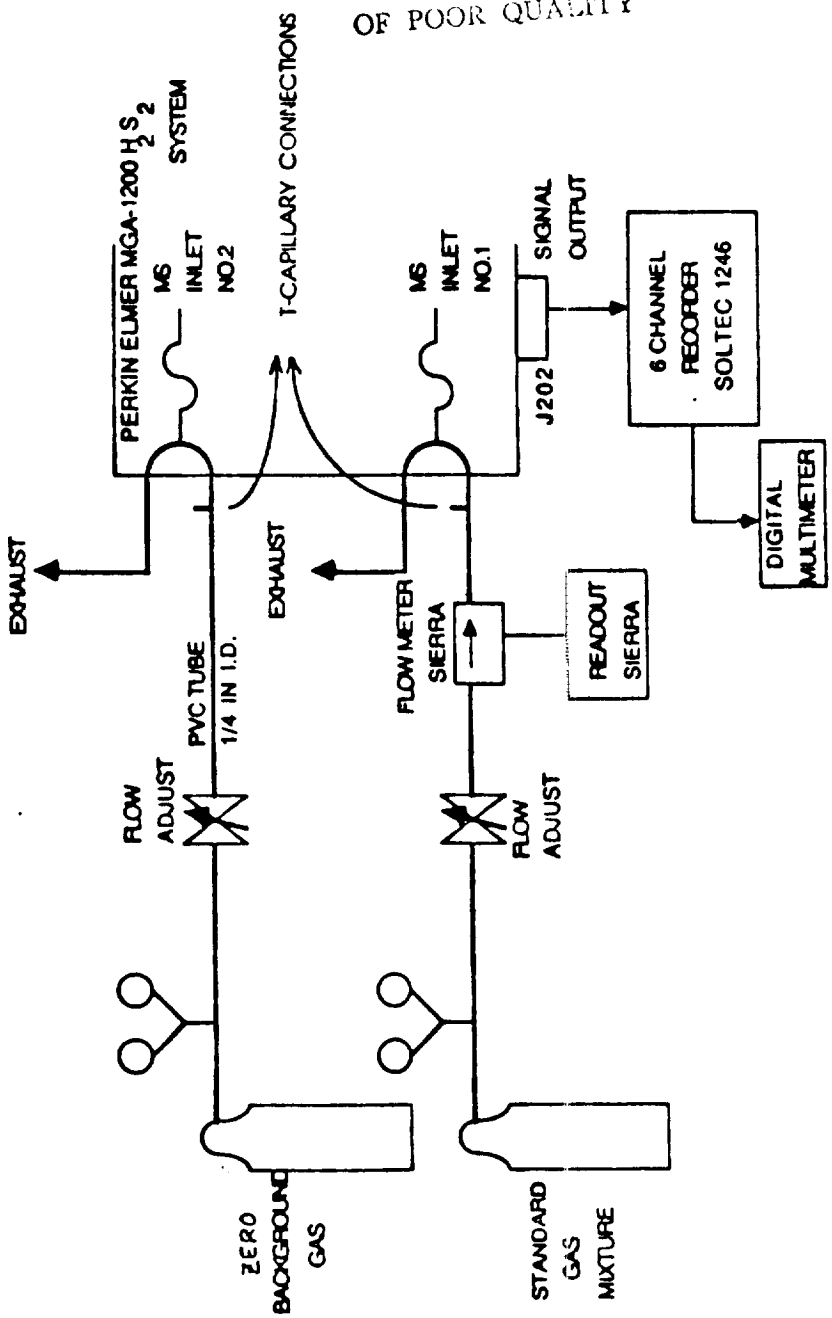
Idealized Operation of a Magnetic Sector Mass Spectrometer

Figure 2B



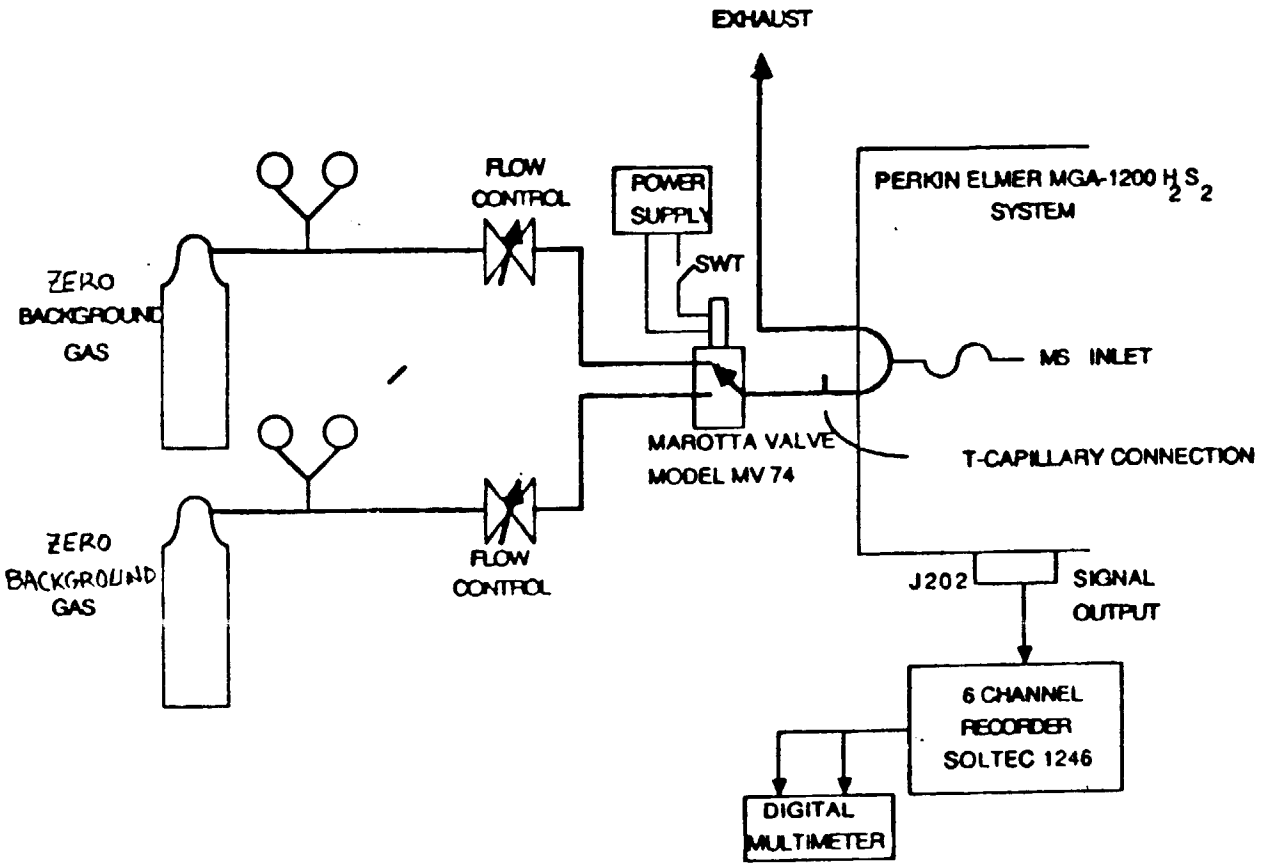
LINEARITY AND PRECISION
TEST SETUP

Figure 3



DRIFT TEST SETUP

Figure 4



RESPONSE TIME SETUP

Figure 5

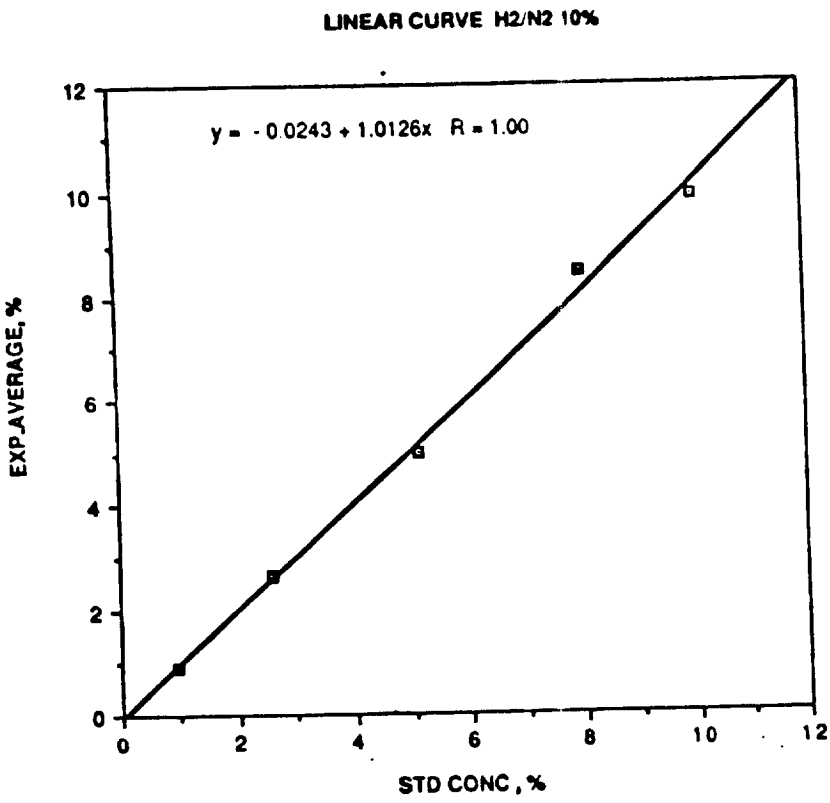


Figure 6A

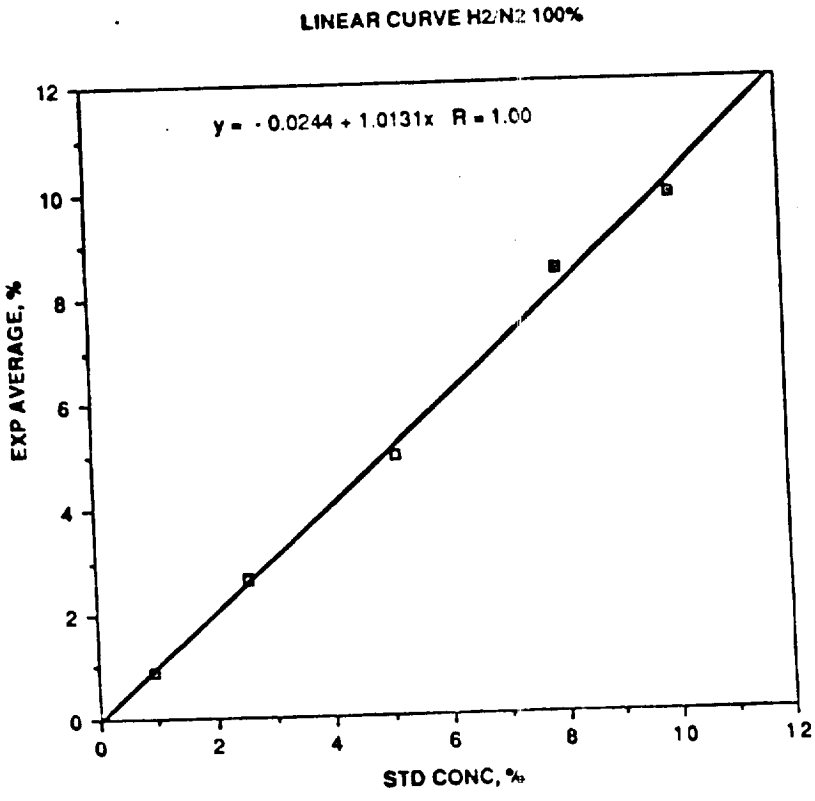


Figure 6B

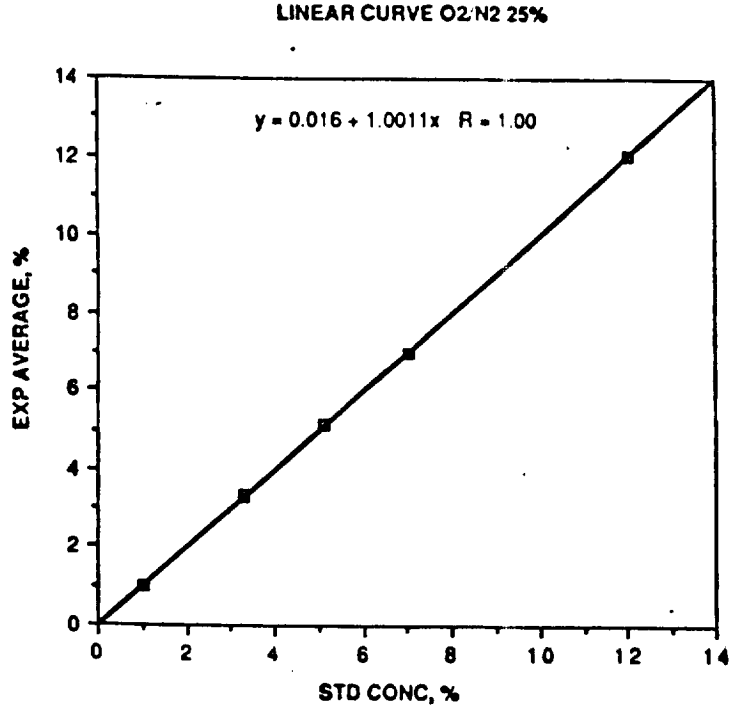


Figure6C

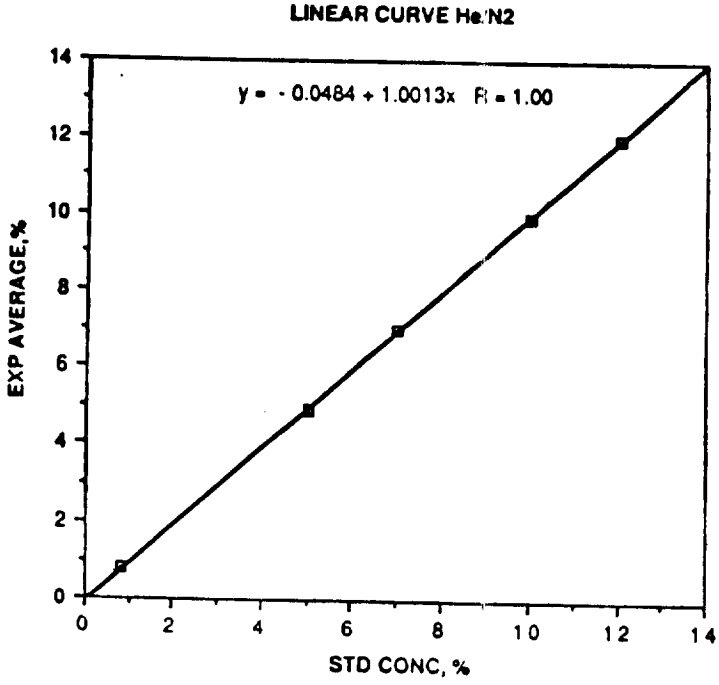


Figure 6D

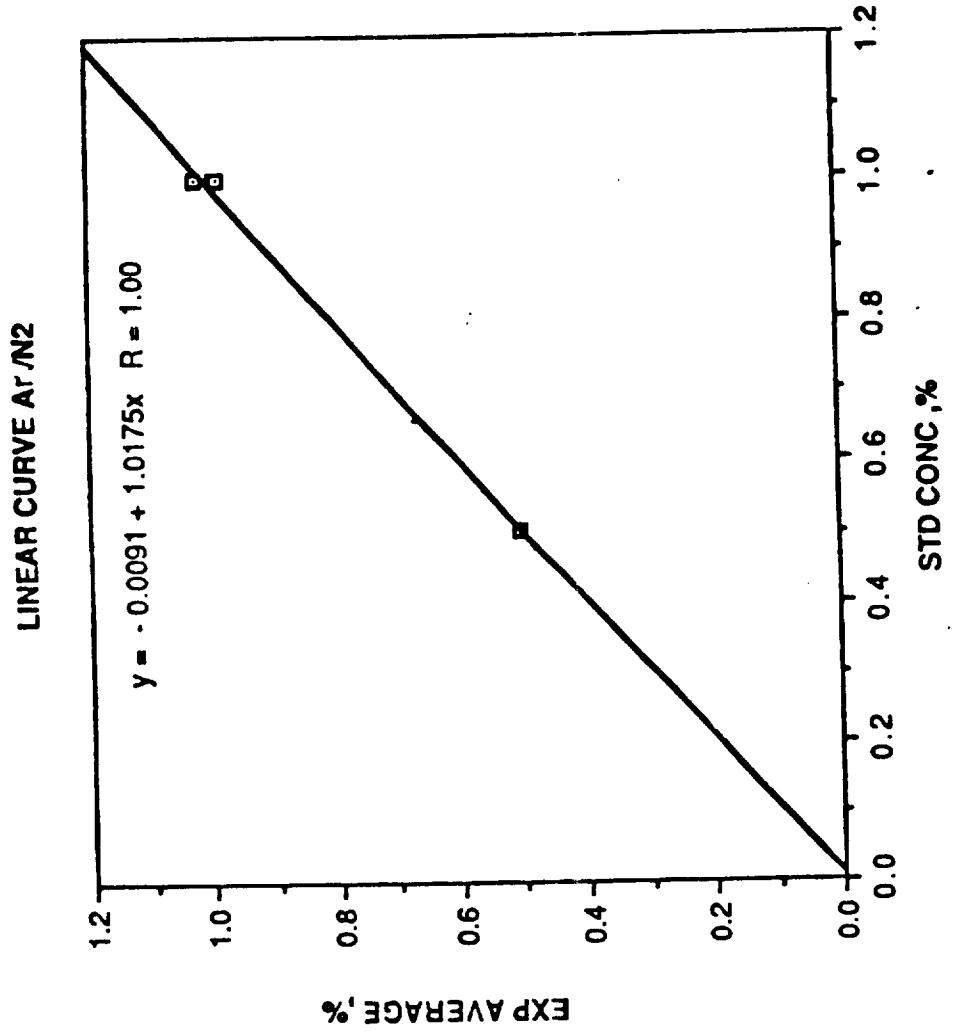

LINEAR CURVE Ar/N2
y = - 0.0091 + 1.0175x R = 1.00
EXP AVERAGE ,%
STD CONC ,%
0.0
0.2
0.4
0.6
0.8
1.0
1.2

Figure 6E

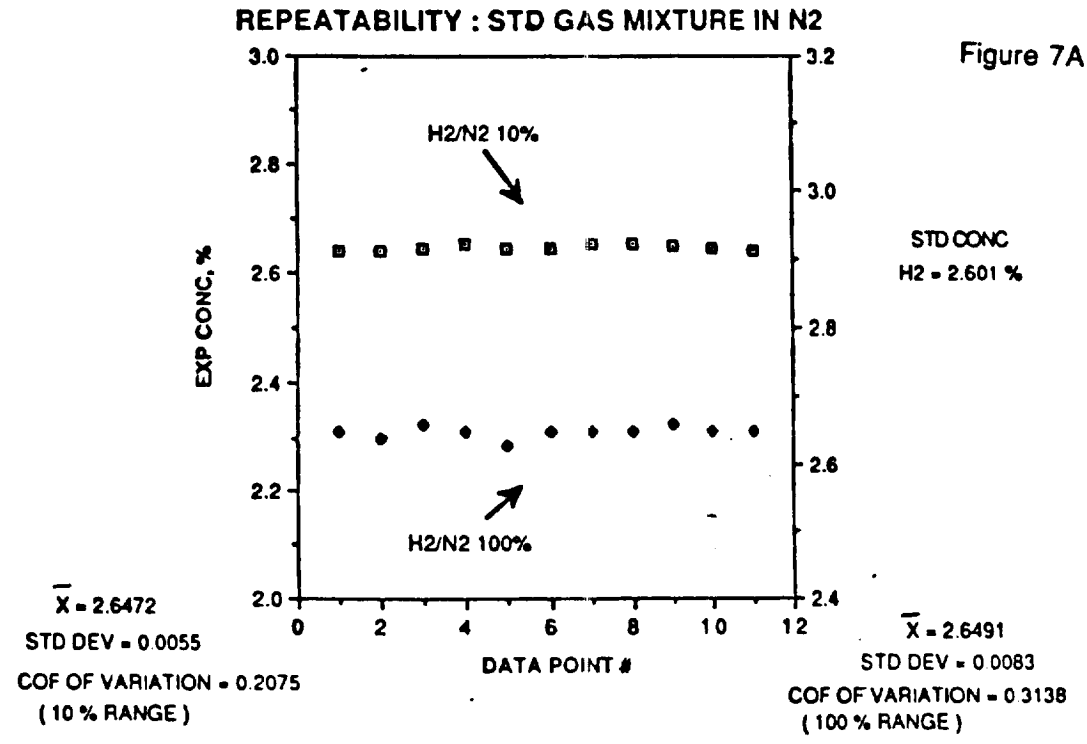


Figure 7A

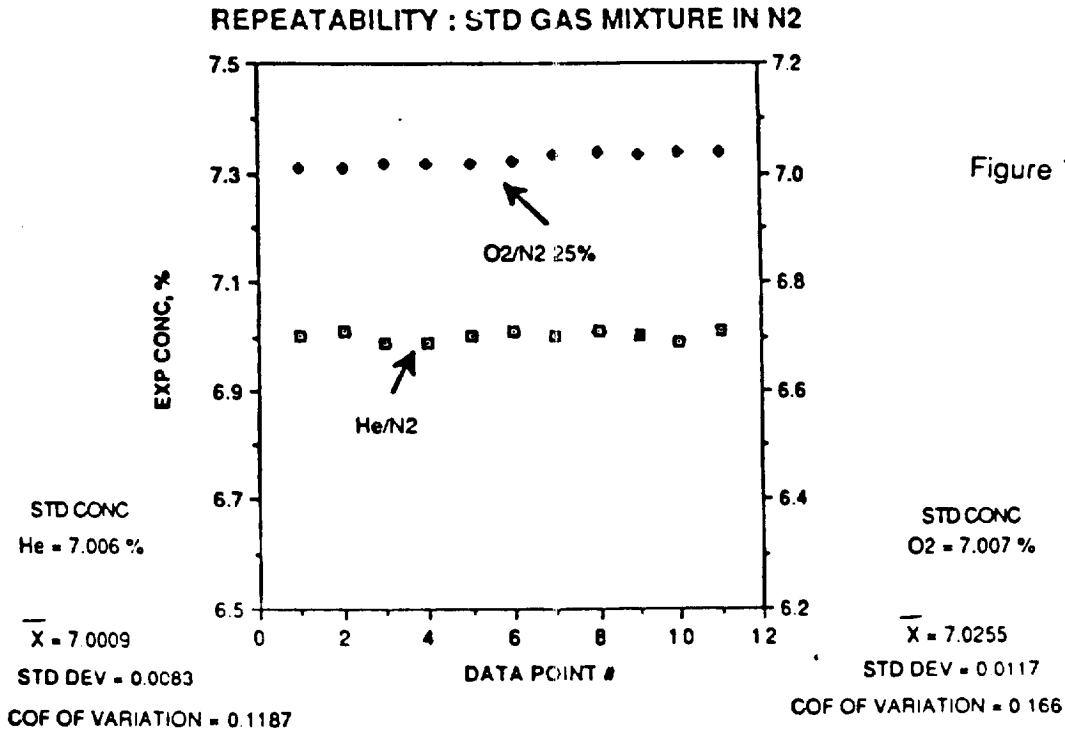


Figure 7B

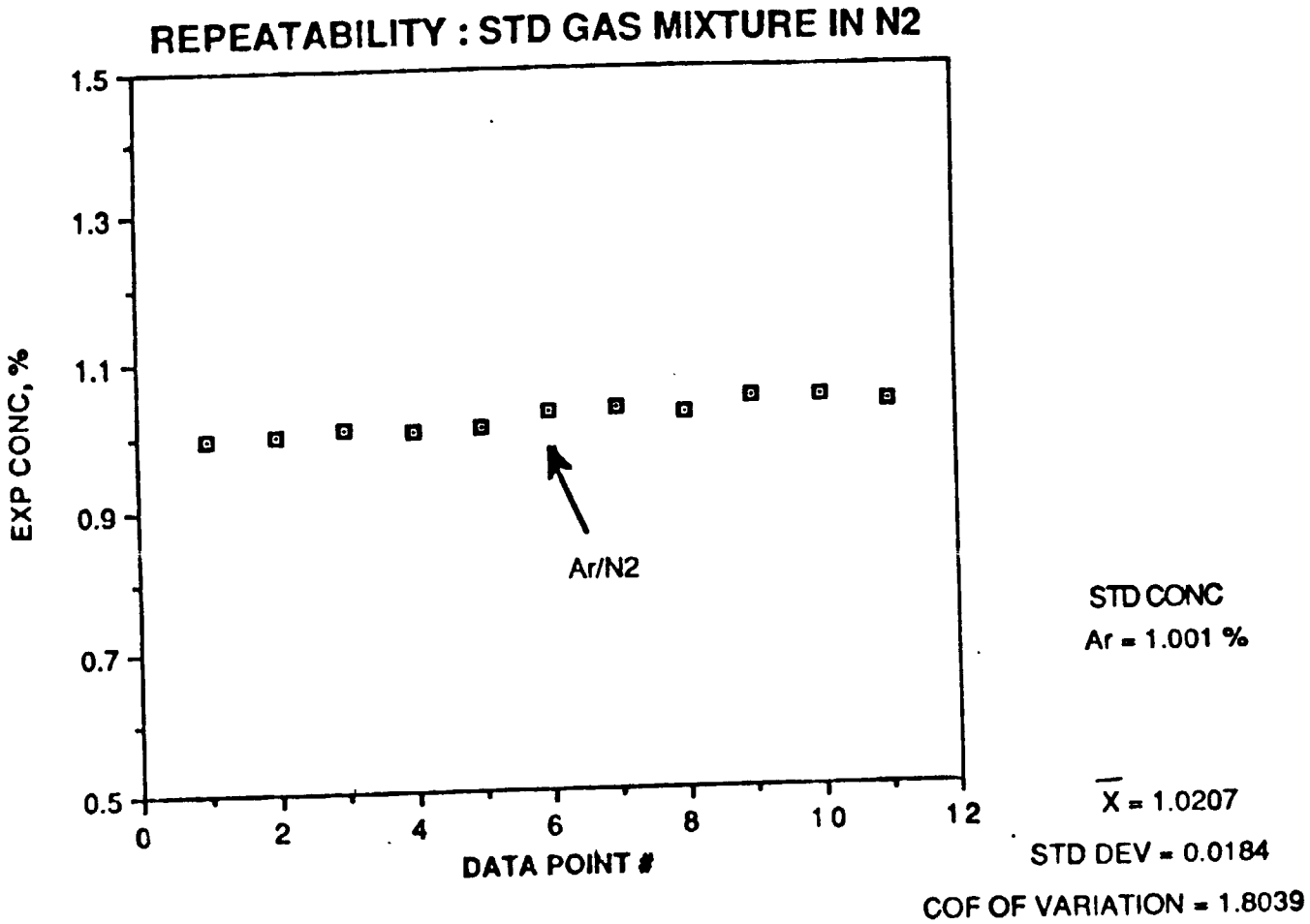

REPEATABILITY : STD GAS MIXTURE IN N2
EXP CONC, %
1.5
1.3
1.1
0.9
0.7
0.5
0
2
4
6
8
10
12
DATA POINT #
Ar/N2
STD CONC
Ar = 1.001 %
X = 1.0207
STD DEV = 0.0184
COF OF VARIATION = 1.8039

Figure 7C

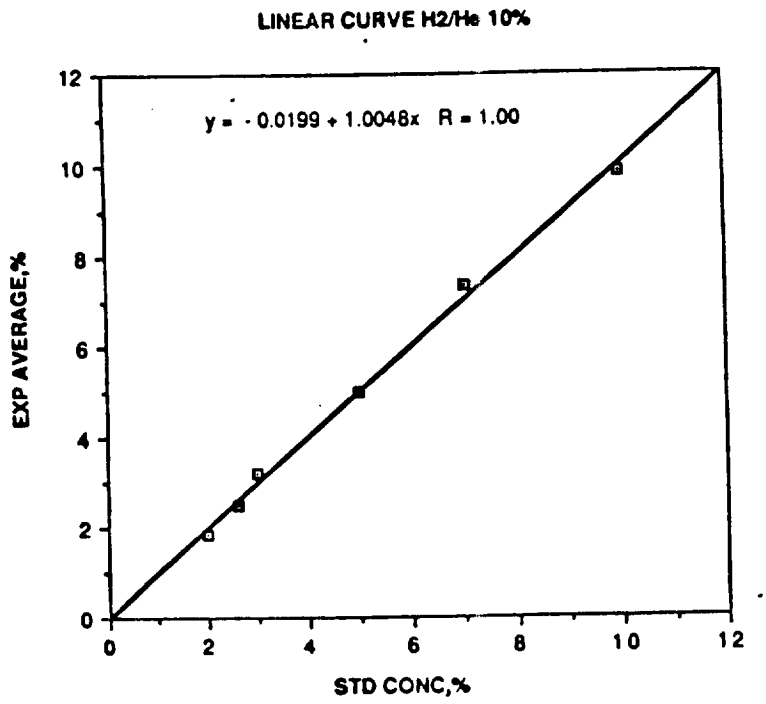


Figure 8A

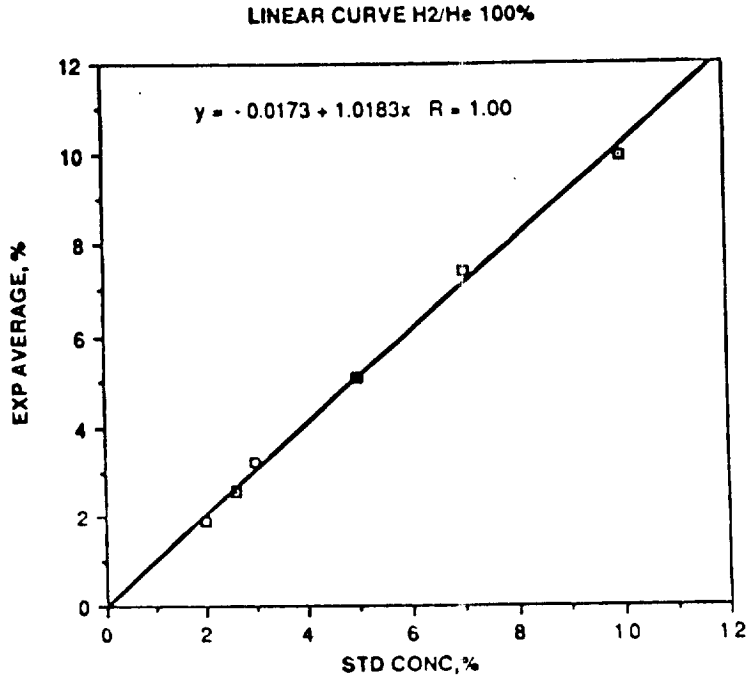


Figure 8B

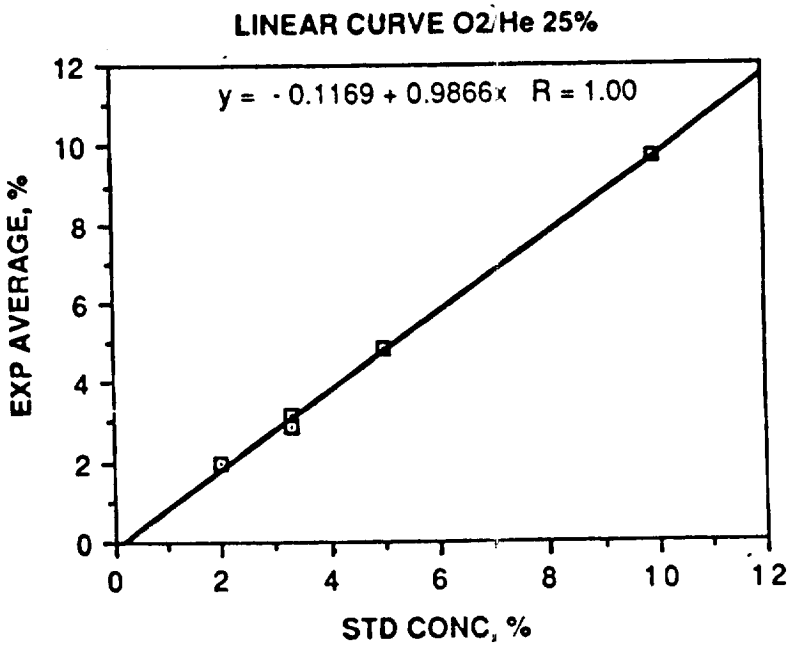


Figure 8C

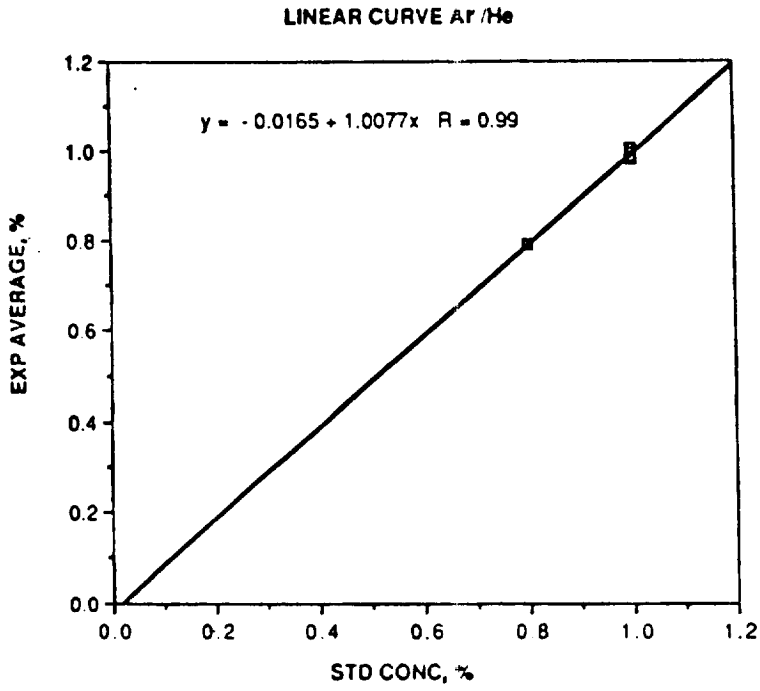


Figure 8D

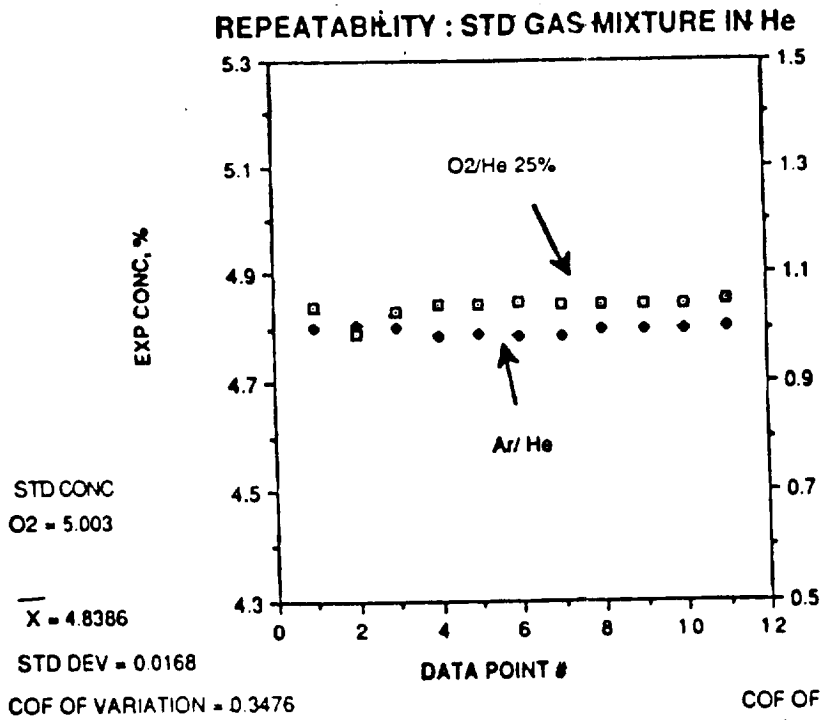


Figure 9A

STD CONC
O2 = 5.003

$\bar{X}$ = 4.8386
STD DEV = 0.0168
COF OF VARIATION = 0.3476

STD CONC
Ar = 1.000

$\bar{X}$ = 0.9956
STD DEV = 0.0077
COF OF VARIATION = 0.7744

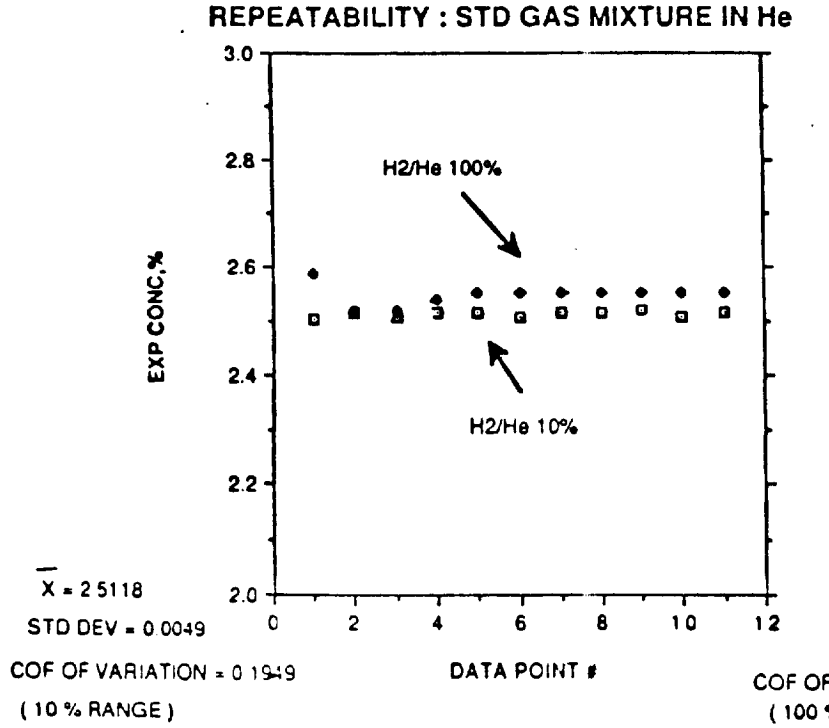


Figure 9B

STD CONC
H2 = 2.600 %

$\bar{X}$ = 2.5118
STD DEV = 0.0049
COF OF VARIATION = 0.1949
(10 % RANGE)

$\bar{X}$ = 2.5473
STD DEV = 0.0185
COF OF VARIATION = 0.7258
(100 % RANGE)

DRIFT STUDY : STD GAS MIXTURE IN N2 WITH BKG CORRECTION

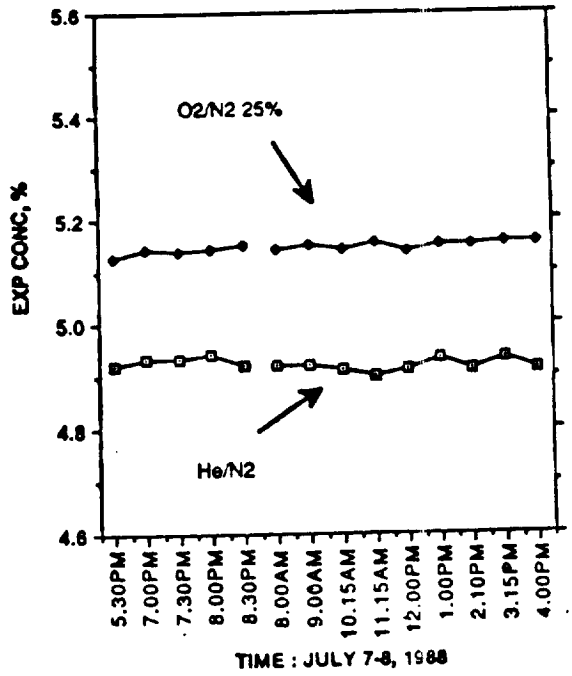


Figure 10A

DRIFT STUDY : STD GAS MIXTURE IN N2 WITH BKG CORRECTION

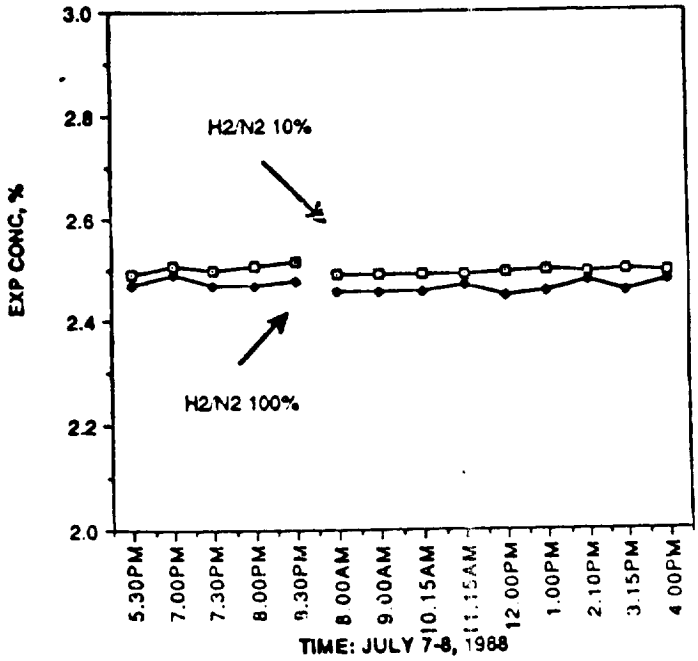


Figure 10B

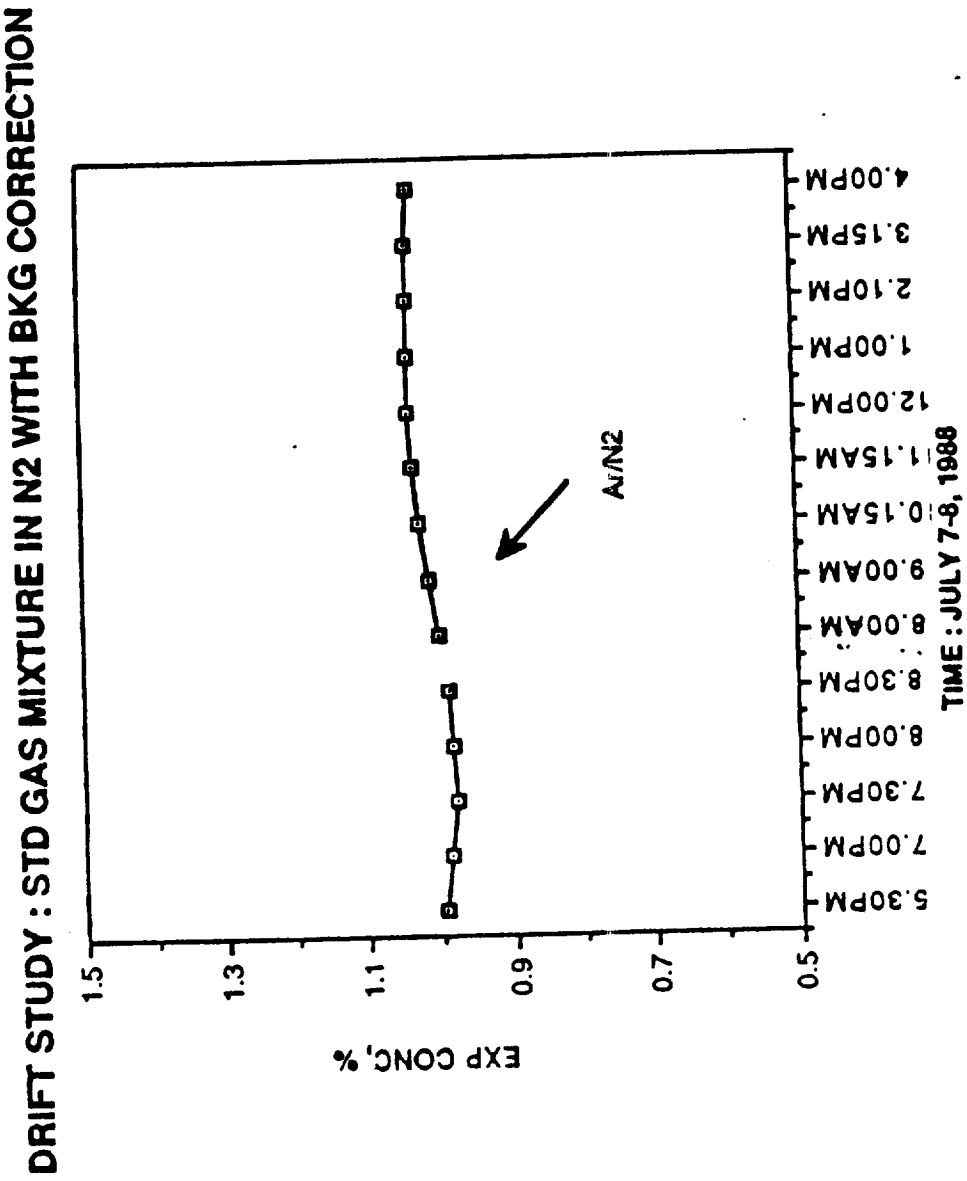

DRIFT STUDY : STD GAS MIXTURE IN N2 WITH BKG CORRECTION
EXP CONC, %
1.5
1.3
1.1
0.9
0.7
0.5
Ar/N2
TIME : JULY 7-8, 1988
5.30PM
7.00PM
7.30PM
8.00PM
8.30PM
8.00AM
9.00AM
10.15AM
11.15AM
12.00PM
1.00PM
2.10PM
3.15PM
4.00PM

Figure 10C

DRIFT STUDY : STD GAS MIXTURE IN He WITH BKG CORRECTION

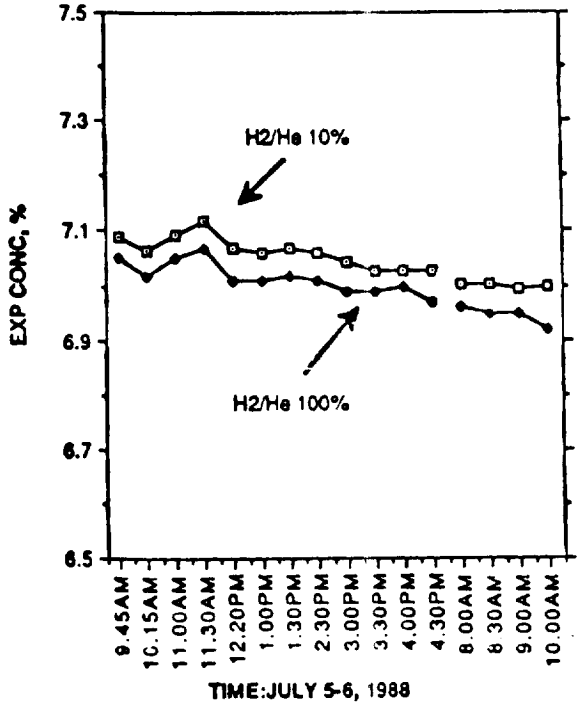


Figure11A

DRIFT STUDY : STD GAS MIXTURE IN He WITH BKG CORRECTION

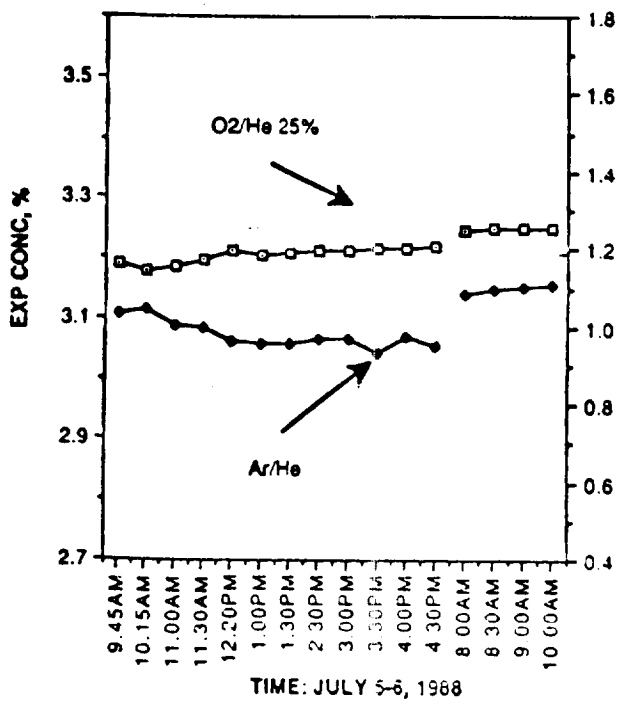


Figure 11B

Figure 12