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THE PERKIN-ELMER CORPORATION
AEROSPACE DIVISION
2855 Metropolitan Place, Pomona, California 91767

FINAL REPORT
UNDERSEA ATMOSPHERIC ANALYZER
VOLUME 6 OF 6
FOR
COMBINED STUDY PROGRAM

By Burd F. Bicksler

March 1971

Perkin-Elmer SPO 30006
NASA Contract Number NAS1-9469

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
Langley Station
Hampton, Virginia 23365

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ABSTRACT

A program was conducted in which an instrument system concept was studied to optimize the application of a mass spectrometer as a sensor for monitoring the primary atmospheric constituents, as well as atmospheric contaminants, on board a manned spacecraft. The program was divided into six individual studies representing the primary system parts complementing the spectrometer: a Carbon Monoxide Accumulator Cell (Volume 1), an Ion Pump (Volume 2), an Ion Pump Power Supply (Volume 3), an Inlet Leak (Volume 4), an Ion Source (Volume 5), and an Undersea Atmospheric Analyzer (Volume 6). The principal goal of the combined study program was the achievement of an instrument concept of minimum power, weight and size without compromising the minimum detection limits of the instrument.

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SUMMARY

This report describes an Undersea Atmospheric Sensor System which has been designed to monitor and display the atmospheric constituents of nitrogen, oxygen, carbon dioxide, water vapor, and argon during at-sea operational deployment of a test vehicle. Data recorded during a five-day sea-trial and during a subsequent 62-day (continuous) sea deployment has indicated unusually stable long-term operation. In addition, data recorded by crew members of the U.S.S. Hammerhead is presented which compares the Perkin-Elmer Undersea Atmospheric Sensor System with other analyzer systems aboard ship - the Mark V and a portable Model D-2 Oxygen Analyzer.

INTRODUCTION

Under the general scope of contract NAS1-9469, the Perkin-Elmer Corporation, Aerospace Division, performed the effort necessary to modify a Government-furnished two gas atmospheric sensor system for use as an Undersea Atmospheric Sensor System. The intent of the experiment was to monitor the atmospheric constituents of nitrogen, oxygen, carbon dioxide, water vapor and argon during operational deployment of a test vehicle. The operation of the Undersea Atmospheric Sensor was to be essentially automatic providing visual display of the atmospheric constituent partial pressures. Trouble free, long term, reliable operation and ease of maintenance were the key system requirements.

During the period 25 September through 3 October, the Undersea Atmospheric Sensor operated continuously under in-use environment conditions, providing continuous output data and maintaining calibration. The results of the five-day sea trial were published in a Perkin-Elmer disclosure "Results of Five-Day Sea Trial on the Undersea Atmospheric Sensor - Uptite" dated October 1970 and submitted to NASA Langley Research Center, NASA contract NAS1-9469, Perkin-Elmer SPO 30006. (Reference: Appendix 1.)

Between 2 October and 6 October Perkin-Elmer personnel performed additional field calibration and final system adjustments in preparation for a long-term, at-sea deployment of the test vehicle with the Undersea Atmospheric Sensor on board. After final calibrations and adjustments, the instrument was operating within 1.0 torr of theoretical values on all channels and within 1.0 torr of the total barometric pressure. The calibration gas sample utilized prior to and at the conclusion of the five-day sea trial was the same sample that was utilized for all subsequent calibrations. The calibration gas sample consisted of 74.8% nitrogen, 20.11% oxygen, 2.13% carbon dioxide, and 3.0% argon. Water vapor calibrations were achieved utilizing relative humidity and temperature at the sample point.

From 1001, 6 October through 0900 6 December, a total of 62 continuous days, the Undersea Atmospheric Sensor System performed without functional interruption or calibration, with the exception of 8 instances, when line power was interrupted intentionally for various drills. During these line power interruptions the Undersea Atmospheric Sensor was inoperative for a total of 110 minutes. Each time line power was restored the system automatically restarted and restabilized.

Between 0900 hours and 1100 hours on 6 December the sample transport pump, a commercially procured auxillary pump utilized to move the air sample to point of analysis, ceased functioning. The non-operating condition of this pump precluded a new air sample from being transported to the analyzer. At-sea repair of the transport pump was not attempted due to impending arrival of the U.S.S. Hammerhead at port.

On 15 December a Perkin-Elmer representative performed replacement of the sample transport pump and calibration of the system. Comparing the Undersea Atmospheric Sensor System output after the sample transport pump had been replaced and the system had stabilized showed that: 1) the nitrogen output was within 4 torr of a standard laboratory air sample; 2) oxygen was within 1.1 torr; 3) argon was within 0.11 torr; and 4) carbon dioxide was within 0.06 torr. The pressure transducer output, utilized as a pressure reference, was within 2.0 torr of the local barometric pressure.

Final system calibration on the calibration gas sample showed that the nitrogen channel was within 6.0 torr of the theoretical 587 torr value and all other channels were within 1.0 torr of their theoretical values.

The Undersea Atmospheric Sensor System was initially calibrated for long term sea deployment such that it was within 0.5% on all channels except argon, a low-level channel, was within 3.0% of the theoretical value. Upon completion of the long term sea deployment of the system, calibration showed that the instrument was within 1% on all channels except for argon, which was within 2.5% of the theoretical value.

Table 1a, 1b, and 1c are copies of the engineering data recorded during the long term sea deployment by members of the U.S.S. Hammerhead's crew. This data was taken periodically for purposes of evaluating the systems internal performance by Perkin-Elmer. Table 1d, 1e, and 1f are copies of engineering data taken by Perkin-Elmer personnel during system calibration at the conclusion of long term sea deployment. The last three lines of data are final system calibration originally recorded in Perkin-Elmer Laboratory Log Book #2599, Page 122.

Table 2a through 2hh are copies of comparison data between the Undersea Atmospheric Sensor System, the Mark V and a portable Model D-2 Oxygen Analyzer. This data was also recorded by U.S.S. Hammerhead crew members.

TABLE 1a.- DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

PERKIN-ELMER
AEROSPACE DIVISION

MASS SPECTROMETER SENSOR DATA FORM #2

Vm= 7.50 Ve = 2.5

SHEET 1 of 3

DATE	TIME	N_2	O_2	CO_2	H_2O	A	Σ_{PP}	T.P. 3	T.P. 4	T.P. 5	T.P. 6	T.P. 7	REMARKS
10/6	1120	593	159.9	1.11	8.9	7.5		131.6	15.8	-136.9	-17.4	38.5	Bd St # 2
10/14	1305	606	150.4	6.59	11.2	7.6		131.6	16.7	-136.9	-18.0	38.5	Bdst #2
10/14	1342	609	150.4	6.76	11.0	7.6		131.6	16.5	-136.9	-17.8	38.4	Board 2
10/14	1355	606	150.5	6.84	8.1	7.5		131.6	16.7	-136.9	-18.0	38.4	–
10/15	1630	588	159.8	.81	10.6	7.3	7665	131.6	16.7	-136.9	-18	38.4	Board #2
10/17	1425	581	147.2	7.07	10.2	7.2	757.7	131.6	16.7	-136.9	-17.9	38.5	" "
10/19	2105	681	153.1	7.57	10.4	7.6	854.7	131.6	16.4	-136.4	-17.6	38.5	" "
10/24	1848	600	1452	6.62	10.1	8.4	770.3	131.6	16.6	-136.8	-17.6	38.6	
11/25	0100	.597	144.0	8.40	10.6	8.3		131.6	16.7	-136.8	-17.9	38 7	
11/5	1015	587	153.3	8.61	~~[illegible]~~ 9.7	7.4	766.0	131.6	16.8	-136.8	-18.0	39.1	
11/17	1400	569	151.5	1.50	7.6	7.0	736.6	131.6	16.8	-136.5	-18.0	39.2	
11/17	1418	599	160.5	1.92	8.0								1415 started Gas sample
11/17	1425	598	160.5	1.91	8.6	Cal gas sample							1438 secured Gas
11/17	1430	598	160.4	1.84	8.9	10% O_2, 1.8% CO_2, 80ppm R-11, 100ppm R-10							
11/17	1435	594	160.4	1.81	9.0	1.5% H_2, BALANCE N_2							Looks stable at this time
11/18	1315	601	158.8	6.10	9.8	7.6	783.3	131.6	16.9	-136.8	-18.1	39.2	
7/28	0115	588	157.1	7.84	9.8	7.4	770.1	131.6	16.5	-136.8	-17.8	39.3	
12/6	0215	601	152.8	5.84	10.9	7.6		131.6	16.9	-136.8	-18.1	39.1	
12/11	2030	594	158.7	0.87	05.0	7.4		131.6	16.5	-136.9	-17.8	39.1	[illegible] TRANSPORT PUMP

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TABLE 1b.- DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

PERKIN-ELMER
AEROSPACE DIVISION

MASS SPECTROMETER SENSOR DATA FORM #2

SHEET 2 OF 3

DATE	TIME	T.P. 8	T.P. 9	T.P. 10	T.P. 11	EMSN DR	ANODE CUR	PRESS	VALVE TEMP	ACCELR CUR	T.P. 17	T.P. 18	REMARKS
10/6	1120	36.1	20.0	18.6	-19.7	13.0	23.6	771	19.2	53.8	—	—	Bd St #2
10/14	13.05	37.6	20.8	19.4	-20.5	13.3	35.1	78.3	19.2	91.5	—	—	Bd st #2
10/14	1347 ~~1355~~	37.4	20.7	19.3	-20.4	13.3	33.8	78.4	19.2	87.8			ION CURRENT LOW 59 μa ~~ADJUSTED LEAK GATE TO~~ 90
10/14	1355	37.7	20.9	19.4	-20.6	12.9	21.0	78.4	19.2	46.6			
10/15	1630	37.8	20.9	19.5	-20.6	13.0	19.9	77.0	19.2	44.2			ION CURRENT 802 Bd St #2
10/17	1425	37.7	20.8	19.4	-20.5	13.0	20.7	78.2	19.1	46.5			set #2
10/19	2105	37.2	20.5	19.1	-20.5	13.0	22.1	77.9	19.1	49.9			
10/24	1848	37.5	20.6	19.3	-20.3	12.9	22.5	768	19.0	50.8			
10/25	0100	37.5	20.6	19.4	-20.4	12.9	23.4	76.2	19.0	53.4			
11/5	10.5	37.6	20.5	19.4	-20.2	13.1	28.6	76.3	18.9	70.4			
11/17	1400	37.4	20.4	19.4	-20.1	13.3	35.1	77.1	19.0	92.3			
11/18	1315	37.6	20.5	19.5	-20.2	13.1	25.0	777	18.9	59.4			
11/27	0115	37.0	20.2	19.2	-19.9	13.3	28.9	764	19.0	72.4			
12/6	0215	37.8	20.8	19.7	-20.5	13.4	17.0	77.4	19.1	44.5			
12/11	2030	37.2	20.4	19.3	-20.2	13.6	28.4	76.4	19.0	52.0			

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TABLE 1c.- DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

PERKIN-ELMER
AEROSPACE DIVISION

MASS SPECTROMETER SENSOR DATA FORM #2

SHEET 3 OF 3

DATE	TIME	T.P. 19	T.P. 20	T.P. 21	T.P. 22	T.P. 23	SAMPLE FLOW	ION PUMP CURRENT	T/C PRESS	REMARKS	DATA READ BY
10/6	1120	—	—	—	—	—	.015	80	←	44%, 74°F	
10/14	1105						.015	80		31.05	J
10/14	1349						.015	59			
10/14	1355						.015	98			
10/15	1630						.015	102		Press 30.38 74°F (771.6)	J
10/17	1425						.015	103		Press 30.84 76°F (783.3)	J
10/19	2105						.015	98		Press 30.63 71°F (778)	J
10/24	1848						.015	100		29.82 @ 1700 (757.4)	
10/25	0100						.015	95		30.16 @ 0200	
11/5	1015						.015	86		29.94 (760.5)	
11/17	1400						.015	91			
11/18	1315						.015	104		Press 30.55 (776)	
11/27	0115						.015	95		30.01 (762)	
12/6	0215						0	155		Fuse F2 Blown Replaced + Keeps	
12/11	0030						0	100		blowing 30.00	

TABLE 1d.- DATA RECORDED BY PERKIN-ELMER PERSONNEL

PERKIN-ELMER
AEROSPACE DIVISION

MASS SPECTROMETER SENSOR DATA FORM #2

SHEET 1 of 3

DATE	TIME	N_2	O_2	CO_2	H_2O	A	Σ_{PP}	T.P. 3	T.P. 4	T.P. 5	T.P. 6	T.P. 7	REMARKS
12-15-70	10:20	602.	160.8	.68	7.6	7.4		131.6	16.3	-136.9	-17.6	+39.0	30.35 [illegible]
12-15	1120	589.	157.2	.82	7.8	7.4		131.6	16.4.	-136.9	-17.7	39.1	SAMPLE TRANSPORT PUMP REPLACED
12-15	1135	601.	161.1	.80	6.9	7.6		131.6	16.4	-136.9	-17.6	39.1	
12-15	1145	600.	161.2	.80	7.3	7.6		131.6	16.4	-136.9	-17.7	39.0	
	1231	600.	161.1	.83	7.8	7.6		131.6	16.3	-136.8	-17.5	39.0	772 [illegible]

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TABLE 1e.- DATA RECORDED BY PERKIN-ELMER PERSONNEL

PERKIN-ELMER
AEROSPACE DIVISION

MASS SPECTROMETER SENSOR DATA FORM #2

SHEET 2 OF 3

DATE	TIME	T.P. 8	T.P. 9	T.P. 10	T.P. 11	EMSN DR	ANODE CUR	PRESS	VALVE TEMP	ACCELR CUR	T.P. 17	T.P. 18	REMARKS
12-15-70	10:20	36.8	20.3	19.1	-20.0	+13.7	31.0	77.3	19.1	83.2	90.7		
12-15	1120	36.9	20.2	19.1	-19.9	13.8	35.1	77.3	19.1	106.2			
12-15	1135	37.0	20.4	19.2	-20.0	13.6	27.6	77.3	19.1	78.1			
12-15	1145	37.0	20.4	19.2	-20.0	13.6	27.6	77.3	19.1	78.2			
	1231	36.7	20.2	19.1	-19.9	13.7	27.9	77.2	19.1	79.2			
	1345	—	—	—	—	13.7	27.7		19.1	78.5	—	—	
SYSTEM SECURED AT 1405. POWER WILL REMAIN ON UNTIL 12/16/70 AM [illegible]													
SYSTEM WILL BE OFF LOADED. R.J. [illegible] 12/15/70													

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TABLE 1f.- DATA RECORDED BY PERKIN-ELMER PERSONNEL

PERKIN-ELMER
AEROSPACE DIVISION

MASS SPECTROMETER SENSOR DATA FORM #2

SHEET 3 OF 3

DATE	TIME	T.P. 19	T.P. 20	T.P. 21	T.P. 22	T.P. 23	SAMPLE FLOW	ION PUMP CURRENT	T/C PRESS	REMARKS	DATA READ BY
12-15-70	10:20						0	92 μa			
12-15	1120						0.15	83 μa		reset inlet leak valve 101 μa I.P.C	
12-15	1135						0.15	103 μa			
12-15	1135						0.15	105 μa			
	1231						0.15	101 μa			
	~~13~~	—	—	—	—	—	0.15	109 μa		Cal on PE Mix 94.8% N_2 20.11% C_2 2.5% CO_2	

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TABLE 2a.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL				
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	COM	SEC
12OCT	2230					167	6	-8	.1	25	1	155	CO_2 .8						
13OCT	0000					167	12	.95	.1	22	1	155	-8						
13OCT	0400					167	7	.99	.05	18	3	155							
13OCT	0700					166	4	-72	.02	20	1			31.2					
13OCT	0810					165	8	-92	.1	18.5	9			29.42					
13OCT	1500					166	5	-85	-1	12	4			30.27					
13OCT	1600					167	3	1.0	-1	37	8			31.00					
13OCT	1700					167	3	1.0	.1	20	8			31.05					
13OCT	1800	152.8	8.74	616	11.5			—				146	—		–				
13OCT	2000	143.6	9.69	585	11.8	159	4	1.3	-1	25	4	138		30.05					
13OCT	2200	156.2	5.14	603	11.2							148							
14OCT	0000	154.2	8.35	614	11.0	171	3	1.1	-1	20	4	155 ~~148~~		31.52					
14OCT	0200	153.3	10.16	620	10.9							146							
14OCT	0400	150.5	10.57	611	10.7	168	3	1.42	.1	10	8	146		31.64					
14OCT	0600	145.6	10.77	598	11.1							145 ~~145~~							
14OCT	0800	145.3	9.88	602	11.1	168	8	.92	.1	18.5	9	140		27.42					

TABLE 2b.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK Ⅴ						PORTABLE			ATM CONTROL				
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	CCM	SEC
14OCT	1000	152.4	5.36	597	11.1							146							
14OCT	1200	151	6.43	604	11.1	165	5	.85	.1	9	8	145		31.05					
14OCT	1400	150.5	6.85	606	8.5							145							
14OCT	1600	142.9	6.78	582	11.5	158	5	.97	.1	9.5	3	143		30.01					
14OCT	1800	143.6	7.24	590	11.2	157	3	.97	.1	12	8	138		29.88					
14OCT	2000	~~157~~ 144.4	7.71	600	11.7	157	5	1.0	.45	20	5	139		30.38					
14OCT	2200	150	4.5	580	10.7							145							
15OCT	0000	146	5.43	577	11.5	161	3	.7	.19	37	1	147		29.42					
15OCT	0200																		
15OCT	0400	144.4	8.25	584	10.1	160	6	~~1.42~~ 1.15	.1	24	3	146		29.87					
15OCT	0600	144.2	8.49	588	10.2							144							
15OCT	0800	145.3	8.00	595	10.3	160	6	1.8	.1	28	5	144		31.08					
15OCT	1000	148.6	4.75	593	11.1							151							
15OCT	1300	158.1	1.24	586	10.7	165	6	[illegible] .6	.1	<10	5	160		30.36					
15OCT	1400	155.9	.86%	586	10.8							162							
15OCT	1600	159.1	.75%	586	10.5	~~158~~ 175	3	[illegible] .1	.1	100	8	162		30.35					

TABLE 2c.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL				
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	COM	SEC
15OCT	1800 ~~2000~~	152.1	2.34	569	10.8							153		29.46					
15OCT	2000	151.6	4.11	575	10.3	168	17	.5	.1	24	4	153		29.70					
15OCT	2200	151	5.70	580	9.9							153							
16OCT	0000	157	3.63	592	10.3	172	3	.5	.1	11	5	161		31.00					
16OCT	0200	156.7	5.12	591	9.9							160							
16OCT	0400	156.4	6.49	608	9.7	172	8	.85	.02	11	3	160		31.52					
16OCT	0600	153.4	7.99	600	9.8							158							
16OCT	0800	146.6	7.79	582 ~~597~~	10.5	162	8	1.1	.1	38	2	149		29.88					
16OCT	1000	146.2	8.53	597 ~~587~~	11.0							147							
16OCT	1200	156.5	2.68	587 ~~594~~	11.2	0	3	0	.5	3	5	158		30.43					
16OCT	1400	157.2	3.31	574 ~~603~~	10.4							158							
16OCT	1600	156.2	5.63	602 ~~616~~	10.0	173	6	.8	.15	20	6	158		30.97					
16OCT	1800	156.5	7.19	610 ~~605~~	9.8							156							
16OCT	2000	153.8	7.15	605	10.6	172	7	1.2	.14	11	3	154 ~~146~~		31.90					
16OCT	2200	144.9	6.86	576	10.9							146 ~~160~~							
17OCT	0000	147	5.86	593	10.5	160	8	.8	.1	43	5	160		30.29					

TABLE 2d.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL				
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	COM	SEC
17 OCT	0200	160	2.78	600	10.1							157.8	TR						
	0400	160	3.88	607	9.8	173	8	.5	.1	38	11	157	TR	31.18					
	0600	151	5.29	583	9.7							148.7	UL OPS						
	0800	151	6.83	590	9.6	166	12	.85	.1	22	8	148.5	UL OPS	30.19					
	1000	152	7.8	593	9.7							147.7	UL OPS						
	1200	155	5.18	597	9.9	173	3	.72	.13	37	5	154.3	TR						
	1400	151	6.93	585	10.0							148.6	TR						
	1600	146	8.07	586	10.1	165	5	1.18	.1	11	3	147.3	TR	30.05					
	1800	145	8.43	592	10.1							147.2	TR						
	2000	151	2.96	595	10.8	175	0	.38	.1	39	13	157.5	TR	30.68					
	2200	151	6.35	603	9.8							154.8	TR						
18 OCT	0000	158	8.14	615	10.3	173	10	1.2	.1	28	4	155.2	UL OPS	31.27					
	0100	161	3.52	607	9.9	175	3	.35	.1	43	3	160.6	UL OPS	31.26					
	0200	154	5.0	587	10.2							153.2	UL OPS						
	0400	154	7.10	595	10.0	171	12	1.0	.1	31	4	152.6	UL OPS	30.56					
	0600	151	7.54	598	10.1							152.2	TR	30.73					

TABLE 2e.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL				
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	COM	SEC
18 OCT	0800	151	7.51	606	10.1							152.3	TR	31.06					
	1000	151	7.37	613	10.0							152.7	TR	31.34					
	1200	151	2.83	572	9.8							150.9	TR	29.45					
	1400	150	5.43	587	10.5							150.6	TR	29.92					
	1600	151	6.91	600	10.1	170	6	1.07	.1	17	8	152.6	TR	30.55					
	1800	151	7.68	606	9.7							151.9	UL OPS	30.76					
	1925	154.7	4.22	596	10.0							156	UL OPS						
	2000	158.4	2.84	600	10.2	175	0	.45	.1	12	1	158	UL OPS	30.56					
	2200	152.8	6.06	595	9.9							154	UL OPS						
19 OCT	0000	148.6	7.27	586	10.3	165	8	1.08	.1	9		150	TR	29.85					
	0200	158.9	3.00	599	10.0							160	TR	30.65					
	0400	156.6	6.31	607	10.1	175	5.5	.99	.1	26	1	158	TR	31.01					
	0600	156.0	7.98	613	10.1							158	TR						
	0800	155.6	9.36	618	10.1	175	5.9	1.5	.1	20	3	156	TR	31.45					
	1000	149.0	7.84	599	10.7							155	TR						
	1200	156.5	4.97	603	10.4	175	3	1.2	.1	20	3	157	UL OPS	30.78					

TABLE 2f.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL					
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	COM	SEC
19 OCT	1400	150.6	5.97	589	10.5							152	UL OPS						
	1600	158	1.68	590	12.3	180	0	.25	.1	17	8	157	UL OPS	31.00					
	1800	154.4	4.62	592	10.5							156	TR	30.25					
	2000	153.3	7.08	600	10.2	190	9	1.1	.1	8	.5	152	TR	30.58					
	2230	154.2	5.74	597	10.1							155	TR	30.42					
20 OCT	0000	147.6	5.49	569	10.4	145	9	.89	.15	8	.8	141	TR	29.60					
	0200	147.1	7.03	576	10.1							142	TR						
	0400	146.9	8.54	582	9.8	150	3	1.4	.05	40	3	150	TR	29.62					
	0600	146.5	8.83	588	9.9			—				147	UL OPS						
	0800	145.7	8.40	592	9.8	150	6	1.3	.1	15	3	147	UL OPS	29.91					
	1025	146.2	6.35	598	10.5							153	UL OPS						
	1200	154.4	4.06	598	09.9	155	5.5	.6	.12	9	13	156	TR	30.40					
	1400	152.8	6.62	605	09.7							154	TR	30.69					
	1650	152.6	4.31	587	10.1	145	3	.62	.02	13	8	154	TR	29.91					
	1800	159.1	2.55	599	9.9							147	TR	30.58					

TABLE 2g.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
20 OCT	2000	160.6	.63% 4.40	613	9.8	165	8	.8	.1	40	11	155	TUNEL HATCH	31.26		X			0		
20 OCT	2200	161.4	.8% 6.39	624	9.5							164	UL OPS	31.11		X			0		
2[illegible] OCT	0100	150.2	7.99	590	9.8	158	12	1.3	.1	23	4	152	UL OPS	30.0					0	0100	0134
21 OCT	0200	155.7	3.34	589	9.4							154	UL OPS	30.03					0		
21 OCT	0400	156.2	6.9	607	9.8	155	8	1.1	.1	22	3	158	UL OPS	30.88		X			0		
21 Oct	0600	153.8	8.13	604	9.7	155	8	1.34	.12	23	3	155	UL OPS	30.58		X			0		
21 OCT	0800	147.6	9.65	588	9.8							150		29.91		X	X	X	0		
21 OCT	1000	147.6	8.71	594	9.8	148	12	1.48	.16	38	3	148	UL OPS	30.11		X	N	X	0		
21 OCT	1200	145	8.49	590	9.6							146	UL OPS	29.26					0	1200	1240
~~21 OCT~~	~~1400~~	~~151~~	~~.78~~			~~151~~	~~.78~~														
21 OCT	1400	147.1	4.57	569	9.8	151	3	.78	.12	12	5	149	UL OPS	28.96		X				SNRKEL 1310	1435
21 Oct	1600	1541	3.01	590	9.3	157	2.5	.53	.1	7	1	158	UL OPS	30.09		X					
21 Oct	~~1605~~ 18[illegible]																				
21 OCT	1800	154.5	6.58	602	9.6	[illegible]						152	UL OPS	30.6	X				0		
21 OCT	2000	152.7	7.15	599	9.6	190	6	1.2	.1	10	1	149	UL OPS	30.6	X				0		
21 OCT	2200	148.1	5.86	587	9.9							148	UL OPS	30.4	X				0	GLS 2225 2240	2318

TABLE 2h.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL					
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	COM	SEC	
22OCT	0000	154.5	3.20	588	9.5	157	3	.43	.1	28	1	156	UL OPS	29.96	X X		0			M
22OCT	0200	153.0	6.01	597	9.5								UL OPS	30.30	X		0			M
22OCT	0400	153.2	6.37	605	9.6	155	10	.99	.14	10	4	155	UL OPS	30.60	X	X	0			M
22OCT	0600	144.2	5.03	577	9.8							139	UL OPS	29.15	X	X	0			
22OCT	0800	144.3	4.76	585	7.9	143	11	.72	.1	11	6	139	UL OPS	29.47	X	X X	0			
"	1000	146.3	4.85	603	9.8							140	UL OPS	30.26	X	X X	0			
22OCT	1200	147.8	5.00	606	9.9	152	17	.8.	.1	11	5	143	UL OPS	30.4	X	X	0	1215 SURFACED		
20OCT	1400	155.1	1.59	581	9.5										X		0	SUBMERGED		G
20OCT	1600	157.0	3.52	600	9.4	162.	10	.8 ~~.06~~	.1	24	8	150.	UL OPS	30.1	X		0	1605		
22 OCT	1800	156.7	5.18	607	9.5							150	UL OPS	30.86	X		0			G
22OCT	2000	155.7	5.64	611	9.6	156	11	.92	.1	11	3	150	UL OPS	30.63	X	X X	0			M
22OCT	2200	153.7	5.99	610	9.6	~~152~~	~~11~~	~~1.29~~	~~.1~~	~~11~~	~~4~~	149	UL OPS	30.82	X	X X	0	Air Charge		M
23OCT	0000	148.8	7.49	597	9.6	152	11	1.29	.1	11	4	143	UL OPS	30.20	X	X X	0			
23OCT	0200	149.6	9.08	607	9.5			1				150	UL OPS	30.62						
23OCT	0400	151.0	8.94	615	9.5	154	11	1.54	.1	10	8	145	UL OPS	30.60	X					
23OCT	0600	152.1	7.49	620	9.7							146	UL OPS	30.6	X	X X	0			

TABLE 2i.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
23OCT	0800	153.5	6.11	596	9.6	156	15	1.02	.1	12	13	146	UL OBS.	30.33	X		X	X	110 AFT		
23OCT	1000	154.4	5.40	601	9.9							148	UL OPS	30.33	X		X		110 AFT	BEING REDUCED TO 100	
23OCT	1800	150.1	.58 6.62	593	9.4	150	11	1.12	.15	28	4	145	UL OPS	30.60	X		X				
23OCT	2000	151.2	5.54	602	9.2							145	UL OPS	30.37							
23OCT	0300	153.5 ~~155~~	6.93	613	9.3	155	14	1.2	.15	36	8	155		31.05		X		X	AFT 50		
24OCT	0600	147.1	7.25	595	10.9	~~150~~	~~15~~	~~1.1~~	[illegible] ~~.1~~	20	~~1~~	146	UL OBS	31.05		X		X	AFT 50		
24OCT	0800	147.7	6.36	602	10.3	150	15	1.1	.1	20	1	142	UL OPS	30.34	X	X	X		50 AFT		
24OCT	1000	148.1	5.32	608	10.1							142	UL OPS	30.56	X	X	X	X	50 AFT		
24OCT	1200	145.0	.65 5.66	611	10.3	152	11 ~~.07~~	.59	.1	11	6	142	UL OPS	30.68	X		X				
24OCT	1700	143.8	6.13	594	10.2	155	10	1.1	.15	12	10	145	UL OPS	29.82	X		X		150 AFT		
24OCT	2200	147.5 ~~156~~	7.94 ~~1.48~~	609	10.3	150	11 ~~1.48~~	1.48	.15	12	28	148	UL OPS	30.68	X				AFT 130		
25OCT	0000	149.4	8.80	617	10.1	153	15	2.4	.1	24	18	144	UL OPS	31.10	X			X	AFT 130		
25OCT	0200	145.4	7.66	598	44.3							138	UL OPS	30.16	X		X	X	AFT 130		
25OCT	0400	142.2	6.50	582	46.5	143	12	1.12	.1	.8	0	140	UL OPS	29.82	X		X	X	AFT 150		
25OCT	0715	147.3	5.78	595	49.0	145	15	.91	.1	24	4	146	UL OPS	30.00							
25OCT	1100	150.3	.82 6.16	606	48.9	154	11	1.1	.1	40	6	145	UL OPS	30.50	X		X	X			

SWITCH IN WRONG POSITION

M

TABLE 2j.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

TEST SWITCH LEFT IN TP-16 POSITION BY MISTAKE

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
~~25 OCT.~~	~~1200~~	mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	CCM	SEC
25 OCT.	1200	151.4	6.07	612	48.8	154	11	1.1	.10	20	18	147	UL OPS	30.86	X		X	X	AFT 120		
25 OCT.	1400	146.0	4.95	590	49.3							145	UL OPS	29.72	X		X	X	AFT 120		
25 OCT.	1600	147.0	4.71	594	48.7	150	12	.83	.10	23	4	145	UL OPS	29.90	X			X	AFT 120		
25 OCT	1800	148.8	5.30	600	49.2							140	UL OPS	30.28	X			X	AFT 120		
25 OCT	2000	149.8	6.07	605	49.3	153	10	1.1	.15	12	8	141	UL OPS	30.54	X			X	AFT 120		
25 OCT	2200	146.2	7.11	583	49.3	[illegible]						138	UL OPS	29.60	X		X	X	AFT 120		
26 OCT	0000	146.5	94 7.52	586	50.1	190	13	1.38	.1	10	24	141	UL OPS	29.67	X		X	X	AFT 120		
26 OCT	0400	149.3	5.63	597	51.1	155	13	1	.15	8	9	151	UL OPS	30.20	X		X	X	AFT 20		
26 OCT.	0600	150.1	5.46	602	50.2			—				146	UL OPS	30.40	X				AFT 100		
26 OCT.	0800	151.9	6.70	610	50.6	155	14	1.2	.10	18	19	150	UL OPS	30.83	X		X		AFT 100		
26 OCT.	1000	145.2	6.43	586	50.3							142	UL OPS	29.60	X		X		AFT 100		
2600	1200	147.5	6.50	593	6 50.9	300 70	125	2.85	.9 ~~.15~~	120	200	142	UL OPS	30.00	X		X	X	AFT 150		
2600	1400	149.4	5.77	599	51.0							145	UL OPS	30.09	X		X	X	AFT 150		
2600	1600	150.8	5.86	605	50.5	155	12	1	.1	15	11	145	UL OPS	30.56	X		X		AFT 60		
26 OCT	1517.9 ~~1700~~	151.9 ~~145~~	8 5.09	613	51.0	300 190	12	.9	.15	20	4	145	UL OPS	30.85	X		X				
26 OCT	1900	152	5.01	615	51.4	155	12	.85	.1	18	4	152	TR	30.94	X		X		AFT 60		

TABLE 2k.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
27 OCT.	0200	146.9	9.46	605	51.6	150	15	1.78	.15	㉑	52	145	UL OPS	30.44	X				AFT 60		
27 OCT.	0400	147.9	9.60	610	52.4							146	UL OPS	30.69	X		X		AFT 120		
27 OCT	0600	150.3	9.64	617	52.6							145		31.08					FWD 130		
27 OCT	0800	145.2	8.55	590	52.0	149	12	1.6	.1	㉛	34	138	UL OPS	29.78	X		X	X	FWD 130		
27 OCT	1000	149.2	7.55	597	52.0	AC						142	UL OPS	30.12	X		X	X	AFT 100		
27 OCT	1400	144	6.11	580	52.0	PEG	15	1.1	.1	⑳	13	144	UL OPS	29.27	X		X	X	AFT 130		
27 OCT	1520	145.5	5.85	587	52.1	150	9	1.	.1	㉓	8	141 ~~139~~	UL OPS	29.54	X		X	Λ			
27 OCT.	1800	147.2	6.87	594	52.4	148	9	1.20	.10	10	12			29.94	X		X		AFT 130		
27 OCT.	2000	148.7	7.94	600	53.1			—	π				—	30.30	X		X		AFT 130		
27 OCT.	2200	151.2	7.46	605	52.9	152	13	1.28	.10	33	15			30.56	X		X	X	AFT 130		
28 OCT	0000	152.8	6.73	610	53.1	158	15	1.2	.25	15	15			30.82	X	X	X	·	AFT 130		
28 OCT	0200	154.6	6.3	617	53.3							158	UL OPS	30.16	X	X	X		AFT 130		
28 OCT	0400	146.9	5.68	587	52.8	150	15	1	.1	25	15	150	UL OPS	29.60	X		X	X	AFT 110		
28 OCT	0600	148.3	5.57	593	52.8							152	UL OPS	29.95	X		X	X	AFT 110		
~~28 OCT~~	0800	151.5	.8 6.16	606	530	155	15	1.1	.1	⑳	6	155	UL OPS	30.66	X		X	X	AFT 110		
28 OCT.	1200	153.7	7.4	614	532	155	15	1.31	.10	10	37	163	UL OPS	31.08	X		X		AFT 100		

TABLE 2l.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
~~28OCT.~~	~~1400~~	mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
28OCT.	1400	148.	7.83	592	54.7							160	UL OPS	29.94	X		X		AFT 110		
28OCT.	1600	149.1	8.23	596	54.7	155	15	1.51	.10	10	62	160	UL OPS	30.18	X		X		AFT 110		
28OCT	1800	150.3	7.30	602	551							155	UL OPS	30.55	X		X		AFT 110		
28OCT	2000	150.8	6.69	606	55.3	155	15	1.2	.10	10	19	155	UL OPS	30.60	X		X		AFT 110		
28OCT	2200	152.6	6.22	611	55.2							155	UL OPS	30.83	x		x		AFT 110		
29 OCT	0130	145.4	5.56	587	54.8	150	15	1	.1	28	10	148	ULCR	29.58	X		X	X	100		
29OCT	0600	148.2	6.7	599	55.7	69 ~~157~~						152	UL OPS	29.76	Y		X	X	120 AFT		
29OCT	0800	150.4	7.28	608	56.0	151	13	1.3	.1	22	19	153	UL OPS	30.69					120 AFT		
29OCT	1000	144.0	7.36	582	55.8							143	UL OPS.		X		X	X	140 AFT		
29OCT	1200	146.1	8.20	590	56.5							150	UL OPS	29.80	x		Λ	x	140 AFT		
29OCT	1530	152.9	4.09	593	55.7	155	8	.68	.1	28	8	156	UL OPS	30.06	X		V	X	142 AFT		
29OCT	2230	156.1	3.09	589	56.2	165	8	.5	.1	30	4	165	UL OPS	29.98							
30OCT	2400	155.8	4.37	593	59.2	160	11	.8	.13	26	1	158	UL OPS	30.11			X		100 AFT		
30OCT	0200	155.2	5.78	592	57.0							158	UL OPS	30.11			X		100 AFT	[illegible] 0156	
30OCT	0400	156.6	3.62	589	56.8	160	8	.62	.1	22	6	160	UL OPS.	30.11			X		100 AFT		022
30 oct	0600	152.2	4.75	574	56.9							155	UL OPS	29.25			V		100 AFT		

TABLE 2m.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL					
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO	H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in				CFH	COM	SEC
30 OCT	0800	155	6.8	588	56.9	160	11	1.25	.12	21	34	135	UL OPS	30.04	X			AFT 100		
30 OCT.	1000	152.2	9.0	568	58.5							155	UL OPS		X			AFT 100		
30 OCT	1900	151.2	11.67	589	58.2	152	11	2.1	.1	10	13	153	UL OPS	30.08	X	X	X	AFT 90		
30 OCT.	2200	147.5	7.90	578	58.4	150	11	1.41	.10	22	28	156	UL OPS	29.30	X	X	X	AFT 100		
31 Oct.	0000	153.3	7.03	599	58.5	165	11	1.25	.1	22	26	154	UL OPS	30.32	/	Y	/	AFT 100		
31 OCT	0400	149.0	5.33	583	58.2	153	11	.95	.1	10	3	153	UL OPS	29.46	Y	Y	Y	AFT 120		
31 OCT	0600	150.9	(.7) 5.43	590	58.7	152	9	1.0	.1	21	11	154	UL OPS	29.85	X	X	X	AFT 120		
31 OCT	1200	153.7	5.42	590	58.8	152	6	1.08	.1	9	7	156	UL OPS	29.89	[illegible]		[illegible]	0		
31 OCT	1400	156.6	.35 2.51	589	59.0							165	UL OPS	29.95	X			40 AFT		
31 OCT	1600	158.0	3.58 3.99	598	59.1	SEE 190	6	.7	.1	24	8	165	UL OPS	29.89	X			100 AFT		
31 OCT	1800	158.3	5.56	604	59.8							165	UL OPS	30.70	X			100 AFT		
31 OCT	2000	160.1	6.56	611	59.6	ODC 192	8	1.2	.1	24	24	165	UL OPS	31.04	X			AFT 100		
31 Oct	2200	160.9	8.06	615	59.7	~~ODC~~						164	UL OPS	31.30	X			AFT 100		
1 Nov	0100	163.0	8.00	625	60.1	PEG	8	1.98	.13	40	63	165	UL OPS	31.10	X	X	X	AFT 100		
1 NOV	0400	156.6	6.71	604	60.4	160	12	1.20	.1	12	22	160	UL OPS	30.60	X	X	X	AFT 100		
1 NOV	1200	154.2	6.63	594	61.5	165	12	1.2	.1	10	24	158	UL OPS	30.20	X	X		AFT 100		

TABLE 2n.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

NOTE: TEST SWITCH LEFT IN ~~[illegible]~~ TP 16. BY MISTAKE

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO	H_2	CO_2	BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in				CFH	COM	SEC	
1 NOV	1600	155.4	4.50	593	61.7	160	8	.8	.02	26	18	159	UL OPS	30.20	X	X		AFT 100			
1 NOV	2000	153.8	7.69	591	62.0							157	UL OPS	30.10							
1 NOV	2325	152.6	9.75	594	61.8							156	UL OPS	30.25							
1 NOV.	2400	152.5	10.11	597	62.1	CALIBRATION 70	113	2.3	.25	112	160	158	UL OPS	30.15	X		X	Ø			
2 NOV.	0200	152.5	7.73	604	62.0							100 ~~150~~	UL OPS ~~[illegible]~~	30.15	X	X	X	Ø			M
2 NOV.	0400	152.4	.84 6.20	609	61.9							160	UL OPS	30.26		X	X	Ø			N
2 NOV	0600	145.6	5.80	584	62.5							160	UL OPS	29.42	X	X	X	Ø			
2 NOV	0600	147.2	5.92	592	62.4	147	11	1.8	.1	20	8	150	UL OPS	29.83	X	X	X	0			M
2 NOV	1000	147.5	6.64	598	62.8			—				150	UL OPS	30.18	X	X	X	0			
2 NOV	1400	144.0	.18% 5.58	585	62.8	154	8	1%	.18	38	0	148	UL OPS	29.43	X	X	X	AFT 130			
2 NOV.	1800	145.2	5.95	582	62.7							152	UL OPS	29.34	X	X		AFT 120			
2 NOV.	2000	146.4	6.52	588	63.7	142	12	1.2	.1	10	6	154	UL OPS.	28.98	X	X		AFT 150			G
3 NOV	0000	155.7	1.67	584	62.4	150	3	.3	.1	9	5	158	UL OPS	29.18	X			AFT 120			
3 NOV	0200	155.9	4.35	593	63.7	...						159	UL OPS	30.19	X			AFT 100			
3 NOV	0400	157	6.16	594	63.6	190	5	1.12	.12	27	8	160	UL OPS	30.52	X			AFT 100			
3 NOV	0800	158.2	.45% 6.72	605	64.0	~~148~~	~~2~~	~~.8~~	~~.1~~	~~27~~	~~3~~	162	UL OPS	30.80							

TABLE 2o.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

NOTE TEST SWITCH LEFT IN TP-16 BY MISTAKE.

		MASS	SPEC			MK V						PORTABLE			ATM			CONTROL			
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO		CO_2		BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in	H_2				CFH	COM	SEC	
NOV 3	0930	148	4.44	559	63.7	148	2	.8	.1	27	3	153	UL OPS	28.48	X	X			AFT 120			
NOV 3	1230	149.6	10.52	570	64.4	152	3	1.2	.1	10	3	155	ULO OPS	28.75	X	X			AFT 120			M
NOV. 3	1600	148.7	9.19	568	61.7	150	3	1.19	.15	40	16	156	UL OPS.	29.03	X	X			120 AFT			
3 NOV	1840	154.1	4.18	582	64.2	155	3	.81	.1	15	1	157	UL OPS	29.64		X	X	l	6			
3 NOV	2000	153.3	6.28	588	65.2	155	8	1.2	.1	18	8	157	UL OPS	29.90		X			0			
3 Nov.		145.6	8.06	571	65.3	145 ~~7110~~	8.5	1.48	.1	12	4	157	UL OPS	29.0	[illegible]	X	X					
4 NOV.	0800	151	5.63	589	65.5	OOC 190	8	1.01	.1	20	11	158	UL OPS.	29.80		X	X	X	130 AFT			
4 NOV	1200	1425	6.06	574	65.9	160	8	1.1	.1	9	3	150	UL OPS	29.08		X	X		130 AFT			M
4 NOV	1400	146.8	6.69	574	66.6							151	UL OPS	29.37		l	l		130 AFT			
4 NOV	1600	151	7.03	586	65.9	148	8	1.25	.1	20	15	154	UL OPS	29.76		l	X		130 AFT			M
4 NOV	2200	153.7	3.35	582	66.0	155	2	.6	.15	10	3	157	UL OPS	29.66								
4 NOV	2400	152.9	5.19	584	66.1	152	8	1.	.1	42	8	160	UL OPS	29.74		X			110 AFT			
5 NOV.	0200	152.6	5.96	580	66.1							160	UL OPS	29.70								
5 NOV.	0400	152.5	(1.025) 7.43	584	66.5	152	8	1.3	.1	24	32	160	UL OPS	29.70		X		X	110 AFT			
5 NOV	0600	147.2	6.95	562	66.0	150	8	1.28	.32	30	24	154	UL OPS	28.88		X			110 AFT			
5 NOV	0800	152.5	7.4	583	66.7							155	UL OPS	29.75		X			110 AFT			

TABLE 2p.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO	H_2	CO_2		BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC	
5 NOV	1000	153.2	8.47	587	106.8	151	11	1.5	.9	11	50	156	UL OPS	29.94		X	X		110 AFT			
5 NOV	1200	153.1	9.20	590	9.7							156	UL OPS	30.08								
5 NOV	1600	153.3	7.32	584	9.6	150	8	1.35	.7	38	18	157	UL OPS	29.76	X		X	X	120 AFT			
5 NOV	1800	155.1	(1.1) 7.91	592	9.7							160	UL OPS	29.65	X	X	X		120 AFT			
5 NOV.	2000	156.2	(1.13) 8.26	599	9.9	153	6	1.42	.8	16	13	160	UL OPS	29.76	X		X	X	130 AFT			
5 NOV.	2200	158.1	(1.0) 7.25	605	9.9							162	UL OPS	29.68	X		X	X	110 AFT			
6 NOV	0000	159.5	6.39	610	10.2	157	8	1.19	1.14	28	13	162	UL OPS	3100	X		X	X	110 AFT			M
6 NOV	0230	1536	5.71	569	9.9							158	UL OPS	29.94	X		X	X	110 AFT			
6 NOV	0400	154.7	6.44	593	9.9	150	8	1.19	.1	20	13	156	UL OPS	30.20	X		X		106 AFT			M
6 NOV	0600	155.6	187 7.26	594	9.4	155	4	1.28	1.8	28	22	160	UL OPS	30.50	X		X		100 AFT			
6 NOV	0800	157	7.95	608	10.1	~~15~~	~~12~~	~~1.30~~	~~1.~~	~~20~~	~~13~~	160	UL OPS	30.96	X	X	X		AFT 110			
6 NOV	1000	151.1	7.40	589	11.1	150	12	1.30	1.35	20	13	159	UL OPS	29.96	X	X	X		AFT 125			
6 NOV	1200	150.9	7.28	591	10.5	190	1.5	1.29	1.65	10	18	160	UL OPS	30.00	X		X	X	AFT 125			
6 NOV	1600	158.1	(.85) 6.29	612	10.1	155	13	1.1	2.25	4	11	105	UL OPS	30.04	X		X	X	AFT 125	[illegible] 1101		1)
~~6 NOV~~	~~1800~~														~~X~~		~~X~~	~~X~~	~~AFT~~ 125			
6 NOV	1800	152.6	5.68	590	10.1	140	12	~~1.08~~ 1.01	1.6	11	10	155	UL OPS	29.97	X		X		AFT 110			M

TABLE 2q.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL							
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	O H_2		CO_2		BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC	
6 Nov	2000	154.4	6.85	598	7.9							157	UL OPS	30.41	X		/		110 AFT			
6 Nov	2200	155.6	7.37	603	7.7	145	12	1.25	1.5	23	43	158	UL OPS	30.67	X		X	X	110 AFT			
7 Nov	0000	157.2	7.59% 6.65	610	10.2							162	UL OPS	31.00								
7 Nov	0200	158	6.28	614	10.1	145	11	1.08	1.9	20	34	162	OPS UL	31.12	X	[illegible]	X	X	110 AFT			
7 Nov	0400	150.9	6.57	586	10.0	f						154	UL OPS	29.67								
7 Nov	0600	150.9	6.22	58.5	9.8	COC						157	UL OPS	29.59	X			X	40 AFT			
7 Nov	0840	154.9	3.30	586	9.6	190	6	.68	2.	17	7	162	UL OKS	29.76	X				100 AFT			
7 Nov	1400	155.8	8.46	605	9.9	~~16~~						160	UL OPS	31.00	X		X		100 AFT			
7 Nov	1600	155.2	7.27	597	9.8	165	12	1.3	1.1	10	87	158	UL OPS	30.34	X		X		100 AFT			M
7 Nov	2000	155.3	3.13	587	9.3	165	12	1.32	1.1	10	87	157	UL OPS	29.78			X		120 AFT	1928	1943	B
7 Nov	2200	156.2	5.22	594	9.8	PEG OOC	0	.7	4.1	10	5	160	UL OPS	30.26								
8 Nov	0325	153.9	7.07	582	9.6	125	0	.9	.5	5	18	166	UL OPS	29.62	X		X		AFT 120			M
8 Nov.	0400	154.3	7.13	583	9.7	125	12	.96	.46	4	24	164	UL OPS	29.74	X		X		AFT 120			
8 Nov	0600	157.4	6.49	596	9.8							160	UL OPS	30.30	X		X	X	AFT 120			
8 Nov	0800	158.9	6.01	599	10.0	127	8	.8	.29	4	8	161	UL OPS	30.51	X		X	X	AFT 120			M
8 Nov	1600	150.7	3.27	570	9.6	120	5	.4	.3	10	13	155	UL OPS	28.95			X		AFT 120			

TABLE 2r.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL					
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO	H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in				CFH	COM	SEC
8NOV.	1800	155	4.61	589	9.4							162	UL OPS.	29.85	X			0		
8NOV.	2000	156.	4.05	590	9.4	180	6	.55	.4	10	4	165	UL OPS	29.85	X			AFT 40		
8NOV.	2200	158	5.06	600	9.2	~~164~~	~~8~~	~~.9~~	.15	10	25	166	UL OPS	29.80	X			AFT 100		
9NOV	0000	159.3	6.76	607	9.3	164	8	.9	.15	10	25	163	UL OPS	30.82	X		X	AFT 100		M
9NOV	0200	160.2	6.95	610	9.4							160	UL OPS	31.00	x		x	AFT 100		
9NOV	0400	161.1	6.90	614	9.4	163	8	.9	.15	5	24	165	UL OPS	31.20	X		X	AFT 100		M
9NOV	0600	153.1	.887 6.64	584	9.2	155	6	.9	.3	5	8	157	UL OPS	29.92		X	X	AFT 100		
9NOV	1000	158.0	3.30	595	9.1	160	3	.45	.3	10	4	161	UL OPS	30.20		X				
9NOV	1200	158	5.45	601	9.2	160	3	.78	.25	9	8	166	UL OPS	30.52		X		AFT 80		M
9NOV	1400	159.8	(1.01) 7.34	609	9.2							168	UL OPS	30.54		X		AFT 80		
9NOV.	1600	158.3	7.87	606	9.4	159	12	1.0	.15	4	73	167	UL OPS	30.50		X	X	AFT 80		
9NOV	2000	157.7	2.27	590	8.8	160	3	.25	.1	4	11	161	UL OPS	29.91		X				
10NOV	0000	159.0	6.19	607	9.5	163	8	.8	.3	4	10	162	UL OPS	29.85		X		AFT 80		
10NOV	0300	160.8	8.16	613	9.6	162	8	.95	.25	4	10	162	UL OPS	31.20		X		AFT 90		
10NOV	0500	161	8.21	620	9.8	162		1%				163	UL OPS	31.56		X	X	AFT 40		
10NOV	0600	157.7	7.95	606	9.4	160		1%				165	UL OPS	31.42		X	X	AFT 40		

TABLE 2s.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
10NOV	0800	154.6	7.87	600	9.5	154	8	.95	.2	3	55	163	UL OPS.	30.38		X	X	X	AFT ~~[illegible]~~ 100		
10NOV	1200	155.5	5.42	576	7.3	157	3	.7	.23	9	21	158	UL OPS	30.16		X			AFT 100		
10 NOV	1400	160.3	1.33	596	7.8							162	UL OPS	30.17		X			AFT 100		
10 NOV	600	160.7	1.05	597	6.9	162	8	.1	.1	9	3	163	UL OPS	30.18		X			AFT 40		
10 NOV	2200	164	2.50	613	8.4	165	6	.3	.8	8	8	165	UL OPS	31.10		X			AFT 40		
10 NOV.	2400	163.9	4.09	617	9.1	165	6	.55	.1	2	13	170	UL OPS	31.12					AFT 40		
		~~[illegible]~~																			
11 NOV.	0200	164.5	575 5.53	623	9.0							172	UL OPS	31.26		X			AFT 40		
11NOV	0400	'59	6.87	607	9.2	162	8	.8	.1	3	64	166	UL OPS	31.21		X			AFT 40		
11NOV	0600	159.1	8.22	608	8.7							165	UL OPS	31.10		X	X		AFT 80		
11NOV	0800	160.9	7.79	618	9.2	163	.8	.9	.1	10	92	163	UL OPS	31.32		X	X		AFT 80		
11NOV	1000	161.7	762	623	9.2							165	UL OPS	31.60		X	X		AFT 80		
11NOV	1300	155	7.53	601	9.4	157	.8	.85	.1	3	162	157	UL OPS	30.97		X	X		AFT 80		
11NOV	1600	157.7	7.81	613	10.0	160	8	.92	.1	10	111	160	UL OPS	31.00		X	X		AFT 80		
11NOV	2000	158	3.99	599	8.9	160	4	.49	.3	9	17	163	UL OPS.	30.99		X			0		
11NOV.	2200	159.7	2.41	598	8.2							166	UL OPS	30.90				X	0		

TABLE 2t.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO	H_2	CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
12 NOV	0000	160	1.94	598	8.2	162	1	0.1	.13	4	3	161	UL OPS	30.25		X					
12 NOV	0400	160.5	1.41	598	7.2	162	5	.13	.1	5	3	162	UL OPS			X					
12NOV	0630	159	2.73	592	8.3	163	2	.38	.1	6	8	162	UL OPS	30.28		X					
12NOV	0900	163.8	4.90	609	9.5	165	2	.6	.18	3	31	165	UL OPS	31.00	X	X					
12 NOV	1100	163	6.10	616	10	165	3	.78	.1	2	72	165	UL OPS	31.35	X				AFT		
12NOV	1200	155.2	.45 7.05	590	9.5	157	3	.78	.1	3	86	162	UL OPS	31.35		X	X		0		G
12NOV	1400	155.4	1.06 7.76	597	9.6							163	UL OPS.	30.36	X		X	-	40 AFT		G
12NOV.	1600	157.7	1.06 7.73	611	10.0	160	6	.84	.1	2	171	166	UL OPS	30.95	X		X		40 AFT		G
12NOV	2000	155.2	1.05 7.75	616	10.0	160	8	.87	.14	2	171	157	UL OPS	30.82	1		X		80 AFT		
13NOV	0000	153.2	1.45% 11.20	608	10.2	154	7	1.1	.15	10	PEG	154	UL OPS	30.72	X		X	X	80 [illegible]		
13NOV	0300	154.0	11.25	513	10.3	157	7	1.0	.24	3	PEG	157	UL OPS	31.0	X		X	X	80 AFT		
13NOV	0500	155.4	9.4	615	9.7	157	5	1.0	.1	10	PEG	157	UL OPS	31.30	X		X	X	80 AFT		
13NOV	0600	153.5	9.12	610	9.8							161	UL OPS.	31.06	X		X	X	55 100 AFT		G
13NOV	0800	151.0	8.74	604	9.9	152	8	.85	.1	2	58	160	UL OPS	30.44	X			X	120 AFT		G
13NOV	1100	152.2	8.01	616	9.8	157	8	.85	.1	2	44	161	UL OPS.	31.02	X		X	X	120 AFT		
13NOV	1220	148.7	.95 7.16	599	9.8	150	9	.65	.1	9	13	158	UL OPS	30.65	X		X	X			

TABLE 2u.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
13 NOV	1600	159.3	1.58	595	8.4	160	0	.18	.1	3	4	162	4L OPS	30.12	X						
13 NOV	1900	154.7	4.32	590	9.3	157	6	.6	.2	5	5	157	UL OPS	29.87	X						
13 NOV	2200	154.7	6.24	598	9.4	158	6	.8	.15	10	13	158	UL OPS	30.20	X						
13 NOV	2400	152.4	7.72	595	9.4	157	6	.9	.15	3	24	156	UL OPS.	30.22	X		X		100 AFT		G
13 NOV	0200	151.3	8.12	595	9.5							155	UL OPS	30.08	X		X	X	110 AFT		
14 NOV	0400	152.4	7.18	599	9.6	154	9	.8	.1	9	13	156	4L OPS	30.21	X		X	X	110 AFT		G
14 NOV	0600	150.5	6.46	589	9.0							155	UL OPS	29.96	X		X	X	110 AFT		
14 NOV	0800	152.8	.94 6.98	600	9.5	155	9	.78	.1	9	15	155	4L OPS	30.25	X		X		110		
14 NOV	1000	155	7.29 ~~6.08~~	608	9.7							155	UL OPS	30.68	X		X		AFT 110		
14 NOV	1530	147.8	2.36	581	9.5	150	9	.8	.1	25	26	160	UL OPS	29.30	X		X		AFT 110		
14 NOV	1800	159.1	1.89	594	8.8	162	0	.19	.45	3	8	166	UL OPS	29.69	X				40 AFT		
14 NOV	2100	158.9	1.77	594	7.8	162	8	.25	.45	14	8	162	UL OPS.	30.00	X				40 AFT		G
15 NOV	0006	157.2	.65 4.87	596	8.9	160	5.5	.5	.29	29	14	159	4L OPS	30.14	X				40 AFT		
15 NOV	0330	159.4	1.45	595	7.3	162	.05	.15	.5	3	3.5	163	UL OPS	30.06	X						
15 NOV.	1200	155.8	3.61	587	8.7	159	7	.45	.1	14	22	160	UL OPS	30.08	X				40 AFT		G
15 NOV.	1630	158.2	7.23	605	9.3	159	7	.72	.1	22	PEG. 1,200	162	UL OPS.	30.68	X				100 AFT		G

TABLE 2v.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
15NOV	2000	152.6	.75 7.54	567	9.3	155	0	0	.13	11	8	155	UL OPS	29.74	X		Y		100 AFT		
16NOV	0400	153.9	6.05	588	9.0	152	8	.7	.15	18	173	155	UL OPS	29.80		X			40 AFT		
16NOV	1600	157	8.38	608	9.8	159	6	.8	.1	12	PEG 200	161	UL OPS	29.81		X	X		80 AFT		
16NOV	1230	153.6	1.01 8.12	598	7.6	158	55	.73	.1	37	200	156	UL OPS	30.24							
16NOV	1600	160.7	1.33	599	6.9	160	0	.15	.13	37	3	163	UL OPS	30.26		X					
16NOV	2100	161.1	.58 3.54	609	8.7		13	0				164	UL OPS	30.80							
16NOV	2200	161.4	.8 5.94	619	9.5							164	UL OPS	31.50		X			80 AFT		
17NOV	0200	161.9	7.37	624	9.8							165	UL OPS	31.58		X			80 AFT		
17NOV	0400	159.9	8.81	617	9.6			—				161	UL OPS	31.40		X	X		80 AFT		
17NOV	0600	157.7	7.76	610	9.3							160	UL OPS	30.86		X	X		80 AFT		
17NOV	0800	159.3	.85 4.66	617	10.1	157	55	.62	.1	19	200	160	UL OPS	31.22		X	X		80 AFT		
17NOV	2000	161.7	1.28	598	7.1	160	5	.2	.15	10	16	165	UL OPS	30.84		X			80 AFT		
17NOV	2200	163.6	.45 3.41	607	9.0							167	UL OPS	30.76		X			80 AFT		
18NOV	0000	164.7	5.20	613	9.7	163	5	.5	.4	20	200	162	UL OPS	31.22		X			80 AFT		
18NOV	0600	160.3	9.10	603	10	160	8	.7	.15	21	116	162	UL OPS	30.75		X			80 AFT		
18NOV	1000	164	6.78	621	10	162	8	.6	.3	12	PEG	166	UL OPS	31.58		X	X	X	80 AFT		

TABLE 2w.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
18 NOV	1200	157.9	(.8) 5.54	598	9.8	157	10	.6	.57	10	PEG 200	160	UL OPS	30.35		X	X		50 AFT		M
18 NOV.	1400	158.	.83 6.38	604	9.5							161	UL OPS	30.61		X	X		80 AFT		M
18 NOV.	1600	159.8	.47 7.00	609	10.5	157	10	.62	.2	27	PEG 200	162	UL OPS	30.90		X	X		80 AFT		M
18 NOV	1800	161.3	7.36	616	10.4							164	UL OPS	31.28		X	X		80 AFT		
18 NOV	2000	161.7	.96 7.69	620	10.4	162	11	.6	.21	11	200	163	UL OPS	31.48		X	X		60 AFT		
19 NOV	0700	157.2	(.75) 5.41	589	9.5	155	15	.49	.2	20	200	159	UL OPS			X			80 AFT		
19 NOV	0800	158.3	(.81) 6.22	595	9.5	157	12	.55	.15	18	200	160	UL OPS	30.26		X	X		50 AFT		
19 NOV	1030	161.5	1.10 7.58	613	10.4	159	12	.6	.1	10	244	165	UL OPS	30.95		X	X		80 AFT		
19 NOV	1500	153.6	5.68	593	10.4	153.0	12	.5	.1	10	204	156	UL OPS	30.00		X	X	Y	80 AFT		
19 NOV	1800	157	4.83	604	10.6	155	15	.45	.1	8	PEG	158	UL OPS	30.56		X	X		80 AFT		
20 NOV	0200	160.3	1.77	595	8.6	157	17	.2	.35	16	42	169	UL OPS	30.18		X			80 AFT		M
20 NOV	0600	160.2	1.80	594	8.8							16.2	UL OPS	30.11		X			80 AFT		
20 NOV	0800	160.8	1.46	594	8.5	160	20	.15	.1	15	36	163	UL OPS	30.11		X			80 AFT		
21 NOV	0000	164.5	4.28	612	9.5	163	12	.30	.2	30	200	165	UL OPS	31.10		X			80 AFT		M
21 NOV	0630	159.9	8.26	601	9.8	160	12	.55	.2	12	PEG	161	UL OPS	30.62		X			80 AFT		G
21 NOV	0930	161.4	8.30	609	10.3	162	12	.65	.15	31	PEG	163	UL OPS	31.00							G

TABLE 2x.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

$\sqrt{z} = (1.26)$

		MASS SPEC				MK V						PORTABLE			ATM CONTROL							
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO	H_2	CO_2		BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC	
21NOV.	1200	162	(1.11) 8.24	613	10.6	162	12	.55	.1	9	PEG 204	165	UL OPS	31.25		X	X	X	80 AFT			G
21NOV.	1400	155.2	(.82) 6.23	592	9.8	151		.45				153	UL OPS	30.04		X	X	X	80 AFT			M
'	1600	156.5	(.75) 5.66	598	9.8	154	12	.44	.2	17	PEG 201	159	UL OPS	32.20		X	X		80 AFT			M
21NOV	2000	152.2	.54 4.4	586	9.7	155	11	.49	.15	9	206	156	UL OPS	29.63		X	X		40 AFT			
21NOV	2200	157.4	1.74	585	8.2							160	UL OPS	27.61		X	1		110 AFT			
22NOV	0400	156.9	6.08	600	9.6	170	8	.5	.2	9	PEG	158	UL OPS	30.35								G
22NOV	0800	151.0	.85 6.37	588	9.7	152	12	.6	.15	9	PEG 200	154	UL OPS	29.54	X				~~80~~ AFT	130		M
22NOV	1000	152.9	1.14 9.72	591	9.3			.55 ↑				155	UL OPS	29.92	X				130 AFT			M
22NOV	1200	154.6	1.25 9.85	596	9.4	155	11.5	~~.45~~	.13	11	200	155	UL OPS	30.25	X		X	X	120 AFT			M
22NOV	1400	155.2	6.16	599	9.4	~~155.2~~						156	UL OPS	30.32	X		λ	/	120 AFT			
22NOV	2300	162.1	6.46	606	8.3	163	8	.5	.1	10	PEG	163	UL OPS	30.85	X			X	120 AFT			G
22NOV	2400	163.1	1.15 8.14	611	9.3	163	12	.5	.1	20	PEG 244	165	UL OPS	30.84	X		X	X	90 AFT			M
23NOV.	0200	157.9	.97 6.85	591	9.7							159	UL OPS	30.75	X		X	X	80 AFT			M
23NOV.	0400	159.1	.75 5.66	597	9.8	159	~~8~~8	.45	.1	18	PEG 244	162	UL OPS	30.34	X		X	X	100 AFT			M
23NOV	0800	160.6	3.9	595	9.3	160	11	.3	.1	19	200	163	UL OPS	30.38	X				100 AFT			
23NOV	1100	168	7.36	626	9.5	168	6	.45	.3	22	PEG	170	UL OPS	31.90								

TABLE 2y.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL				
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFH	COM	SEC
23NOV.	2400	161.6	.24 2.99	601	8.4	162	13	.25	.15	20	34	165	UL OPS		X		90 AFT		
24NOV	0000	163.3	.89 6.98	611	9.2	165	11	.43	.1	12	200	164	42 OPS	31.13	X	X	90 AFT		
24NOV	0200	164.7	7.41	616	9.4							165	UL OPS	31.43	1	X	96 AFT		
24NOV	0600	163	7.04	613	9.3	165	12	.48	.1	18	PEG	165	UL OPS	31.24		X X	90 AFT		G
24NOV	0900	160	7.03	607	9.2							161	UL OPS	30.80	X	X X	90 AFT		
24NOV	1100	163	6.97	617	9.4	166	11	.45	.1	9	00 C	165	UL OPS	30.3	X	X X	AFT		
24NOV	1800	159.2	.88 6.9	605	9.1	160	8	.44	.1	26	200	161	4L OPS	30.72	X		96 AFT		
24NOV	2200	162.1	.46 7.78	621	9.2	162	8	.49	.1	28	206	164	4L OPS	31.49	X	X	96 AFT		M
25NOV	0000	155.7	7.35	591	9.3	158	8	.5	.1	20	00 C	158	UL OPS	31.35	X	X	90 AFT		G
25NOV	0200	155.5	7.45	680	9.6	158	8	.5	.1	20	00 C	158	UL OPS	30.38		X	90 AFT		G
25NOV	0400	157	7.42	607	9.4	~~157~~	~~8~~	~~.4~~	~~.19~~	~~22~~	~~00 C~~	160	UL OPS	30.72	X	X	90 AFT		G
25NOV	1500	156.6	.82 6.18	595	10.1	157	8	.4	.19	22	00 C	156	4L OPS	30.21	X		70 AFT		
25NOV	1700	157.8	7.56	601	10.1							159	4L OPS		X		70 AFT		
25NOV	1800	151	.11 8.37	580	10.1	154	6	.45	.15	28	00 C	153	UL OPS	29.45	X	X	70 AFT		G
25NOV	2200	154.3	6.56	597	10.2							156	UL OPS	30.20	X	X	70 AFT		
25NOV.	2400	148	.72 5.46	577	10.3	150	7	.38	.15	10	PEG 200	150	UL OPS	30.19	X	X	70 AFT		

TABLE 2z.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
26 NOV	0600	150.6	.54 6.41	577	9.1	152	8	(.4)	.13	11	200	152	UL OPS	29.42	X	X			120 AFT		
26 NOV	0800	152.9	1.08 8.3	590	10	155	11	(.49)	.12	20	208	154	UL OPS	29.91							
26 NOV	1300	155.8	8.4	600	10.3	162	11	[illegible]	.15	10	200	158	UL OPS	30.58	X		X	X	120 AFT		
26 NOV	1500	155.0	6.9	577	9.7							153	UL OPS	29.22							
26 NOV	2400	161.6	.6 4.13	603	9.6	162	12	35 ~~[illegible]~~	.55	23	145	165	UL OPS	30.09		X		[illegible]	120 AFT		
27 NOV	0000	156.1	.93 7.17	583	7.9	157	8	(.4)	.14	10	200	157	UL OPS	29.73		X		X	100 AFT		
27 NOV	2200	157.5	1.08 8.40	591	67.1							159	UL OPS	30.13		X			100 AFT		
27 NOV	0400	158.9	1.07 7.99	596	66.3	160	11.5	.4	.4	15	200	159	UL OPS	30.39		X		X	100 AFT		
27 NOV	0600	159.4	7.74	596	65.3	160	6	.26	.1	21	200	162	UL [illegible]	30.60	X		X		100 AFT		
27 NOV	0830	162	7.86	611	66.3							165	UL OPS	7.11	X		X		100 AFT		
27 NOV	1000	154	6.90	580	66.6	151	12	[illegible]	.1	21	200	157	UL OB	31.12	X		X	X	100 AFT		
27 NOV	1200	156	.82 6.08	587	66	157	12	.34	.2	10	REG HI	158	UL OPS	31.45		X	X	X	100 AFT		
27 NOV	1800	163.7	.67 4.85	609	66.1	165	9	.35	.3	15	200	164	UL OPS	31.04		X	X		100 AFT		
27 NOV	2000	165.2	5.65	616	67.2							165	UL OPS	31.42		X	X		100 AFT		
27 NOV	2200	158.4	.76 5.8	595	66.7	162	8	.32	.1	22	200	161	UL OPS	30.30		X	X		100 AFT		
28 NOV	0000	158.8	6.32	595	67.3							161	UL OB	30.38		X	X		100 AFT		

TABLE 2aa.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE ATM CONTROL										
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		CO_2		BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC	
28 NOV	0200	160.1	6.78	601	10.7	160	6	.006	.2	30	ooc	163	UL OPS	30.63		X	N		100 AFT			
28 NOV	0400	162.4	7.05	610	10.6							163	UL OPS	31.05		X	X		100 AFT			
28 NOV.	0600	164.2	.86 6.32	613	10.4							166	UL OPS.	30.50		X	X	X	~~[illegible]~~ AFT	90		B
	0800	166.2	.9 5.56	624	10.9	167	6	32	.1	10	PEG [illegible]	169	UL OPS	31.74		X	X	X	70 AFT			M
28 NOV	1200	162.8	2.65	606	10	165	16	.2	.13	10	150	164	UL OPS	30.82		X			70 AFT			
28 NOV	1400	163.6	5.51	613	10.4							165	UL OPS	31.21		X			70 AFT			
28 NOV	1600	164	.92 7.61	621	10	165	18	.49	.13	10 ~~35~~	ooc	164	UL OPS	31.39		X			90 AFT			
28 NOV	2000	150.1	3.79	563	9.8	152	11	00 2	.3	10	40	152	UL OPS	28.59		X			100 AFT			
29 NOV	2200	152.0	6.0[illegible]	575	10.6			—				155	UL OPS	30.48		X			100 AFT			
29 NOV	0100	146.4	1.02 7.45	563	9.9	147	8	.48	.1	17	160	148	UL OPS	30.54	X	X	X		120 AFT			M
29 NOV	0400	148.4	1.03 7.54	569	10.7	150	8	.50	.1	15	148	151	UL OPS	28.94	X	X	X		120 AFT			M
29 NOV	0534	149.5	.88 6.54	569	10.3	152	11	.49	.1	9	147	157	UL OPS	29.12	X	X	X		90 AFT			
29 NOV	0609	150.4	5.64	579	10.7							154	UL OPS	29.32	X	X	X		90 AFT			
29 NOV	1900	152.8	.8 6.05	588	10.6	155	11	.4	.1		109	154	UL OPS	29.19	X	X		X	100 AFT			
29 NOV	1200	153.3	6.54	591	10.9							155	UL OPS	29.94			X		80 AFT	1219	1305	
29 NOV	1400	157.7	3.24	592	10.0	160	15	.2	.35	20	26	160	UL OPS	30.08	N				0			B

TABLE 2bb.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO_2 H_2		C[illegible]		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
NOV 29	1600	157.5	5.34	599	7.5							160	UC OPS	30.32							
29 NOV.	1800	156.9	(.96) 7.00	604	9.9							158	UC OPS	30.60	X				90	2150	222
29 NOV	2000	157.6	(1.05) 7.74	612	10.8	160	6	.49	.25	25	184	159	UC OPS	30.72	X		X		600 AFT		
30 NOV	0000	158.6	.69 5.11	604	10	160	5	.38	.1	30	95	159	UL OPS	30.61	X				70 AFT		
30 NOV	0200	158.6	7.48	610	10.5							160	UL OPS	30.76	X				70 AFT		~~2250~~
30 NOV	0400	160.4	1.11 8.45	619	10.4	162	2.5	.45	.19	20	200	161	UL OPS	31.45	X				70 AFT		
30 NOV	0600	158.9	1.18 9.2	614	10.2							159	UC OPS	31.44	X		X	X	0		
30 NOV	0800	155.3	7.42	607	10.0	156	3	OOC	.3	10	OOC	156	UC OPS	30.70	X		X	X	0		
30 NOV	1100	153.3	3.62	583	10.4						OOC	154	UC OPS	29.56	X				0	0955	1025
30 NOV	1200	154.4	6.16	597	10.0	158	3	.4	.3	10	OOC	162	UL OPS	30.24	X				0		
30 NOV	1400	151.4	7.92	593	10.0							159	UL OPS	29.99	X				60		
30 NOV	1600	152.1	9.36	598	10.8	153	3	.5	.15	5	OOC	160	UL OPS	30.31	X				60		
30 NOV	1800	152.4	9.97	603	10.9							154	UL OPS	30.49	X				66		
30 NOV	2000	151.7	2.55	567	11	152	[illegible]	.21	.1	22	200	154	UL OPS	28.58	X			X			
1 DEC	0030	152.4	7.60	584	10.2							154	UC OPS	29.72	X			X	120		
1 DEC	0230	153.8	8.30	593	11.4							154	UC OPS	30.20					120		

TABLE 2cc.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL						
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO H_2		[illegible]		BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC
1DEC	0500	157.5	7.01	597 ~~71~~	11.3	157	3	00C	.2	20	00C	157	UC OPS	30.55	X	X	X	X	120 AFT		
1DEC	0600	155	6.20	596	11.0			00C				166	UL OPS	30.52	X	X	X	X	120 AFT		
1DEC	0800	149.8	5.4	578	10.6	152	8	.35 ~~3.5~~	.15	11	00C	160	UL OPS	29.21	X	X	X	X	120 AFT		
1DEC	1100	157.8	3.07	591	10.2							160	UL OPS	30.07	X				Ø		
1Dec	1200	158.2	3.07	597	10.2	160	15	.25	.1	7	00C	159	UL OPS	30.12	X						
1Dec	16ØØ	157.6	7.71	609	11.7	160	5	.4	.1	10	00C	158	UL OPS	30.75	X		X		Ø		
1DEC	1800	151.6	7.5	593	11.0							152	UL OPS	30.00	X		X		0		
1DEC	2000	152.3	4.91	601	12.7	152	6	00C	.1	10	00C	153	UL OPS	30.50							
1DEC	2300	153.6	4.22	587	10.6							157	UL OPS		X		X			2200	2240
2DEC	0000	154.9	4.85	594	10.4	155	8	.25	.1	5	00C	157	UL OPS	30.12	X		X		100 AFT		
2DEC	0200	156.1	7.4	603	10.6							156	UL OPS	30.58	X				100 AFT		
2DEC	0400	152.0	3.66	588	10.7	153	5	.4	.1	8	00C	153	UL OPS	29.87	X				100 AFT		
2Dec	06ØP	152.5	7.96 7.69	587	10.5	155	3	.4	.13	13	00C	155	UL OPS	30.05	X		X	X	100 Fwd		
2 Dec	Ø8ØØ	155.6	6.63	598	11							156	UL OPS	30.38	X		X	X	100 Fwd.		
2Dec	1000	157	6.77 5.84	603	10.9	157	3	.3	.1	21	00C	158	UL OPS	30.67	X		X				
2DEC	1300	151.6	7.93	618	11.5							160	UC OPS	31.35	X		X		100 Fwd		

TABLE 2dd.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL							
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO_2 H_2		[illegible]		BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC	
2 DEC	1400	157.2	3.95	596	11.0	157	8	00C	.15	12	85	158	UL OPS	30.29	X				0	1358	1432	
2 DEC	1800	154.3	7.11	606	10.6							157	UL OPS		X				0.			M
2 DEC	2000	154.7	9.39	6.16	11.7	157	3	.4	.2	8	00C	157	UL OPS	31.3	X		X		0			M
2 DEC	2200	149.3	7.94	5.94	11.2							151	UL OPS	30.09				X	100 [illegible] ~~0~~			M
3 Dec	2342 ~~0200~~	151.4	.64 6.88	604	10.9	152	2.5	.38	.1	35	00C	153	UL OPS	30.49						2340	0026	
3 Dec	0025	160.5	3.66	412	10.6	160	10	.19	.11	9	00C	162	UL OPS	31.08	X							
3 Dec	2400	161.4	.87 7.03	628	102	162	10	.33	.1	7	00C	161	UL OPS	31.79		λ	X					
3 DEC	0630	161.6	7.51	637	10.7	162	6	00C	.15	10	00C	162	UL OPS	32.10		λ	X					[illegible]
3 DEC	0800	152.3	6.97	696	10.7							153	UL OPS	30.60		[illegible]	[illegible]					[illegible]
3 DEC	1000	158.5	7.74	638	12.5	157	3	00C	.25	10	00C	157	UL OPS	32.06		N	X					[illegible]
3 DEC	1200	151.3	8.53	614	12.2	152	2	.35	.25	10	00C	151	UL OPS	30.91		X			100 AFT	1330	1410	M
3 DEC	1400	151.5	7.27	600	10.5							160	UL OPS	31.02		X			0			
3 DEC	1600	156.8	6.72	612	11.1	158	8	.42	.2	5	00C	157	UL OPS	31.02		X			0.			M
3 DEC	1800	156.8	6.41	620	11	157	5	.4	.1	6	00C	158	UL OPS	31.41		X	X		0			
3 DEC	2000	156.1	6.65	604	11.1							157	UL OPS	30.52		λ	X					
3 DEC	2200	148.2	8.72	600	11	150	5	.38	.1	12	00C	150	UL OPS	30.15		X	X	X	~~A~~ 100			

TABLE 2ee.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL							
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	[illegible]		[illegible]		BLEED	VENTILATION		
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in					CFH	COM	SEC	
4DEC	0030	160.7	2.76	610	11.0							163	UL OPS	31.00						2320	0015	
4DEC	0230	152.3	4.88	592	11.4	153	9	00	.1	10	114	154	UL OPS	30.00		X			0			B
~~4DEC~~		~~153.2~~	~~6.4~~	~~602~~	~~10.7~~	~~153~~	~~9~~	~~00~~	~~.1~~	~~10~~	~~114~~					~~X~~			0			
4DEC	0400	153.2	.85% 6.4	602	10.7							154	UL OPS	30.47		X			O			
4DEC	0600	153.7	6.74	610	10.3							155	UL OPS	30.99		X	X		Ø			
4DEC	0800	147.8	6.97	597	10.8	155	0	.35	.2	14	oc	152	UL OPS	30.05		X			Ø	0800	0840	
4DEC	1000	152.7	4.47	588	10.8	1						155	UL OPS	29.8		X			Ø			WM
4Dec	1335	152.9	1.13 7.33	612	11.7	155	2.5	.4	.1	3	oc	154	UL OPS	31.01		X	(	(	0			
4Dec	1600	151.0	1.0 8.16	617	11.6	152 ~~147~~	2.5	.32	.22	20	oc	154	UL OPS	30.82		X	X	X				
4DEC	1800	149.6	6.68	612	11.7							152	UL OPS	30.80		X	Y	X	O			B
4DEC	2200	155.5	4.10	598	10.7							156	UL OPS	[illegible]		X			O	1848	2005	
5DEC	[illegible]	147.0	4.00	570	9.6	148	7	.3	.35	2	oc	152	UL OPS	23.8		X			Ø			B
5DEC	0200	148.9	4.09	578	9.7							147	UL OPS	29.17		X			Ø			
5DEC	0400	150.3	4.18	584	9.8	148	6	.35	.4	2	oc	147	UL OPS	29.46		X			Ø			WM
5Dec	0600	150	4.26	585	9.5	148	8	.38	.3	3	oc	148	UL OPS	29.78		X						
5Dec	0745	143.5	4.17	559	9.9	140	2.5	.4	.3	3	oc	140	UL OPS	28.20		X						

TABLE 2ff.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK V						PORTABLE			ATM CONTROL				
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	[illegible]	[illegible]	BLEE	VENTILATION	
~~SPEC~~		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in			CFM		SEC
5 Dec		152	4.70	593	10.5	153 ~~153~~	14	.19	.32	9	OC C	157	UL OPS	29.45	X		0	0952	1034
5DEC	1300	153.7	4.96	600	10.7	153	6	.38	.3	9	OO C	153	UL OPS	30.31	X				
5DEC	1500	155.6	5.19	608	10.9							154	UL OPS	30.76					
5DEC	1100	151.7	5.21	594	10.9	148	6	OOC	.6	10	OO C	148	UL OPS	30.06			100		
5DEC.	1800	152.3	.72 5.28	596	10.9							150	UL OPS.	30.10	X	X	130 FD.		
5DEC	1930	153.5	.75 5.43	601	11.0	151	0	.32	.29	9	PH HIGH	152	UL OPS.	30.34	X	X	~~130 FWD~~ 100 FWD		
5DEC.	2000	156.6	.78 5.77	614	11.1							154	UL OPS	30.80	X	X	100 FWD		
6DEC	0000	147.9	.75 5.5	561	10.5	145	2.5	.33 [illegible]	.11	2	OO C	147	UL OPS	29.37	X	X	110		
6 Dec	0345	153.3	.79 5.95	606	10.9	152	.5	.25 [illegible]	.33	4	OO C	155	UL OPS	30.66	X	X	0	NOTE CO ACR	
6 DEC	0700	155.5	6.17	616	10.7	153	6	OO C	.15	11	OO C	152	UL OPS	31.02	X	X	0		
6DEC	0900	151	6.12	598	10.5							151	UL OPS	30.70			0		
6DEC	1100	151.1	6.23	602	10.5	153	15	OOC	.2	11	OOC	159	UL OPS	30.32	X		0	0955	1133
6DEC	1200	152.6	.84 6.39	608	10.6	155	12	.25	.25	4	148	159	UL OPS	30.40	X		0		
6DEC	1400	PORT OUT	CO_2	.80 OF COMM	MLO							158	UL OPS	29.46	X		0		
6DEC	1600	PORT OUT OF	CO_2	.75 COMMISSION	MLO	147	6	.3 [illegible]	.2	10	PH.	159	UL OPS	29.57	X	X	0		
6DEC	1600	Port 0	CO_2 0	.8 C	MLO	148	5.5	.39	.1	9	PH	153	UL OPS	29.92	X	X	106 AFT		

TABLE 2gg.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

AT ____ IC1 Johnson discovered that the Mass spectrometer had zero flow rate indicated. A blown fuse was discovered in the supply to the sample pump Replacement fuses blew with switch (pump) placed in On. Mass spec. considered OOC; however, appears to be reading correct atmosphere.

TABLE 2hh.- COMPARISON DATA RECORDED BY U.S.S. HAMMERHEAD'S CREW

		MASS SPEC				MK. V						OOC PORTABLE			ATM CONTROL					
DATE	TIME	O_2	CO_2	N_2	H_2O	O_2	CO	CO_2	H_2	F11	F12	O_2	LOC	BARO	CO	H_2	CO_2	BLEED	VENTILATION	
		mm	mm	mm	mm	mm	ppm	%	%	ppm	ppm	mm		in				CFH	COM	SEC
6 Dec	2200	Port.	CO_2	2	.8	149	8	.32	.1	6	OOC	149	UL ABS	29.83		X	X	120 AFT		
7 DEC	0000					OPL	8	OOL	.2	7	OOL	147	UU OPS		X	X	X	120 AFT	PORT + O_2 9%	

PERFORMANCE SUMMARY

Final system calibration prior to deployment of the Undersea Atmospheric Sensor was achieved at 1001 on 6 October 1970. A specially prepared gas mixture from Matheson Scientific, consisting of 74.8% nitrogen, 20.11% oxygen, 2.13% carbon dioxide and 3.0% argon, was utilized both during calibrations for the five-day sea trial and the final sea deployment. This standard mix now resides at NASA/Langley Research Center. Figure 1 is a graphical presentation of the system calibrations before and after the 62-day deployment of the Undersea Atmospheric Sensor. Also, as a correlation to the system calibration, standard ships air data before and after the deployment is also presented. Water vapor calibration, originally achieved utilizing relative humidity and temperature at the sample point, has remained stable during the sea deployment.

The variations in torr between theoretical output and system outputs before and after sea deployment are as follows:

Calibration Before Sea Deployment	Gas Constituent	Calibration After Sea Deployment
0	N_2	+5.22
+0.5	0_2	+0.98
+0.04	CO_2	-0.12
+0.65	A_r	+0.53
0	H_2O	0
+1.24	P_{TOTAL}	+6.92

Comparing the instrument calibration prior to the deployment with the calibration verification after deployment, it can be seen that all parameter, except argon, have remained within 1.0% of their theoretical values; and argon, a low-level constituent, has shifted less than 0.6% from the original calibration during the 62-day test.

Figures 3a through 3e are graphical presentations of the carbon dioxide output from the Undersea Atmospheric Sensor during sea deployment. Absolute carbon dioxide outputs, rather than delta values, are plotted in an effort to draw correlation between shipboard activities and levels of carbon dioxide experienced. In these figures it is possible to correlate the reduction in CO_2 scrubbers, ventilation, snorkel, and various air bleeds.

It has been reported that the operating efficiency of shipboard CO_2 scrubbers improved as the CO_2 level increases above a nominal 1%, such that the higher the carbon dioxide level the more efficient the scrubbers. Final system calibration, however, showed that CO_2 was within 1% of the theoretical value. This results in a ±0.11 torr error out of a nominal 7.6 torr control level. Clearly this level of uncertainty is of little or no concern relating to a decision to start CO_2 scrubbers or not.

Figures 4a through 4e are comparisons of the Mark V carbon dioxide outputs with the Perkin-Elmer Undersea Atmospheric Sensor taken as a reference. A ±5.7% full-scale error band or ±0.95 torr based on 16.74 torr full scale has been shown for purposes of data evaluation. This error band relates to previous theoretical worst case analysis performed on the mass spectrometer attributed to system performance characteristics occurring simultaneously.

Figures 5a through 5e represent the summation of the partial pressure outputs during sea deployment of the Undersea Atmospheric Sensor. Since nitrogen, oxygen, carbon dioxide and water vapor were the four atmospheric constituents displayed and argon constitutes approximately 1% of the nominal atmosphere, 7.4 torr has been added to the recorded data outputs for the contribution of argon, in order to more closely approximate the ambient pressure. From 0200, 25 October through 1000, 5 November, and from 0200, 27 November through 2400, 27 November, the Test Mode Select switch was left in a position other than H_2O output. During these periods 10.0 torr, a nominal water vapor output level, has been added to the summation of the data outputs recorded. The resulting summation of the partial pressures is assumed to be within ±0.25% of the actual data outputs during the periods when the Test Mode Select switch was in the wrong position. During the remainder of the data it is expected that the summation of the partial pressures is within ±0.1% of the actual summation if argon would have been recorded.

In Figure 5a, from 13 October through 23 October, the summation of the partial pressures increased approximately 9.5 torr from a nominal level which was 6.5 torr lower than the barometric pressure. This positive system drift is basically attributed to system thermal stability. Factors contributing to long term system instability are thermal coefficients of system electronic components and the pressure transducer utilized. The Undersea Atmospheric Sensor experienced an ambient temperature change from 54°F to 28°F, or a delta change of 26°F during sea deployment. Relating this thermal variation to system drift, a 0.37 torr/°F system thermal shift was observed. The Undersea Atmospheric Sensor was originally developed for use in a relatively constant ambient atmosphere, and thus rigorous consideration of thermal variation was not made. Future applications would be addressed to satisfying more stringent ambient conditions.

A ±1%, 7.6 torr error band has been added for purposes of system evaluation, to Figure 5a through 5e, about a nominal +2.5 torr assumed thermally stable system partial pressure summation. It can be seen that the majority of the summation of the Undersea Atmospheric Sensor outputs fall well within this ±1% error band.

Major perturbations below the nominal partial pressure summation are attributed to possible reduction of inlet leak conductance. Since Engineering data was not recorded during the periods when the summation of the partial pressures were significantly below the barometric reading, it is impossible to positively identify the source of the nonconformance. If, however, one were to sum the partial pressures recorded in Tables 1a, 1b, and 1c on 17 November at 1400 hours, one would see that the summation of the partial pressures was equal to 736 torr, while the pressure transducer output was 771 torr - a variation of -35 torr. As the inlet valve conductance is reduced, the anode current increases in an attempt to maintain stable closed-loop operation. Closed-loop operation of the Undersea Atmospheric Sensor has been limited to 35.0 microamperes anode current. If the system demands more anode current - due to change in inlet leak conductance - than can be supplied by the preset limitation of 35 microamperes anode current, the sum of the partials will start to deviate from the barometric pressure. In all instances this will be a negative deviation from the barometric pressure.

The reason for inlet leak conductance variation is not obvious from the data available. A thermal transient in the inlet valve, or a vibration transient, seems to be the most reasonable explanation. However, a discrete contaminant or particulant water in the inlet leak area might also provide similar behavior. The data does, however, indicate that inlet conductance does recover to the original value within two hours.

Major perturbations above the nominal partial pressure summation are attributed in most cases to barometric pressure reading error. It should be noted that in many instances when the summation of the partial pressures is higher than the barometric pressure, the deviation between the two is approximately 1 inch of mercury. While this does not appear indicative of all the barometric pressure readings, it was determined that accurate reading of the available barometer does require more familiarity than should normally be required. This conclusion was reached during predeployment calibration when members of the ship's crew were asked for barometric pressure readings and, when once taken, were found to be in error by a significant amount.

A comparison of the major perturbations in the summation of partial pressures, Figures 5a through 5e, and the oxygen partial pressure output, Figures 2a through 2e, reveals no correlation. If the major perturbations in the summation of partial pressures are accepted for what they are, it is found that the maximum error in Figure 5 is approximately ±6% of 760 torr. This same error related to the oxygen output or carbon dioxide output would produce approximately ±9.6 torr error in oxygen based on 160 torr nominal level and ±0.67 torr error in carbon dioxide based on 11.1 torr maximum level. Negative perturbations can be eliminated in the future by thermal and vibrational isolation of the inlet leak valve, additional sample filtration and higher anode current set point. Positive errors can be eliminated through additional care in observing and recording barometric pressure readings.

SAMPLE TRANSPORT PUMP FAILURE

On 6 December, between 0900 hours and 1100 hours, the sample transport pump, a commercially procured auxiliary pump utilized to move the air sample through the sample line, ceased functioning. This failure resulted in the absence of new gas sample at the inlet to the mass spectrometer. The transport pump has been replaced and a failure analysis performed. The results of the failure analysis are shown in Figures 6 and 7. The Gast pump, Model 0531-102347, has four carbon vanes inserted into a steel rotor hub which, in turn, is mounted in a cast housing (with eccentric cavity). These carbon vanes are designed such, that, as the rotor rotates, the vanes slide in and out of the rotor hub following the contour of the eccentric housing and moving a gas sample through the system. The mechanical fit between the rotor and vanes is such that abrasion of the vane results. Continuous operation of this pump eventually produces failure of the vane which, when fractured, tends to jam the motion of the rotor and subsequently causes the pump fuse to blow. Future systems utilizing a similar sample transport scheme must provide access to the rotor area of the pump and adequate replacement vane spares to insure considerably longer system operation.

CONCLUSIONS

The Undersea Atmosphere Sensor System, described in Appendix 3, Operation and Maintenance Manual, Undersea Atmospheric Sensor, has proven to be a reliable, automatic and accurate tool for monitoring the atmospheric constituents of nitrogen, oxygen, carbon dioxide, water vapor and argon under in-use undersea environment conditions.

Virtually maintenance-free operation was provided during 62 continuous days of sea deployment. Calibrations were performed at the beginning and end of sea deployment, the results of which indicate unusually stable long term operation. During the period of sea deployment, the readings provided by the Undersea Atmospheric Sensor were in close agreement with other atmospheric analyzing equipment, both fixed and portable. By observing atmospheric trends, carbon dioxide scrubber operation, ventilation and air bleed modes, the operational reliability of the Undersea Atmospheric Sensor can be verified. This close agreement with other on-board equipment and the stability of system calibration indicate that, with the addition of other monitoring functions - not presently included in the Undersea Atmospheric Sensor, - the requirement for total atmospheric constituent monitoring can be provided in a compact, reliable, automatic configuration.

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NASA CR-111890

APPENDIX 1

RESULTS OF FIVE DAY SEA TRIAL ON THE UNDERSEA ATMOSPHERIC SENSOR UPTITE

October 1970

Perkin-Elmer SPO 30006
NASA Contract Number NAS1-9469

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
Langley Station
Hampton, Virginia 23365

NASA CR-111890

RESULTS OF FIVE DAY SEA TRIAL ON THE UNDERSEA ATMOSPHERIC SENSOR UPTITE

October 1970

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RESULTS OF FIVE DAY SEA TRIAL ON THE UNDERSEA ATMOSPHERIC SENSOR

UPTITE

INTRODUCTION

Under the general scope of Contract NAS1-9469, the Perkin-Elmer Corporation, Aerospace Division, undertook as Contract Item II, the effort necessary to modify a Government-Furnished Two Gas Atmospheric Sensor System for continuous use as an Undersea Atmospheric Sensor System. The intent of the experiment was to monitor the atmospheric constituents of nitrogen, oxygen, carbon dioxide, water vapor, and argon over an extended period of time, in an undersea cabin atmosphere. The operation of the Undersea Atmospheric Sensor was to be essentially automatic with visual display of the nitrogen, oxygen, carbon dioxide, and water vapor atmosphere constituents. Ease of maintenance and troubleshooting and reliable long-term operation of the instrument were the key requirements.

On 25 September 1970, the Undersea Atmospheric Sensor System, UPTITE, was delivered, placed in operation, and calibrated for a preliminary five day sea trial. Table 1-1a, 1-1b, and 1-1c are copies of the engineering data recorded during the five day sea trial by a member of the Naval Research Laboratory staff. This data was taken periodically for purposes of monitoring the system's internal performance by Perkin-Elmer.

Table 1-2a, 1-2b, 1-2c are copies of data forms maintained during the five day sea trial by the same NRL staff member that recorded the data on Table 1-1a through 1-1c. The data in Table 1-2a through 1-2c would normally be recorded by members of the crew during each watch period.

As the instrument was initially calibrated on a special Perkin-Elmer gas mixture of 74.8% nitrogen, 20.11% oxygen, 2.13% carbon dioxide and 3.0% argon, each readout parameter was within 2.0 torr of the theoretical value. The summation of the partial pressures was within 5.0 torr of the barometric pressure. The performance of the system on standard air was such that the readout parameters were within 1.5 torr of theoretical values, and the summation of the partial pressures was within 2.0 torr of the barometric pressure. Throughout the five day sea trial the system performed steadily, retaining the level of calibration initially observed. Calibration verification performance at the conclusion of the five day sea trial showed that: 1) nitrogen was within 2.84 torr of the 563.17 torr theoretical value; 2) oxygen was within 2.4 torr of the 151.4 torr theoretical value; 3) carbon dioxide was within 0.14 torr of the 16.04 torr theoretical value; 4) argon was within 0.62 torr of the 22.58 torr theoretical value; and 5) the summation of the partial pressures was within 0.82% of the barometric pressure.

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AEROSPACE DIVISION

TABLE 1-1a
MASS SPECTROMETER SENSOR DATA FORM #2

SHEET 1 of 3

DATE	TIME	N_2	O_2	CO_2	H_2O	A torr	Σ_{PP}	RegB+ T.P. 3	unReg B+ T.P. 4	RegB- T.P. 5	unReg B- T.P. 6	Reg Electro Bias T.P. 7	REMARKS
9/27	1237	583	158.0	1.16	9.9	7.3	759.36	137.0	16.5	-144.7	-17.7	37.2	T 79.5°F RH 93%, Bar 759
9/27	1257	582	152.9	1.16	10.0	7.3	758.36	137.1	16.5	-144.8	-17.7	37.2	79°F RH43% Bar759
9-28	2130	576	152.9	3.60	9.6	7.2	749.30	136.9	16.6	-144.7	-17.8	37.0	78°F Bar. 29.38 in 746.25 torr
9-29	2340	578	150.2	5.69	9.2	7.3	750.39	136.9	16.6	-144.7	-17.8	37.1	78°F 29.51 in 750
9-30	2330	592	144.8	7.20	9.8	7.4	761.20	136.9	16.6	-144.7	-17.7	37.1	82°F 29.90 759
10-1	2100	575	147.3	7.16	9.3	7.3	746.06	136.9	16.7	-149.7	-17.8	37.0	76°F 29.40 746

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TABLE 1-1b
MASS SPECTROMETER SENSOR DATA FORM #2

SHEET 2 OF 3

DATE	TIME	unreg Electr Bias T.P. 8	H.V. Reg. T.P. 9	Emis Reg Pos. T.P. 10	Emis Reg Neg. T.P. 11	12 EMSN DR	13 ANODE CUR μa	Total PRESS Amuser Torr	Vari Leak VALVE TEMP	Elex ACCELR CUR	T.P. 17	T.P. 18	REMARKS
9/27	1240	37.5	20.7	19.1	-20.5	13.1	19.7	759	20.4	43.1			
9/27	1257	37.5	20.7	19.1	-20.5	13.1	20.0	758	20.4	43.8			
9/28	2130	37.8	20.8	19.3	-20.6	13.0	19.8	745	20.3	43.6			
9/29	2340	37.6	20.7	19.2	-20.4	13.1	22.1	749	20.3	52.3			
9/30	2330	37.5	20.6	19.2	-20.4	13.1	24.0	759	20.3	56.7			
10/1	2100	37.8	20.8	19.3	-20.6	12.9	16.1	745	20.3	33.9			

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TABLE 1-1c
MASS SPECTROMETER SENSOR DATA FORM #2

29.38

SHEET 3 OF 3

DATE	TIME	T.P. 19	T.P. 20	T.P. 21	T.P. 22	T.P. 23	Red SAMPLE FLOW Line	ION PUMP CURRENT	T/C PRESS	REMARKS	DATA READ BY
9/27	1240						.015	98uA	0		BFB
9/27	1257						.015	100µa	0		RSO
9-28	2130						.015	97µa	0		RSO
9-29	2340						.015	87µa	0		RSO
9-30	2330						.015	75µa	0		RSO
10-1	2100						.015	115µa	0		RSO

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TABLE 1-2a
MASS SPECTROMETER SENSOR DATA FORM #1

DATE	TIME	N_2	O_2	CO_2	H_2O	Σ_{PP}	REMARKS	DATA READ BY
9-26	2200	579. 581.	155.5 156.0	0.71 1.19	11.9 13.6		← fluctuating (35%RH) 763. torr	RSO
9-26	2345	592.	158.8 158.9	0.92 0.95	12.8 12.9		← " (" ") " "	RSO
9-27	0045	592.	158.7 158.8	0.47 1.03	12.8 13.0		← " (" ") " "	RSO
9-27	0220 ~~1420~~	591. 592.	158.7 158.8	0.44 1.00	12.7 12.8		← " (34% ") 762 torr	RSO
9-27	0430	591.	158.6 158.7	0.43 0.76	12.0 12.1		← " (33%RH) 761 torr	RSO
9-27	0630	591.	158.6 158.5	0.89 0.91	11.7 11.8		← " (32½%RH) 760 torr	RSO
9-27	0800	590.	158.4 158.5	0.85 0.89	11.8 11.9		← " (32½%RH) 760 torr	RSO
9-27	0927	586	157.0	1.03	12.5	−3.5T 756.53	82°F (33% RH) 760 Torr	B.PB
9-27	1300	581	157.7	1.15	10.1	−10.0 749.95	79°F	RSO
9-27	1450	582	157.9	1.20	10.2	751.30	78°F Sample Inlet Barom 29.4" 759.46 torr	RSO
9-27	1700	583	158.6	0.99	9.7	752.29	80°F Samp. Inlet. Barom. 29.99 761.75 torr	RSO
9-27	2103	585	158.5	1.32	9.9	754.72	78°F Bar. 30.04 763.02 torr	RSO
9-27	2325	585	158.3	1.58	9.5	754.38	76°F Bar. 30.04 763.02 torr	RSO
9-28	0105	585	158.3	1.55	9.9	754.75	76°F Bar. 30.05 763.27 torr	RSO
9-28	0200	585	158.3	1.49	9.8	754.59	76°F Bar. 30.05 763.27 torr	RSO
9-28	0838	545	158.4	1.43	10.2	755.03	80°F Bar. 30.05 763.27 torr	RSO
9-28	0435	585	159.7	1.28	10.3	755.28	82°F Surface ventilate note lower CO2 Bar. 30.07 763.78 torr	RSO
9-28	1035	586	158.8	1.21	10.3	756.31	80°F Bar. 30.07 763.78 torr	RSO
9-28	1155	585	158.7	1.16	10.2	755.06	79°F Bar 30.05 763.27 torr	RSO
9-28	1255	584	158.4	1.22	10.1	73 753.27	78°F Moderate pitching & rolling. (readings steady) Bar. 30.00 762.00 torr	RSO

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TABLE 1-2b
MASS SPECTROMETER SENSOR DATA FORM #1

DATE	TIME	N_2	O_2	CO_2	H_2O	Σ_{PP}	REMARKS	DATA READ BY
9-28	1410	584	158.3	1.15	10.0	753.45	29.97 Bar. ~~742.34~~ torr 761.24 78°F	RSO
9-28	1800	584	158.4	1.15	9.7	753.23	29.99 Bar. - 761.75 torr 78°F	RSO
9-28	1900	580	156.9	1.51	9.7	748.11	29.77 Bar. 756.16 Submerged 1848 77°F On recirculate air 1823	RSO
9-28	2000	601	161.0	2.84	9.5	774.34	30.77 Bar 782.07 torr. 76°F Surfaced ~~2130~~ ~~1930~~ 1910	RSO
9-28	2400	583	152.5	5.48	8.8	749.78	29.76 Bar 755.40 76°F Resubmerged 2030	RSO
9-~~30~~ 29	0118	587	152.2	6.62	8.9	754.72	29.98 Bar. 761.49 76°F	RSO
9-~~30~~ 29	0330	593	151.8	8.07	8.6		30.20 75°F	RSO
9-~~30~~ 29	0430	596	151.8	8.63	8.6		30.34 75°F	RSO.
9-~~30~~ 29	0530	591	150.1	9.05	8.6	758.75	30.09-764.~~07~~.28 75°F	RSO.
9-~~30~~ 29	0730	577	144.7	10.01	9.8		29.40- 80°F (0720) Start CO_2 scrubber	RSO
9-~~30~~ 29	1125	592	144.8	8.80	11.3	756.93	30.02-762.51 82°F	RSO
9-29	1415	596	145.2	6.66	10.1		30.12 84°F surfaced and opened hatch appx. 1300	RSO.
9-29	1530	586	145.0	6.64	9.4		30.03 81°F surface ventilate (1525)	RSO
9-29	1705	591	154.4	2.93	8.9		30.12 80°F	RSO
9-29	2156	603	158.1	4.68	8.8		30.78 76°F recirculate air 1923 Dive 1935	RSO
9-30	0237	591	152.4	8.04	9.0		30.16 77°F	RSO
9-30	0550	573	146.2	8.74	9.5		29.22 79°F	RSO
9-30	0948	589	152.6	6.08	10.0		30.08 83°F	RSO
9-30	1145	593	149.4	8.58	9.8		30.18 80°F	RSO
9-30	0015	595	149.6	9.13	9.5		30.23 80°F	RSO

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TABLE 1-2c
MASS SPECTROMETER SENSOR DATA FORM #1

DATE	TIME	N_2	O_2	CO_2	H_2O	ΣPP	REMARKS	DATA READ BY
9-30	1338	600	149.4	10.40	9.2	769	30.49-774.45 79°F	RSO
9-30	1648	609	149.1	12.63	9.0		~~30.84~~ 30.91 76°F Scrubbers on 1615 Took air sample 1648	RSO
9-30	1800	616	149.5	10.78	9.2		31.16 76°F	RSO
9-30	1915	587	141.3	8.87	9.2		29.56 84°F 1910 Fire drill 1920 Snorkeling	RSO
10-1	0210	603	144.7	9.19	9.0		30.36 78°F 1930 Secure Snorkeling Start scrubbers (0130)	RSO
10-1	0445	612	146.6	7.26	8.9	774.76+7.4 (782.16)	30.73 = 780 78°F	RSO
10-1	0805	591	150.9	3.23	9.4		29.94 80°F	RSO
10-1	0910	587	155.4	2.23	9.8		29.96 81°F Surface Ventilate 0920	RSO
10-1	1030	586	157.2	1.78	9.7		29.97 80°F	RSO
10-1	1145	586	157.5	1.80	9.3		29.97 78°F	RSO
10-1	1410	585	158.4	1.57	9.0		29.86 76°F	RSO
10-1	1650	570	153.8	2.69	8.8		29.22 76.°F	RSO
10-1	2031	581	153.1	4.68	9.4		29.68 76°F	RSO
10-2	1143	586	1584.4	1.77	9.4		30.00 76°F	RSO

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PERFORMANCE SUMMARY

Final system calibration was achieved just prior to 0927, 27 September 1970 on a Perkin-Elmer supplied calibration gas sample containing 74.8% nitrogen, 20.11% oxygen, 2.13% carbon dioxide and 3.0% argon. Calibration of the water vapor output was achieved using the existing relative humidity and temperature at the sample point. The system outputs were as follows in torr (MM Hg).

N_2	565
O_2	153.5
CO_2	16.38
Ar	23.3
H_2O	5.5
P_{TOTAL}	763.7

Theoretical outputs in torr are as follows:

N_2	563.6
O_2	151.5
CO_2	16.05
Ar	22.6
H_2O	5.5
P_{BAR}	759

The variations between theoretical output and the instrument outputs (error) are as follows:

N_2 + 1.4	Torr	out of 563.6 torr
O_2 + 2.0	Torr	out of 151.5 torr
CO_2 + 0.33	Torr	out of 16.05 torr
Ar + 0.70	Torr	out of 22.6 torr
H_2O 0.00	Torr	--
P_{TOTAL} 4.7	Torr	out of 759 torr

Figure 8 is a graphical representation of the data presented in Tables 1-2a, 1-2b, and 1-2c. For clarity, it should be noted that on 30 September 1970, shortly after 1145 and prior to 1334 hours, a line of data was taken with a time of 0015 hours. It has been assumed that the time was actually 1215 hours. It should also be noted that at 1143, 2 October 1970, a line of data was taken which would indicate that 1584.4 torr of oxygen was present. Since the digital voltmeter can physically display only 3 1/2 digits, 199.9 being the largest, it has been assumed that the oxygen data was entered on the log sheet incorrectly.

The first and last sets of data presented on the graph, Figure 8 , were taken by Perkin-Elmer personnel and are circled for identification.

At 1029 on 3 October 1970, the Undersea Atmospheric Sensor System was recalibrated on Perkin-Elmer calibration gas. The calibration sample was the same that was used previously; 74.8% nitrogen, 20.11% oxygen, 2.13% carbon dioxide, and 3.0% argon. The system outputs were as follows:

N_2	566
O_2	153.8
CO_2	16.18
Ar	23.2
H_2O	6.1
P_{TOTAL}	765.28

Theoretical outputs in torr are as follows:

N_2	563.17
O_2	151.4
CO_2	16.04
Ar	22.58
H_2O	6.1
P_{BAR}	759

The variations between theoretical outputs and actual outputs after the five day sea trial are as follows:

N_2	+ 2.84	Torr out of 563.17 torr
O_2	+ 2.4	Torr out of 151.4 torr
CO_2	+ 0.14	Torr out of 16.04 torr
Ar	+ 0.62	Torr out of 22.6 torr
H_2O	0.00	Torr --
P_{TOTAL}	6.28	Torr out of 759 torr

Comparing the instrument calibration prior to the five day sea trial with the calibration verification after the sea trial, it can be seen that the instrument performance has remained within 1% on all parameters.

APPENDIX 2

EVALUATION OF A FOUR GAS MASS SPECTROMETER USED FOR ATMOSPHERIC CONTROL DURING THE NINETY DAY TEST

By Michael R. Ruecker

SUMMARY

The design and performance of a Mass Spectrometer Atmospheric Sensor System which was utilized for monitoring and control of the atmosphere of a manned space station simulator during a 90 day test is reviewed. The instrument was a modified Two Gas Atmosphere Sensor System which was operated with a new closed loop electronics control system for improved long term stability. Based upon calibration verification data taken during the 5-day and 90-day runs the instrument was demonstrated to hold its calibration within one percent for nitrogen, two percent for oxygen and three percent for carbon dioxide for a period of 132 days. It also monitored water vapor partial pressure. The output signal from the oxygen channel was employed by an atmosphere control system for maintaining the oxygen partial pressure of the Space Station Simulator. The instrument demonstrated its ability to perform reliably and its potential value as equipment for ECS applications.

INTRODUCTION

In 1965 a phased program was initiated with Langley Research Center aimed at the development of a mass spectrometer system for monitoring the major constituents of a buffered two gas atmosphere as well as the primary metabolic products of respiration. The Two Gas Atmosphere Sensor System, a single focusing magnetic sector mass spectrometer, evolved from this program, which was capable of continuously monitoring nitrogen, oxygen, carbon dioxide, and water vapor. An engineering test model and four prototype units were fabricated on this program. One of these units is shown in Figure 9. These instruments have been employed in several applications for atmospheric and respiratory measurements in various laboratories, a space station simulator and two undersea habitats. One of these applications was in conjunction with the 60-Day Manned Space Cabin Simulator Test in 1968. At that time the Two Gas Atmosphere Sensor System was operated externally to the Space Cabin Simulator with a laboratory vacuum system, and sampled the cabin atmosphere through a capillary-bypass inlet system.

In the most recent application, the subject of this paper, one of the original instruments was refurbished, equipped with updated electronics, repackaged with a close coupled ion pump and a direct entry sample inlet system, and mounted inside the Space Station Simulator where it monitored the partial pressures of oxygen, nitrogen, carbon dioxide, and water vapor. The output signal of the mass spectrometer's oxygen channel was provided as the input to the atmospheric control system which controlled the oxygen partial pressure. The performance of the combined system was more than adequate to hold the oxygen partial pressure within the limits required for constant physiological functioning of the crew.

PRINCIPLES OF OPERATION

The Two Gas Atmosphere Sensor System is a single focusing magnetic sector mass spectrometer that is designed to provide four simultaneous outputs that are proportional to the partial pressures of N_2, O_2, CO_2 and H_2O. The fundamentals of the operation of the mass spectrometer are diagrammed in Figure 10. A small quantity of the gas sample to be analyzed is continuously introduced to the mass spectrometer through a molecular inlet leak. The characteristics of this leak allow each constituent of the sample to flow through the leak independent of the other components. The resulting partial pressures within the ion source are proportional to the corresponding partial pressures in the sample environment.

The ion source performs the function of ionizing part of the gas to form charged particles which are then acted upon by the electrostatic and magnetic fields within the instrument. Ionization is accomplished by bombardment of an electron beam which is derived from a hot wire filament. The ions are repelled from the ionizing region, focused by an electrostatic lens and passed through the ion source exit slit into the magnetic sector. A permanent magnet provides a uniform magnetic field through which the ion beam passes within the vacuum envelope. The ions are deflected into circular arcs by the magnetic field, their radii being proportional to the square root of the mass to charge ratios of the ions. Since all of the ions of interest are singly charged, the radii are proportional to $m^{\frac{1}{2}}$. Consequently, the ions are dispersed as they leave the magnetic field and collected by four Faraday cage type collectors located along a focal plane. The collectors are attached to single pin feedthroughs that pass the current through the vacuum envelope to four electrometer amplifiers that amplify the small currents to provide output voltages which are proportional to the ion currents. The output signals are therefore proportional to their respective partial pressures. The internal vacuum necessary for operation of the analyzer is maintained by a suitable high vacuum pump which is connected to the mass spectrometer by means of a pump tube.

The Two Gas Atmosphere Sensor mass spectrometer analyzer assembly is shown in Figure 11. The vacuum envelope, permanent magnet, single pin feedthroughs and the pump tube are clearly visible. The multipin feedthroughs that are visible in the ion source housing provide the voltages that operate the ion source filament and focusing electrodes.

REQUIREMENTS FOR THE 90-DAY TEST

The requirements for the 90-Day Space Station Simulator (SSS) application were to monitor the partial pressures of nitrogen, oxygen, carbon dioxide, and water vapor using a modified Two Gas Atmosphere Sensor. The principal requirements are summarized in Table 2-1.

The instrument was to be located within a specified volume within the SSS and to give continuous outputs within a specified tolerance for the entire 90-day period without requiring recalibration. In order to provide information for engineering evaluation of the instrument's performance, a method of making calibration verification was required. The instrument was to be provided with the necessary support equipment to maintain its internal vacuum through a power failure. Dual outputs were necessary for internal signal monitoring by meters as well as voltage outputs to be monitored by the computer system external to the SSS.

TABLE 2-1

Requirements for 90-Day SSS Atmospheric Sensor

Monitored Species:	H_2O, N_2, O_2 and CO_2
Monitored Masses:	m/e 18, m/e 28, m/e 32, and m/e 44
Full Scale Ranges:	20 torr, 500 torr, 200 torr and 120 torr respectively
Total Pressure:	Nominally 10 lbf/in^2 abs or 517 torr
Configuration:	Limited size consistent with available space and commercial support components
Operating Controls:	None for normal operation. Inlet system valving for initial setup and calibration verification. Power on-off, ion pump and emission current adjusts.
Maintenance:	None
Outputs:	Internal: four meters Remote: four buffered, linear, zero to 5 volt
Performance Monitors:	Anode current, ion pump current, and battery voltage
Sample Inlet:	Sample transport line w/3 inch H_2O head
Nominal Accuracy:	±2% of full scale for N_2 and O_2 ±3% of full scale for CO_2 ±5% of full scale for H_2O
Environment:	Compatible with operation in the Space Station Simulator

SYSTEM DESCRIPTION

The description of the 90-Day SSS Atmospheric Sensor is facilitated by considering its major system components which are: first, the sample inlet and calibration inlet system; second, the mass spectrometer subsystem including its vacuum pump; and third, the support electronics subsystem which includes the electronics required to operate the analyzer and ion pump as well as the output circuits. A block diagram of the system is shown in Figure 12 and can be used for reference in the following discussion. The sample and calibration inlet system shown in the upper left hand corner of Figure 12 is shown in greater detail in Figure 13 with the front panel of the system shown in Figure 14.

To simplify the system description, each part of the system referred to has been assigned an index number as shown in Figures 13 and 14. Sample gases enter the inlet system from the one-eighth inch sample line at the sample inlet point (1). The sample gas then passes through a needle flow control valve on the front panel of the instrument (2). After passing through the flow controlling valve the sample gas goes to the mode selector valve (3) which determines the mode of operation, that is, operating in the calibration mode or the normally operating sample mode. After passing through the mode selector valve the gas is filtered by a two stage inline filter (4). On the sample outlet corresponding sets of filters (5) are present. The gas mixture then passes through a sample flowmeter (6), which measures the rate of gas flow through the instrument, and therefore, allowing the pressure drops through the inlet system to be checked. After passing through the flowmeter the sample travels past a total pressure transducer (16) and out the sample vent (17). Between the double filters the gas passes through the variable leak valve (7). This variable leak valve is fitted with a temperature control system. The heater switch (8) controls the heater for the inlet valve. The calibration gas mixture is stored in a pressure tank (9) with regulator (10). Passing through the regulator the sample gas goes to a protection shutoff valve (14), and then to a needle flow control valve (15), then to the selector valve (3). Part of the gas to be sampled (either in the sample gas or the calibration gas) passes through the restriction in the leak valve and through a small diameter line (11) into the mass spectrometer (12), and finally to the ion pump (13). There is a roughing valve (25) located within the analyzer chassis for initially pumping down the instrument. The conductance of the variable leak valve can be adjusted by means of a slotted screw adjustment (28) on the front panel. The ion currents coming out of the mass spectrometer are detected and amplified by four electrometers. The electrometer outputs go to the output meters (26) and also to buffered outputs. The zero levels of the electrometers can be checked by pressing the press to test button (27) which cuts off the ion beams. The main power to the mass spectrometer is provided by a 28 Vdc power supply, requiring a 115 volt ac input.

There is a front panel switch (18) that controls the operation of the 28 volt power supply. Other items on the front panel are the ion pump meter switch (19) and the ion pump current meter (20). These monitor the current flowing to the ion pump from the high voltage supply, and therefore, indirectly monitor the analyzer pressure. There are two other meters on the front panel of the Analyzer Control Module. One of these is the battery voltage indicator (21). This indicates the stage of readiness of the emergency batteries that are used for powering the ion pump in a power off situation. The other front panel meter is the anode current meter (22). This meter measures the anode current and gives an indication of the sensitivity at which the source is being operated. The anode current may be adjusted only in open-loop mode by the anode current adjustor potentiometer (23). The mode of operation, open or closed loop, is controlled by a selector switch (24) on the front panel.

An important feature of the system is the closed loop mode of operation which automatically compensates for any common mode variations. The four electrometer outputs are scaled to provide signals that are all proportional to pressure with the same volt per torr sensitivity and summed to give a "total pressure" signal. Since the four components of interest comprise essentially all of the atmosphere this signal can be compared with the output of a total pressure transducer, which is reflecting the true pressure seen by the sample inlet system. The resulting error signal represents the sensitivity error of the mass spectrometer. This signal is fed back to the emission regulator that controls the level of ionizing electron current in the ion source and, thereby, the levels of the ion currents which are detected at the collectors. In this way the summation of the partial pressures is held at the prevailing ambient pressure level and, consequently, common mode variations due to such factors as changes in the inlet leak conductance or ion source sensitivity are eliminated. This method of operation represents a significant improvement in mass spectrometer design and allows a high level of accuracy to be maintained for a long period of time.

Other elements of the system, which are shown in Figure 12, are the power supplies that provide voltages to the ion source, the ion pump and its high voltage power supply, the power supply system, the front panel control and monitoring functions, and the output buffer amplifiers.

The complete 90-Day SSS Atmospheric Sensor is shown in Figure 15 and the internal construction of the upper and lower bays is shown in Figures 16 and 17 respectively. The upper bay contains the mass spectrometer, ion pump, their support electronics, the sample inlet and calibration inlet systems, and the calibration gas supply. The lower module houses the main power supply, the battery pack and charger, the buffer amplifiers, output and monitoring meters, and the buffer amplifiers and pressure transducer power supplies.

CALIBRATION

The Atmospheric Sensor was calibrated using a calibrated gas mixture of N_2, O_2 and CO_2. In order to calibrate the instrument as close as possible to the expected operating conditions the calibration gas was admitted to a laboratory inlet system in which the pressure was held at 10 lbf/in^2 abs (psia) (517 torr) and from this reservoir it was introduced into the mass spectrometer inlet system. The volt per torr sensitivity at the electrometer amplifier output of each channel was computed and this information was utilized to adjust the summing resistors so that the current arriving at the summing junction of the summing operational amplifier from each channel has the same ampere per torr sensitivity. Then the gains of the buffer amplifiers are set so that the proper full scale value for each channel is achieved at five volts. During the dry gas calibration the pressure was exercized between 400 and 634 torr to verify that the channels were tracking pressure. This is a ±22.6 percent pressure variation which is much greater than the expected variation of the Space Station Simulator atmospheric pressure. The final calibration data over this pressure range is shown in Table 2-2.

TABLE 2-2

Table of Calibration Errors at Final Calibration

Pressure	Error		
	N_2	O_2	CO_2
400 torr	+0.37%	-0.85%	-2.86%
517 torr	-0.01%	+0.01%	+0.31%
634 torr	-0.29%	+0.58%	+2.87%

The water vapor channel was calibrated by allowing the inlet system to sample laboratory air and comparing the H_2O electrometer output with the partial pressure, as computed from the relative humidity indicated by a wet bulb - dry bulb Mason's form hygrometer. Since the instrument was sampling at one atmosphere during this test the variable inlet leak valve was closed down to maintain the normal internal partial pressures. The water sensitivity was compared with the nitrogen sensitivity as determined from the air composition and this data was utilized to set the water vapor channel summing resistor and buffer amplifier gain.

OPERATIONAL RESULTS

During the 5-day test run the calibration of the Atmospheric Sensor was verified twice by admitting a calibration gas sample. During the first verification the gains of the buffer amplifiers for the dry gas channels were reset. The oxygen buffer amplifier gain had somehow shifted during the process of shipment, inspection and installation. The other buffer amplifiers were very close to their proper values. The data from this calibration verification and a second one taken later during the run is shown in Table 2-3. In both cases the error is less than one percent on all dry channels.

During the 5-day test it was found that the water vapor channel was reading high compared with the Cambridge Dew Point Hygrometer. The dew point indicator was reading 11.3 torr while the mass spectrometer was reading 23.1 torr, with a buffer amplifier output of 4.68 volts. Just prior to the end of the run the buffer amplifier was adjusted to give an output of 2.82 volts based upon an 11.3 torr partial pressure and a desired system gain of 20 torr/ 5 volts. This correction gave the proper water output, but it did not correct the summing resistor for the water channel, which was also apparently in error. One effect of this adjustment is seen in the data presented in Figure 18. This shows the error between the sum of the partial pressures as indicated by the mass spectrometer and the total cabin pressure as measured by the Wallace-Tiernan gauge. During the 5-day run the sum of the partial pressures agreed with the total pressure within one percent or better except for the final reading which was 2.9 percent low. This final value was taken after the water vapor channel was readjusted. This additional two percent error amounts to an error of 10.5 torr at 525 torr total pressure, which is very nearly equal to the 11.8 torr error that existed in the water output prior to adjustment of the buffer amplifier.

This error results from the action of the closed-loop, which makes up for the erroneously high H_2O electrometer amplifier output by dropping the ionizing current to achieve the correct total pressure. Reduction of the H_2O buffer gain led to a low value for the summation of the partial pressures.

TABLE 2-3

Results of Calibration Verification During the 5-Day Test

	ERRORS, PERCENT			
	N_2	O_2	CO_2	pp
INITIAL	+0.23	+0.23	+0.47	+0.23
FINAL	-0.91	-0.71	-0.70	-0.84

During the 90-day test the Atmospheric Sensor performed without malfunction. Five calibration verifications were run during the course of the test and the data from these is presented in Table 2-4. This data shows that the mass spectrometer maintained its calibration within very close tolerances. The last adjustment of the instrument was made on 30 April 1970. Therefore, the analyzer maintained its calibration on N_2, O_2, and CO_2 within 0.9, 2.1 and

2.7 percent respectively for a period of 132 days. The sum of the dry gas partial pressures remained within 0.84 percent during the same period. It is difficult to evaluate the performance of the instrument by any means other than the calibration verification data. Typical output data for the instrument is shown in Figures 19 through 21. This data was taken from the computer reduced data obtained on the MDAC Low Speed Data Acquisition System at 1800 hours on each day of the test. This time was selected because it was considered the most "normal", with the least unprogrammed activity, and should give a more representative picture of the cabin atmosphere from day to day.

Figure 19 shows the variations in the oxygen and nitrogen partial pressures; Figure 20, the variations in the carbon dioxide and water vapor partial pressures; and Figure 21, the variation the cabin pressure, the sum of the partial pressures and the difference between these two values. A cursory review of the data has indicated that the fluctuations in the partial pressures are usually accounted for by specific known events that occurred within the SSS. The oxygen partial pressure was controlled within a total variation of 2.9 torr or better than ±1 percent. The total pressure variations are much wider primarily due to a lower gain in the nitrogen make up portion of the atmospheric control system. The variations in the carbon dioxide and water vapor partial pressures reflect changes in the status of the solid amine and molecular sieve CO_2 scrubber systems. The summation of the partial pressures is consistently low because of the incorrect summing resistor in the water channel as predicted by the last data point taken during the 5-day test run. This effect from the water channel is further substantiated by comparing the correlation between the water vapor output and the error in the summation of the partial pressures. Note that whenever the water vapor level goes up the summation of the partial pressures goes down and visa versa. This is exactly what was expected from a detailed analysis that was made of the interchannel effects of an incorrectly established summing resistor.

TABLE 2-4

Results of Calibration Verification During the 90-Day Test

		Error, Percent			
DATE	TIME	O_2	N_2	CO_2	pp
6-13	1315	+1.1	+0.1	-1.5	+0.4
6-18	1902	+0.7	-0.4	0.0	0.0
7-8	1135	+0.9	-0.6	+0.8	0.0
7-13	1346	+1.3	-0.5	+0.6	0.0
9-9	0250	+2.1	-0.3	+2.7	+0.1

During the course of the 90-day test it was found that the CO_2 output of the mass spectrometer was not in agreement with the infrared analyzer. Consequently, on 21 August 1970 a portion of the gas utilized to make the initial calibration of the mass spectrometer was sent to the laboratory that made the original mixture analysis. The results are shown in Table 2-5.

TABLE 2-5

Comparison of Calibration Gas Analyses

	Mixture 7130P	
Component	1/30/70	8/21/70
Nitrogen	66.166	66.336%
Oxygen	31.271	31.632%
Carbon Dioxide	2.544	2.012%

Note that the calibration for CO_2 changed by more than 20 percent. If the later calibration figures are utilized the agreement with the infrared analyzer is very close. There is no reason to suspect that the calibration gas changed during this period, and therefore, it must be concluded that the original calibration was in error.

At the conclusion of the 90-day test the Atmospheric Sensor was shut down and returned to Perkin-Elmer Aerospace Division where it is now being operated on laboratory ambient atmosphere for a period of 180 days.

CONCLUSIONS

The Atmospheric Sensor was shown to be a reliable and accurate instrument for monitoring nitrogen, oxygen, carbon dioxide, and water vapor during the course of the 90-Day Manned SSS Test. It demonstrated its capability not only to monitor these constituents but to provide outputs that could be utilized by an atmospheric control system for regulation of the primary atmospheric constituents of a closed environment. The closed-loop operating mode controlled the sensitivity of the mass spectrometer so that it could operate for a period of 132 days without a calibration. The accuracy of the outputs was affected by the initial calibration which was found to be in error because of a faulty calibration technique in the case of water vapor, and an inaccurate calibration gas mixture in the instance of carbon dioxide. These procedural matters have been rectified and should allow the Atmospheric Sensor to perform to its full capability in future applications.

The 90-Day Manned SSS Test was intended to prove out equipment for application to future space stations. It is therefore important to assess the feasibility of reducing the size, weight and power of the Atmospheric Analyzer to levels that are compatible with a flight program. A contract, under the direction of NASA Manned Spacecraft Center, is currently in progress for the development of a flight qualified Mass Spectrometer Atmospheric Sensor System (MASS) as well as a modified version to be used as a respiratory gas analyzer as part of the M-171 Metabolic Analyzer which will be used in Skylab in 1972. A photograph of the instrument is shown in Figure 22.

These units are fully self-contained, requiring only a sample inlet and bypass line, a small diameter vacuum line to outer space for initial roughing of the mass spectrometer, system power, and command functions for the ion pump mass spectrometer electronics, open-loop/closed-loop control, and selection of one of the dual ion source filaments. The system is fully protected against operation at excessive pressures and provides status indicator outputs on all important functions that can change during operation. The inputs and outputs are fully isolated and protected and the instrument has sample inlet heaters and ion source temperature control for improved performance.

The design is fully compatible with Apollo and Skylab environments including a 38 lbf/in^2 abs over-pressure requirement. The atmospheric monitoring version of this instrument measures the partial pressures of hydrogen, water vapor, nitrogen, oxygen, carbon dioxide, and hydrocarbons in the mass range 50 to 120 u (amu). The final configuration of this system weighs 21 pounds, requires 19 watts of power during normal operation and has a cylindrical enclosure with a diameter of 7.2 inches and a length of 12.5 inches. The first design verification test unit of the MASS is scheduled for delivery to NASA/MSC in November 1970.

APPENDIX 3

OPERATION AND MAINTENANCE MANUAL
UNDERSEA ATMOSPHERIC SENSOR

Revised

16 October 1970

Perkin-Elmer SPO 30006
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Prepared for
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DESCRIPTION AND OPERATION

The Undersea Atmospheric Sensor (Figure 23) is a mass spectrometer system which continuously monitors the following atmospheric constituents: water vapor, nitrogen, oxygen, argon, and carbon dioxide. A functional block diagram of the system is shown in Figure 24.

The following brief discussion of the system is given as an overall familiarization with the instrument. The sample to be monitored enters the sample inlet when the sample shutoff valve is opened. It passes through a double filter and then through the bypass line in an inlet leak valve. It continues through a flow meter, another double filter assembly, a flow control valve, and finally to the sample transport pump where it is exhausted to the atmosphere. A small portion of this sample is admitted to the mass spectrometer (called the analyzer) when the leak valve is open. This gas passes into the ion source where it is ionized and the resulting charged particles are resolved in the magnetic field of the analyzer magnet to form separate beams of ion current. The ion current strikes individual collectors located at the proper positions for the masses of interest. This instrument monitors water vapor at mass 18, nitrogen at mass 28, oxygen at mass 32, argon at mass 40, and carbon dioxide at mass 44. The ion current is converted to electron current in the leads attached to the collectors. These leads pass through single-pin feedthroughs to electrometer amplifiers. The amplifiers amplify the currents, which are in the range of 10^{-14} to 10^{-10} amperes, to provide full-scale output voltages of the order of -10 volts. The output signals are scaled by a voltage divider network and then displayed on digital voltmeters which are calibrated in torr (mm of Hg).

A central feature of the mass spectrometer is its closed loop electronic control system which automatically controls the gain of the mass spectrometer against any common-mode errors. This is accomplished by scaling each of the electrometer outputs to give an output voltage which is proportional to torr (i.e., each channel is scaled to have the same gain, since 1 torr of oxygen is the same as 1 torr of nitrogen, etc.). At this point the outputs are summed with an operational amplifier to give a total pressure signal. This signal is compared with the output of a total pressure transducer which is located in the sample inlet line, and the error signal is fed back to the emission regulator where it is used to control the filament drive and the resulting ionizing current.

Other components of the electronics subsystem are the power supply system consisting of the following: 1) an EMI filter and transformer; 2) an electrode bias supply and voltage divider network, which provides voltages to operate the ion source; and 3) the B+ and B- supply for the electrometer amplifiers, summing amplifier, and total pressure transducer amplifier.

In addition to the inlet system, analyzer, and electronics subsystem described above, there is a vacuum support system. Most of these components are located in the upper module, whereas the inlet system, analyzer, and electronics subsystem are located in the lower module. A 20 liter/second ion pump provides the primary vacuum required for the operation of the mass spectrometer. It is attached to the analyzer by means of a vacuum adapter which also interfaces the thermocouple gauge, the roughing line, and the ionization pressure gauge (for laboratory use only). The ion pump is operated by a 5 kV power supply, and is controlled by the output of the thermocouple gauge, so that it can only turn on when the pressure is below a preset level. The ion pump current, which indicates the internal pressure, is sensed by an overpressure protection circuit which inhibits the mass spectrometer electronics unless the ion pump pressure is less than 1.5×10^{-6} torr (500 μA).

When the pressure is above the point at which the ion pump can turn on, it is necessary to rough down the system through the roughing valve. This is accomplished by a mechanical rough pump which is protected by a molecular sieve trap to prevent backstreaming oil vapors from contaminating the analyzer.

Also housed in the upper module is a temperature controller which drives the heaters on the inlet leak valve and the connecting line to the analyzer.

The Undersea Atmospheric Sensor is housed in three modules:

a.	Display Module:	Contains four digital output meters.
b.	Upper Module:	Contains vacuum support components and the inlet leak valve temperature control.
c.	Lower Module:	Contains the analyzer, mass spectrometer electronics, inlet system, and ion pump.

The Upper and Lower Modules are covered with separate panel covers which may be removed with quarter-turn fasteners (Figure 25).

Table 3-1 along with Figures 26 (a-c) identify all system controls which will be discussed in this manual.

TABLE 3-1

Controls and Monitors

	NO.	CONTROL OR MONITOR	LOCATION		TITLE	FUNCTION	REMARKS
			MODULE	AREA			
See Figure 26a	1.	Nitrogen Display Meter	Display	Upper Left	N_2	Displays the nitrogen partial pressure in torr.	
	2.	Oxygen Display Meter	Display	Lower Left	O_2	Displays the oxygen partial pressure in torr.	
	3.	Carbon Dioxide Display Meter	Display	Lower Right	CO_2	Displays the carbon dioxide partial pressure in torr.	
	4.	Water Vapor Display Meter	Display	Upper Right	H_2O	Displays the water vapor partial pressure in torr.	Also displays 15 other parameters as selected by monitor switch.
See Figure 26b	5.	Ion Pump "On" Light	Upper	Upper Left	High Voltage	When lit, indicates that high voltage is being applied to the ion pump.	Lights when the adjacent circuit breaker is turned on.
	6.	Ion Pump "On" Breaker	Upper	Upper Left	(None)	Turns on the ion pump power supply.	
	7.	Ion Pump "Start" Light	Upper	Middle Left	Start	Indicates when the start-run switch is in the start mode.	Start mode allows maximum (150 μA current for starting. Run mode turns off the ion pump at or above 4 x 10^{-5} torr. (10 μA)
	8.	Ion Pump "Start-Run" Switch	Upper	Middle Left	Start-Run	Places the ion pump power supply in the start or run mode.	

TABLE 3-1 (Cont)

See Figure 26b

NO.	CONTROL OR MONITOR	LOCATION		TITLE	FUNCTION	REMARKS
		MODULE	AREA			
9.	Ion Pump Control Meter	Upper	Upper Center	None	Indicates ion pump current, pressure, or voltage as selected by the Range Selector Switch .	Ion pump current is proportional to the internal pressure. See Figure 27.
10.	Ion Pump Meter Range Selector Switch	Upper	Upper Right	Range Selector	Selects ion pump current range, pressure or voltage.	
11.	Thermocouple Gauge Readout Meter	Upper	Lower Left	Analyzer Pressure	Indicates the internal pressure in microns (black needle).	
12.	Thermocouple Gauge Set Point Control Knob	Upper	Lower Left	None	Sets the trip point (red needle) below which the ion pump is allowed to turn on.	Set so that the trip point occurs when the indicated pressure is 10 μ.
13.	Rough Pump On-Off Circuit Breaker	Upper	Lower Left	Rough Pump	Turns on the rough pump to initially evacuate the system.	Normally off.
14.	Trap Heater On-Off Switch	Upper	Lower Center	Trap Heater	Turns on the molecular sieve trap for regeneration of the trap.	Disconnected.
15.	Current Relay Power On Light	Upper	Lower Right	Power	Light turns on when the ion pump control is turned on.	Redundant to the high voltage light.
16.	Ion Pump Current Set Point Selector Switch	Upper	Lower Right	None	Sets the ion pump current below which the mass spectrometer electronics are allowed to turn on.	Set at 500 μA. Trips at about 440 μA.

TABLE 3-1 (Cont)

	NO.	CONTROL OR MONITOR	LOCATION		TITLE	FUNCTION	REMARKS
			MODULE	AREA			
See Figure 26b	17.	Ion Pump Current Relay Light	Upper	Lower Right	Relay Light Energize	Light turns on when ion pump current is below the relay set point.	Mass spectrometer electronics can be turned on when light is on.
See Figure 26c	18.	Inlet Leak Valve Control Knob	Lower	Lower Left	None	Turning the double knurled knob CCW opens the inlet leak admitting sample gas to the mass spectrometer.	Caution must be used when adjusting valve. Monitor the ion pump current meter (200 µA range). There will be no indication for a few turns but then the pressure rises very rapidly.
	19.	Sample Shut Off Valve	Lower	Upper Left Center	Sample Shut Off	When opened this valve allows sample gas to flow through the inlet system.	Use for shut off only.
	20.	Flow Control Valve	Lower	Upper Left Center	Flow Control	Adjusts the flow rate of sample gas through the sample inlet system.	Not to be used for shut off.
	21.	Flow Meter	Lower	Upper Center	None	Indicates the flow rate of sample gas through the inlet system in CFM.	Normally set at 0.015 CFM
	22.	Sample Transport Pump On-Off Switch	Lower	Center	Trans. Pump	Turns on the sample transport pump which pulls sample gas through the inlet system.	
	23.	Fuse Holder	Lower	Left Center	F2-3A	3 amp fuse in sample transport pump power line	

TABLE 3-1 (Cont)

See Figure 26c

NO.	CONTROL OR MONITOR	LOCATION		TITLE	FUNCTION	REMARKS
		MODULE	AREA			
24.	Fuse Holder	Lower	Right Center	F3-5A	2 amp fuse in valve heater power lines	
25.	Roughing Valve	Lower	Lower Center	Rough Valve	This valve is opened (CCW) when it is desired to initially evacuate the analyzer during a pump down cycle.	DO NOT TOUCH unless it is intended to rough down the analyzer.
26.	System Power Circuit Breaker	Lower	Lower Center	System Power	Primary power circuit breaker for entire system.	The thermocouple gauge and two cooling fans are directly turned on by this breaker.
27.	Mass Spectrometer Power "On-Off" Switch	Lower	Lower Right Center	M/S	Turns on the mass spectrometer electronics when not inhibited by the ion pump current relay.	
28.	Filament Select Switch	Lower	Lower Left Center	Fil 1-Fil 2	Selects which ion source filament the mass spectrometer is operating on.	Initially set on filament #2. Switch only if a filament malfunction develops.
29.	Inlet Leak Valve Heater "On-Off" Switch	Lower	Lower Left Center	Heater	Turns on the inlet leak valve heater and temperature controller.	
30.	Open Loop Emission Adjust Potentiometer	Lower	Lower Left Center	Emission Adjust	Adjusts the emission when in open loop mode and sets the maximum closed loop emission.	

TABLE 3-1 (Concluded)

See Figure 26c

NO.	CONTROL OR MONITOR	LOCATION		TITLE	FUNCTION	REMARKS
		MODULE	AREA			
31.	Loop Mode Switch	Lower	Lower Left Center	Loop Mode	Selects system control mode - open or closed.	Normally set to closed.
32.	Zero Check Push Button	Lower	Lower Left Center	Zero Check	Used only in open loop mode to check electrometer zeros.	
33.	Test Mode Selector Switch	Lower	Lower Extreme Left	Test Monitor	Switches the H_2O digital panel meter to various test points throughout the system. See Table 3-2.	Normally set on H_2O.
34.	Fuse Holder	Lower	Lower Left Center	1/2 ASB	M/S electronics fuse.	
35.	Ion Gauge	Lower	Lower Center	None	Ionization gauge for initial laboratory setup. Requires ionization gauge controls for operation.	Function not required for normal operation of system.

UNDERSEA ATMOSPHERIC SENSOR OPERATING PROCEDURES

INITIAL PUMP DOWN PROCEDURE (Reference Paragraph 2-1)

a. Remove the front cover panel.

b. Check the following switches. They should be in the positions indicated:

1.	System power	OFF
2.	M/S power	OFF
3.	Ion pump control power	OFF
4.	Rough pump	OFF
5.	Loop mode	OPEN
6.	Filament select	FIL #1 or #2
7.	Ion pump, start-run	START
8.	Ion pump range selector	200 mA
9.	Emission adjust	Full CCW
10.	Test monitor switch	H_2O

c. Check the following controls. They should be in the positions indicated:

1.	Sample shut off	Closed
2.	Variable leak valve	Closed
3.	Roughing line valve	Closed

d. Set the SYSTEM POWER circuit breaker switch to ON. This energizes the fans and the thermocouple gauge control (analyzer pressure).

e. Allow the Thermocouple Gauge to warm up for a few minutes and observe the reading. If the reading is less than or equal to 10 microns, the ion pump may be started immediately. (See Step i.) If the pressure remains above 10 microns, continue to the next step.

f. Set the ROUGH PUMP circuit breaker to ON. This commences the pump-down of the roughing line.

g. Wait 10 minutes for the line to pump down.

h. Open the ROUGHING LINE VALVE. This begins the evacuation of the analyzer.

i. Observe the Thermocouple Gauge, and when the pressure approaches 10 microns set the ION PUMP CONTROL power circuit breaker to ON. The ion pump control will remain inhibited until the pressure reaches 10 microns, at which time it will turn on automatically.

CAUTION

> From the time the operator turns on the ion pump control power until the ion pump control is switched to RUN, the operator must remain in attendance.

j. Observe the ion pump control meter and watch for a current indication on the 200 milliampere range. When the control unit switches ON there will be an indication on the meter. Also the power on (HIGH VOLTAGE) light will illuminate.

k. When the ion pump turns ON as indicated above, immediately close the ROUGHING LINE VALVE.

CAUTION

> Prolonged operation of the ion pump with the ROUGHING LINE VALVE open can damage the ion pump.

ℓ. Continue to observe the pumpdown of the analyzer on the Ion Pump Control Meter. As the pressure reduces, the ion pump current will go down and its progress can be observed by turning the RANGE SELECTOR switch as indicated in the table below. The ion pump pressure can be checked by referring to Figure 27 which gives the correlation between pressure and current.

RANGE	RANGE SWITCH POINT	NEXT RANGE
200 mA	2	20 mA
20 mA	2	2 mA
2 mA	2	200 μA
200 μA	2	20 μA
20 μA	2	----

m. When the ion pump current reaches 200 μA, the M/S power toggle switch may be turned ON. This turns on the mass spectrometer electronics. The ROUGH PUMP switch may now be turned OFF and the VALVE HEATER should now be turned ON.

n. Wait 5 minutes for the electronics to warm up and then observe the outputs as indicated by the four digital meters. The outputs should be less than the values indicated in the table below. The Argon output can be checked by turning the TEST MONITOR switch to AR.

CHANNEL	ACCEPTABLE ZERO LEVEL (In Digits)
Nitrogen (N_2)	001.
Oxygen (O_2)	±000.1
Carbon Dioxide (CO_2)	± 00.1
Water Vapor (H_2O)	± 00.1
Argon (AR)	± 00.1

o. After the zero levels have been established the mass spectrometer background outputs can be established. Turn the TEST MONITOR switch to ANODE CUR, and then slowly turn the EMISSION ADJUST clockwise (CW), until a reading is seen on the TEST MONITOR meter. Continue turning the EMISSION ADJUST until output of the TEST MONITOR digital meter reads 20.0; this corresponds to 20 μA anode current.

p. When the emission current is set the outputs as read on the digital meters will indicate the background signal existing within the analyzer. As the analyzer warms up due to the heat input from the filament and the valve, the Water output may rise but it should go back down. After the valve heater has been on 1 hour, the background levels should be below the values shown in the following table. The VALVE TEMP position of the TEST MONITOR selector switch should indicate 20.0 to 22.0. Again Water and Argon are checked by operating the TEST MONITOR selector switch to the desired locations.

OUTPUT	ACCEPTABLE BACKGROUND LEVELS (Torr)
Nitrogen (N_2)	000.
Oxygen(O_2)	000.2
Carbon Dioxide (CO_2)	00.1
Water Vapor (H_2O)	00.5
Argon (AR)	00.1

q. After establishing the background levels the sample may be introduced. Turn ON the sample TRANS PUMP and turn the SAMPLE SHUT OFF valve to full OPEN.

r. Adjust the FLOW CONTROL valve until a flow of 0.015 CFM is read on the Flow Meter.

s. Turn the Ion Pump Control RANGE SELECTOR switch to 200 μA.

t. Admit the sample to the mass spectrometer by opening the Inlet Leak Valve (Item 18, Figure 26c). Turn the double lock knob counterclockwise (CCW); 1 1/2 revolutions of the knob will be required before the valve starts to open. At this point turn the valve VERY CAUTIOUSLY to avoid over pressurization. Watch the ion pump control meter and bring the current up to 100 μA.

u. Turn the TEST MONITOR switch to the ANODE CUR position.

v. Adjust the EMISSION ADJUST until the anode current is 35.0 on the Digital Panel Indicator (i.e., 35.0 μA anode current).

w. Place the LOOP MODE switch in the CLOSED position. The anode current should reduce to approximately 20 μA.

x. Readjust the Inlet Leak Valve until the anode current is 20.0 μA. The ion pump current should be very nearly 100 μA.

y. Turn the TEST MONITOR selector switch to H_2O.

z. The system is now operational and the outputs may be read on the Digital Display with the exception of Argon (AR).

aa. Replace the cover panels and secure.

CALIBRATION VERIFICATION

The purpose of the Calibration Verification is to determine whether the Undersea Atmospheric Sensor is in calibration. It should be realized that if a calibration gas mixture is used which does not have constituents which are known to a high degree of precision, or which is different from the mixture which was used to calibrate the instrument, then the indicated outputs may differ from the expected outputs. In this case it is necessary to consider the outputs only on a relative, day to day basis. To avoid this problem it is recommended that the calibration verification of the instrument be carried out using the gas mixture supplied by Perkin-Elmer.

a. Attach the Calibration Verification Gas Mixture to be used to the Sample Inlet Point.

b. Set a small positive pressure (less than 1 pound) on the pressure regulator and purge the inlet system for about 30 seconds by opening the FLOW CONTROL valve full CCW. Next, adjust the sample flow with the FLOW CONTROL valve to the normal flow rate of 0.015 CFM as seen on the Flow Meter. Caution must be used at this point not to over pressure this inlet system. Monitor the transducer pressure on the H_2O Digital Panel Meter by switching the TEST MONITOR Switch to PRESS (pressure). Do not exceed 80.0 (800 torr). It may be necessary to reduce the sample gas pressure regulator setting.

c. Allow 2 to 5 minutes for the calibration gas to stabilize within the inlet system and the water vapor to be removed from the inlet system. The WATER OUTPUT can be monitored to determine when a minimum output level is reached (less than 3 torr).

d. When stable outputs have been reached, compare them with predetermined values as indicated by the following computation. It is necessary to know the total applied pressure in torr (mm Hg) in order to make the comparison. This is obtained from the pressure transducer output. Set the TEST MONITOR Switch on PRESS and multiply by 10 (i.e., 76.0 = 760 torr). If the water output is significant (i.e., greater than 1 torr) when monitoring the dry gas mixture it is necessary to correct the Total Pressure by the following computation in order to correct Calibration Verification Values. Corrected Total Pressure (torr) = Cabin Pressure (torr) - H_2O Pressure (torr).

COMPONENT	PERCENTAGE (%)		CORRECTED TOTAL PRESSURE (torr)		PARTIAL PRESSURE (torr)
Nitrogen	TBD* X 0.01	X	____________	=	____________
Oxygen	TBD* X 0.1	X	____________	=	____________
Carbon Dioxide	TBD* X 0.01	X	____________	=	____________
Argon	TBD* X 0.01	X	____________	=	____________

*See percentage composition attached to calibration gas bottle.

e. Then note the partial pressures as read on the Display Module and compare them with the computed values above.

f. If the above comparison is acceptable, disconnect the Calibration Verification Gas Mixture and return to normal atmospheric sampling.

OPERATION

The Undersea Atmospheric Sensor will operate for extended periods of time without any monitoring or adjustment. The following procedure is given to allow an operator to check the system operation.

a. Record the outputs as given by the Digital Display.

b. Note any significant variations from the previous readings.

c. Add the outputs as given by the Display for Nitrogen, Oxygen, Carbon Dioxide, and Water Vapor.

d. Add 7 torr for the Argon partial pressure.

e. Compare this total to the total pressure for agreement.

f. If the outputs appear to be normal based upon these tests, then no further check is necessary.

g. If anything appears to be abnormal, a further check of the operation can be made as indicated in the following section.

OPERATION VERIFICATION

a. Verify that the sample transport line is attached to the SAMPLE INLET and that all external valving or plumbing is correct (i.e., not plugged or kinked).

b. Remove the FRONT PANEL.

c. Check to see that all switches and controls listed below are in the positions indicated.

1.	System Power Switch	ON
2.	M/S Power Switch	ON
3.	Ion Pump Control Power Switch	ON
4.	Rough Pump Switch	OFF
5.	Loop Mode Switch	CLOSED LOOP
6.	Filament Select Switch	FIL #2
7.	Ion Pump Start-Run Switch	RUN
8.	Test Monitor Switch	H_2O
9.	Sample Shut Off Valve	Full CCW

d. Check the following meter displays.

		READING	TOLERANCE
1.	Flow Meter	0.015	.010 - .020
2.	Ion Pump Current	100 μA	70 - 130 μA

e. Turn the TEST MONITOR selector switch through the first 16 positions and observe the values on the TEST MONITOR Digital Display. They should fall within the ranges specified in Table 3-2.

f. If any are out of tolerance, refer to the following section.

TABLE 3-2

Position	Nominal Value		Tolerance		Function
	Set 1	Set 2	High	Low	
1	+10.0		20.0	2.0	H_2O Output
2	+7.0		15.0	5.0	Argon Output
3	127.3	131.0	+133.0	+125.0	Regulated Elect B+
4	15.7		+17.0	+15.5	Unregulated Elect B+
5	-133.4		-145.5	-125.5	Regulated Elect B-
6	-17.0		-17.9	-16.5	Unregulated Elect B-
7	+37.0	+38.5	+40.5	+36.6	Regulated Electrode Bias
8	+36.5		+38.8	+35.8	Unregulated Electrode Bias
9	+19.7		+21.0	+19.5	High Voltage Regulator
10	+18.3		+19.0	+17.8	Emission Regulator Positive
11	-19.6		-20.5	-19.0	Emission Regulator Negative
EMSN DR	+13.0		+19.0	+10.0	Emission Regulator Drive
ANODE CUR	20.0		30.0	10.0	Anode Current
PRESS	76.0		80.0	70.0	Total Pressure Transducer
VALVE TEMP	21.0		22.0	18.5	Variable Leak Temperature
ACCELR CUR	45.0		90.0	20.0	Electron Accelerator Current

ELECTRONIC SUBSYSTEM OPERATION AND MAINTENANCE

GENERAL

The Undersea Atmospheric Sensor System should not be subdivided into independent mechanical or electrical subsystem operation but should be considered as an integral system. Each subcomponent relies upon another for proper performance. DURING SERVICE OF THE SYSTEM, NO POTENTIOMETER SHOULD BE MOVED OR READJUSTED. They have been previously set for system calibration, and readjustment would destroy calibration.

ELECTRICAL SUBSYSTEMS

The electrical subsystems can be classified into two basic categories: the electronic subsystem, and the ac power distribution system.

The electronic subsystem provides the necessary conditioned voltages and signals to power the atmospheric analyzer and provide data outputs.

The ac power distribution system provides the necessary power as well as a measure of protection for all other remaining subsystems, both mechanical and electrical. The ac power interlock protection system is primarily housed in the upper module of the Undersea Atmospheric Sensor. (Ref.: Figure 26c.)

A very useful aid, the Test Monitor Switch (Item 33, Figure 26c) is provided in the lower module. This switch allows the operator to quickly and positively identify a questionable area, should it exist, and lend to its correction with a minimum amount of effort.

The other aids for determining proper instrument operation are located in the upper module, Figure 26b.

Automatic Restart

The Undersea Atmospheric Sensor System has been carefully checked out, calibrated, and placed in stable operating condition. This instrument will remain in this stable, calibrated condition as long as uninterrupted 115 Vac, 60 cps line power is applied through the safety locked convenience outlet box provided. Should line power be interrupted for a short period - less than 30 minutes - no action should be required on the part of the operator. This instrument has been provided with adequate safeguards so that the filament will be turned off, the inlet valve closed, and the ion pump power supply turned off automatically without degrading the instrument performance or calibration. Once line power is restored, the instrument will restart automatically. In approximately 30 minutes after line power is restored, the digital outputs should again read as they did prior to the power shortage.

If for some reason, power to the instrument has been interrupted longer than 30 minutes or the thermocouple gauge readout meter (black indicator hand; Item 11, Figure 26b) reads greater than 10 microns, automatic restarting cannot be accomplished. Manual restart will be required. (Ref.: Page 79, Para 2.1, for restarting the system with the exception of 2.1c, 1 and 2.) If the procedure of Paragraph 2.1 is required, and after all switches, knobs, levels, etc., have been placed in the proper position for starting, a check of the three fuses should be made (Items 23, 24, and 34, Figure 26c). Once it has been determined that these fuses are good, the procedure on Pages 79 through 82, except c, c.1, and c.2 can be followed.

Electronic Component Failure

An undersea atmospheric analyzer engineering data book has been provided which should be maintained once a day. Should the data outputs on the data sheet vary beyond the tolerances provided in Table 3-2 and the summation of the partial pressures, barometric pressure, and pressure transducer output (position 14) not coincide any closer than 1% (7 mm Hg) some electronic component has possibly failed or is in the process of failing. Should this set of circumstances occur, the installed set of seven electronic circuit boards should be replaced in the following manner.

a. Remove front covers

b. Switch loop mode switch (Item 31, Figure 26c) into open loop.

c. Turn emission current potentiometer (Item 30, Figure 26c) full CCW (counterclockwise). Monitor output with test monitor switch in ANODE CUR position. Output will be on the water digital voltmeter channel. This should go to 00.0.

d. Turn mass spectrometer power switch off (Item 27, Figure 26c).

All seven electronic boards may now be replaced.

NOTE

The shield boards (clad on both sides) do not require replacement.

Using the card ejector at the top of each card eject one card at a time replacing it with its counterpart from the spares provided. Once all cards have been replaced and are securely installed the mass spectrometer power switch can be switched to the on position, (Item 27, Figure 26c). Turn emission adjust potentiometer up until 35.0 is read on the ANODE CUR position of the TEST MONITOR switch. Switch the LOOP MODE switch (Item 31, Figure 26c) into the CLOSED position. The anode current should drop to approximately 20.0.

Allow 15 minutes for complete system warm up and record all data in Engineering Data Book. The system should once again be in calibration. Cross check the Engineering Data with the permissible tolerance band provided in Table 3-2, according to the board set being used.

CONTINGENCY PROCEDURES

a. Anode Current out of tolerance:

1. Check that ion pump current is 100 μA ±20 μA. If not, readjust leak valve.

CAUTION

Extreme care should be exercised when adjusting this valve.

2. Check Electron Accelerator current. If out of tolerance, switch filaments.

3. If none of the above corrects the problem, switch all electronic circuit cards.

b. Ion Pump Current out of tolerance:

1. Check valve temperature. If out of tolerance, readjust valve setting to make ion pump current 100 μA ±20 μA.

2. Check pressure transducer output and compare to ship's ambient pressure gauge. If they do not compare, check inlet system for proper flows and no obstructions.

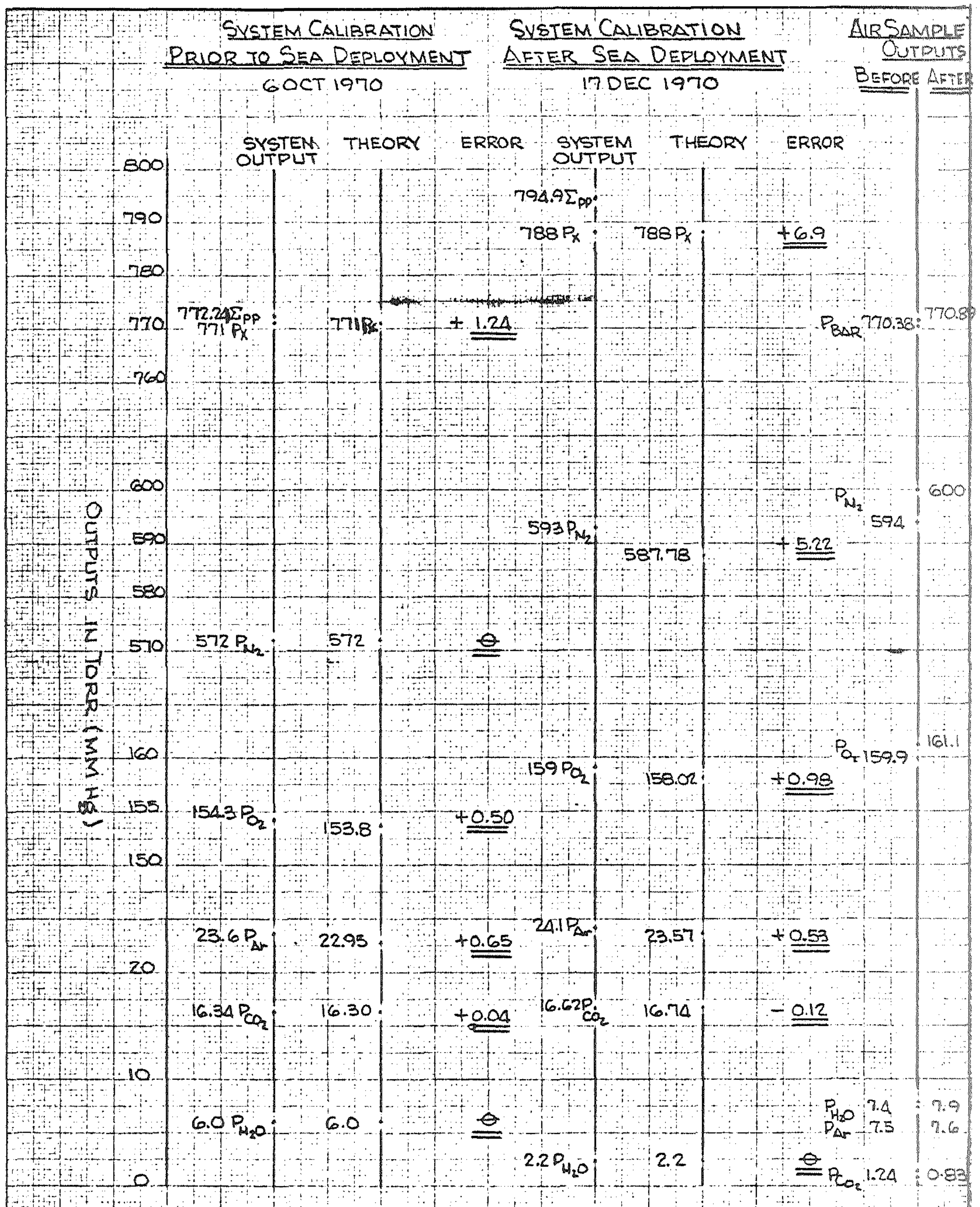
c. Loss of electrometer output (H_2O, N_2, O_2, CO_2 or AR output)

1. This would be indicated by a no signal output (all zeros) or a greater than full-scale output; and therefore, the ΣPP would not equal the total pressure by a gross amount.

2. In this event, the suspect amplifier should be replaced with its spare counterpart.

CAUTION

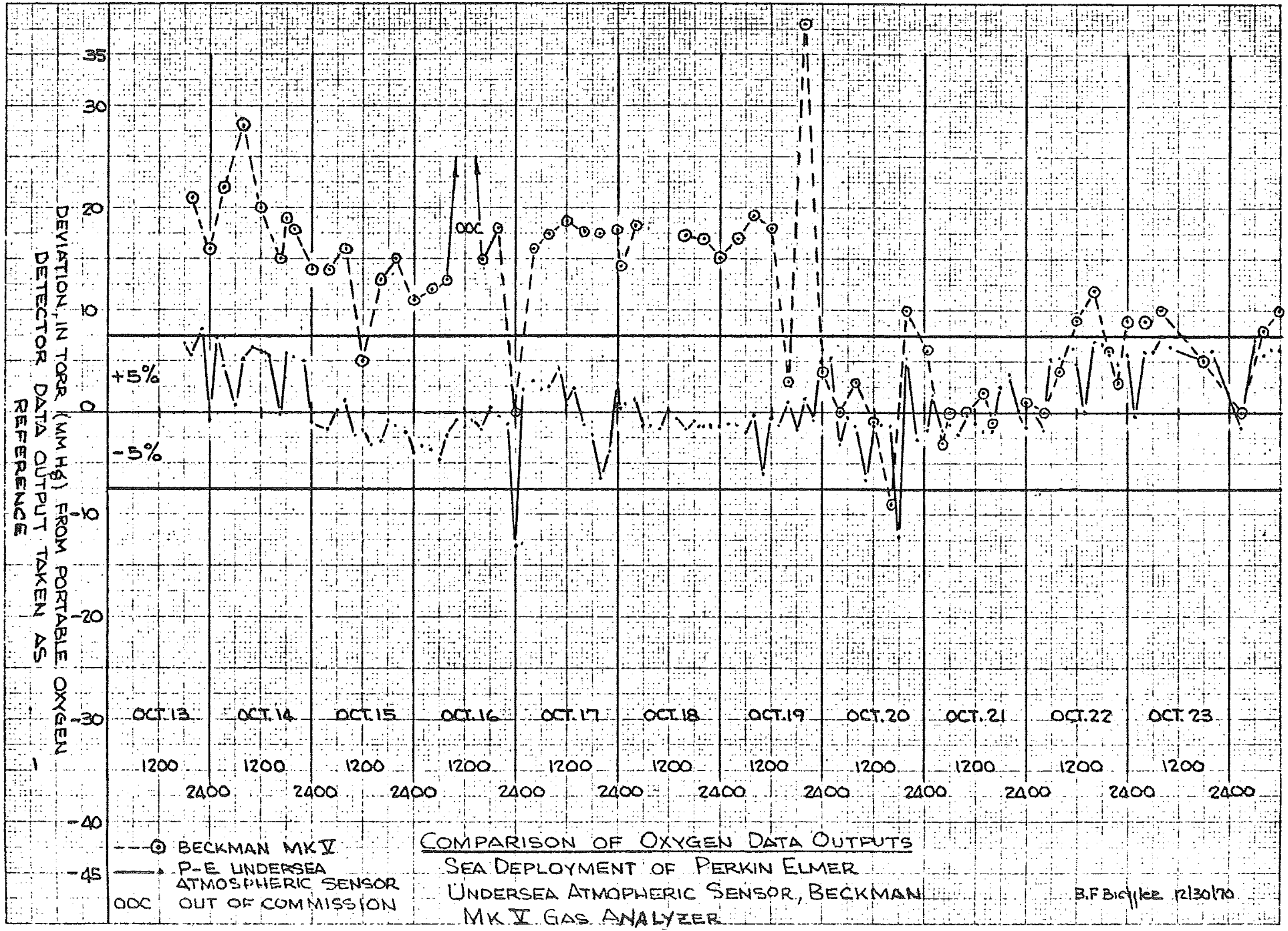
Use extreme care in handling these electrometers, since they may be damaged by static charge.



Undersea Atmospheric Sensor
System Calibration
Before and After Sea Deployment

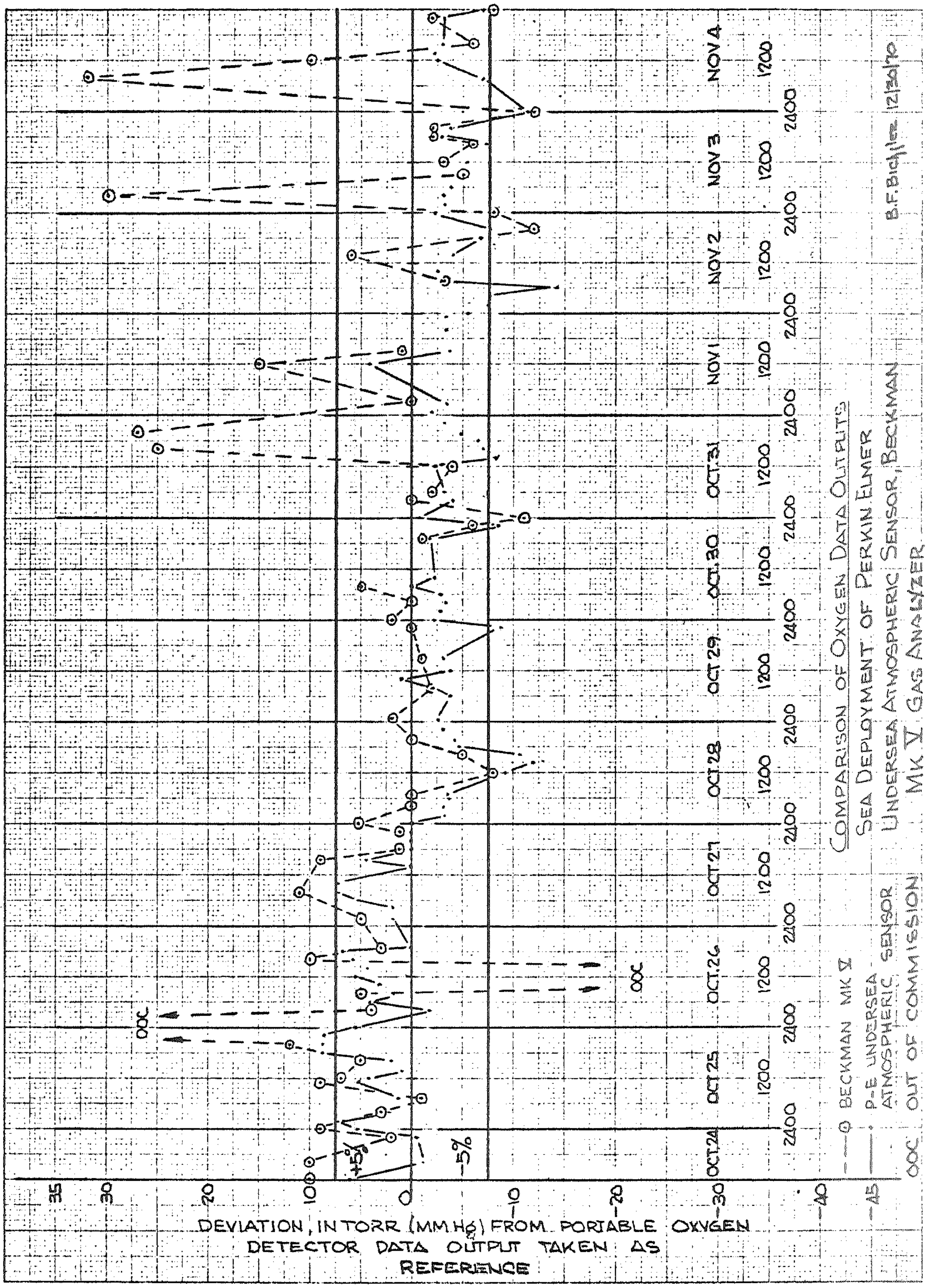
FIGURE 1

B.F. Biehler 1/7/71



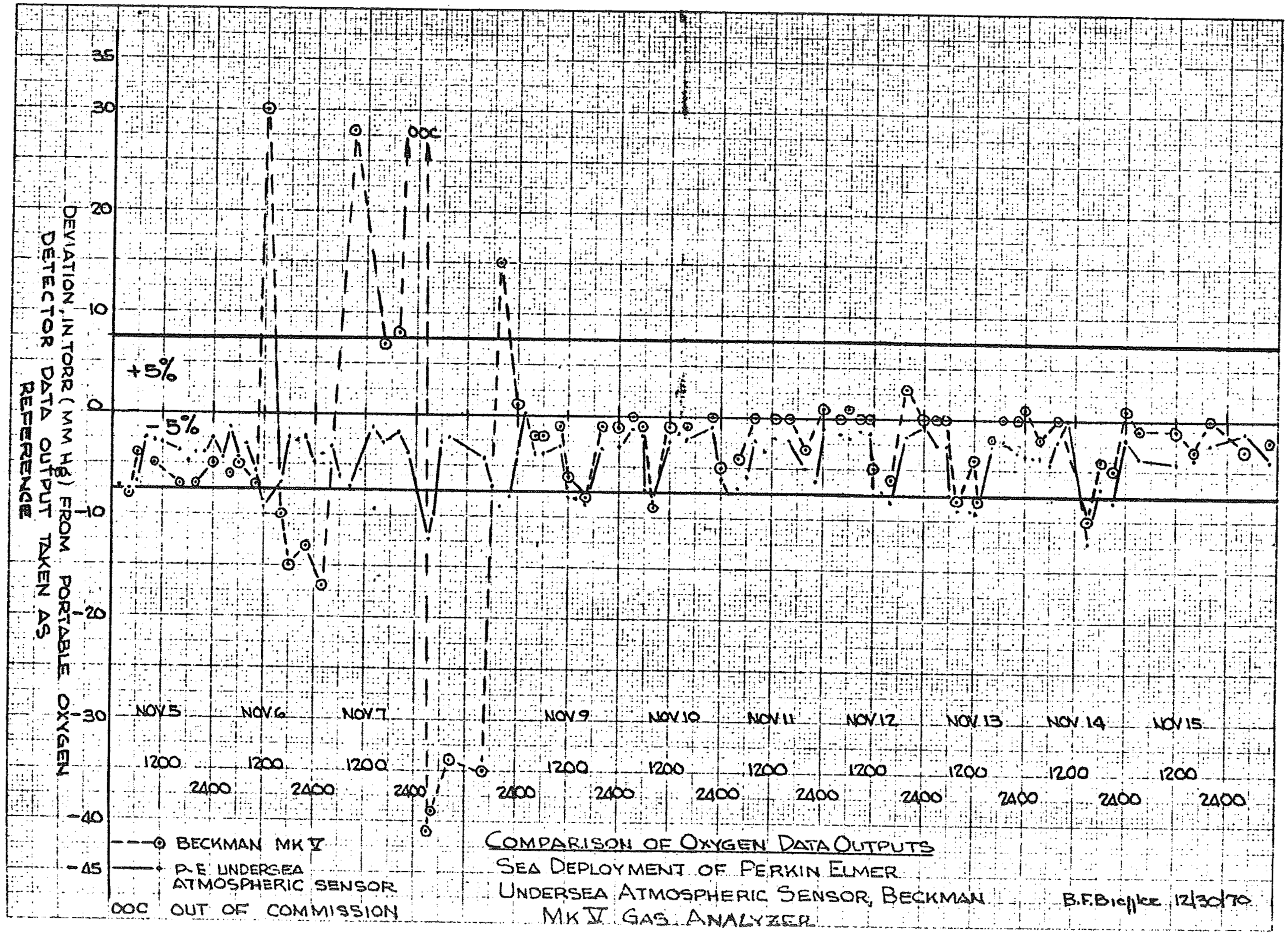
COMPARISON OF OXYGEN DATA OUTPUTS
SEA DEPLOYMENT OF PERKIN ELMER
UNDERSEA ATMOPHERIC SENSOR, BECKMAN
MK V GAS ANALYZER

FIGURE 2a



COMPARISON OF OXYGEN DATA OUTPUTS
SEA DEPLOYMENT OF PERKIN ELMER
UNDERSEA ATMOSPHERIC SENSOR, BECKMAN
MK. V GAS ANALYZER

FIGURE 2b



COMPARISON OF OXYGEN DATA OUTPUTS
SEA DEPLOYMENT OF PERKIN ELMER
UNDERSEA ATMOSPHERIC SENSOR, BECKMAN
MK V GAS ANALYZER

FIGURE 2c

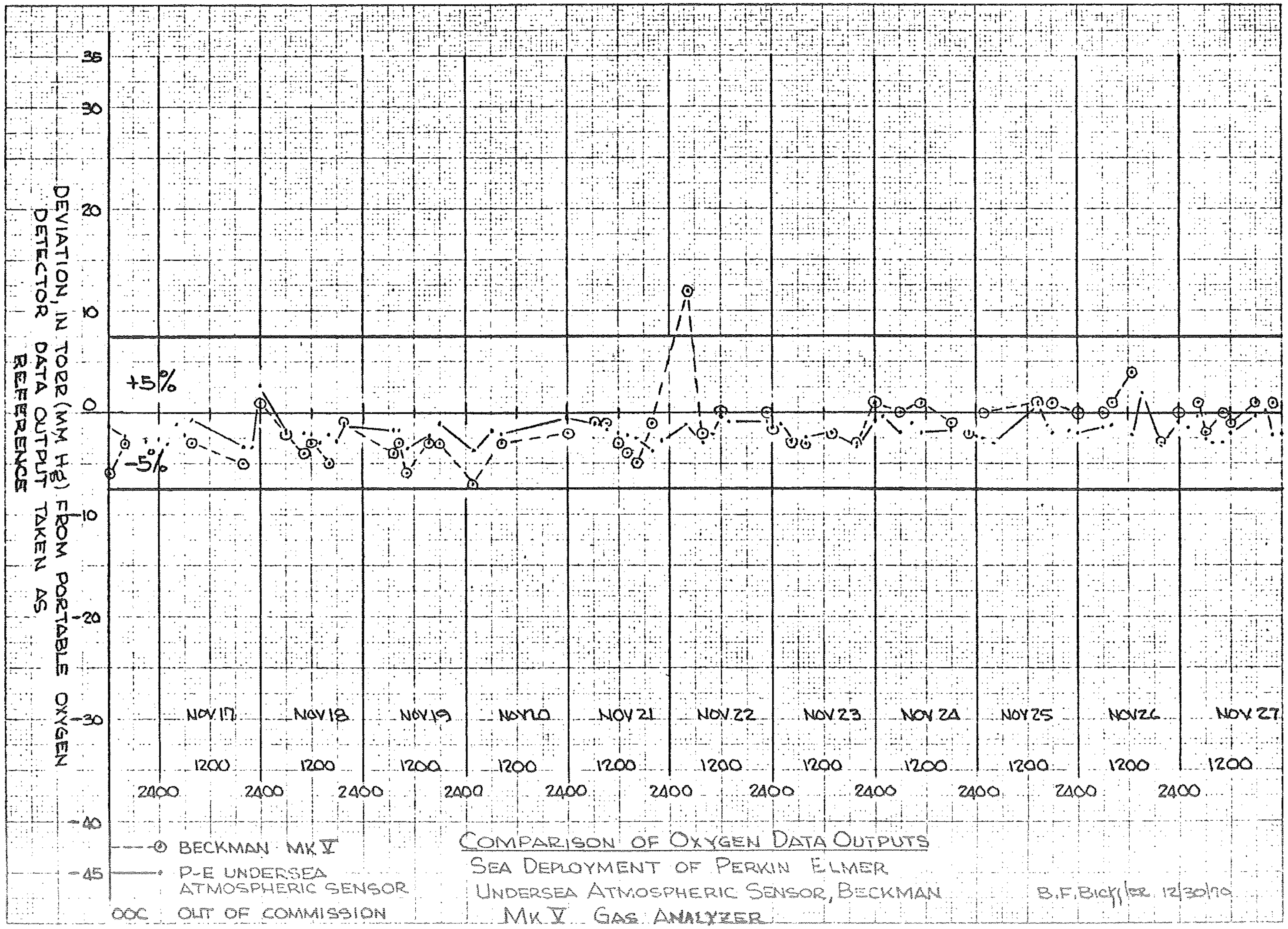

DEVIATION, IN TORR (MM Hg) FROM PORTABLE OXYGEN DETECTOR DATA OUTPUT TAKEN AS REFERENCE
35
30
20
10
0
-10
-20
-30
-40
-45
+5%
-5%
NOV 17
NOV 18
NOV 19
NOV 20
NOV 21
NOV 22
NOV 23
NOV 24
NOV 25
NOV 26
NOV 27
1200
2400
BECKMAN MK V
P-E UNDERSEA ATMOSPHERIC SENSOR
OOC OUT OF COMMISSION
COMPARISON OF OXYGEN DATA OUTPUTS
SEA DEPLOYMENT OF PERKIN ELMER
UNDERSEA ATMOSPHERIC SENSOR, BECKMAN
MK V GAS ANALYZER
B.F. Bickler 12/30/70

FIGURE 2d

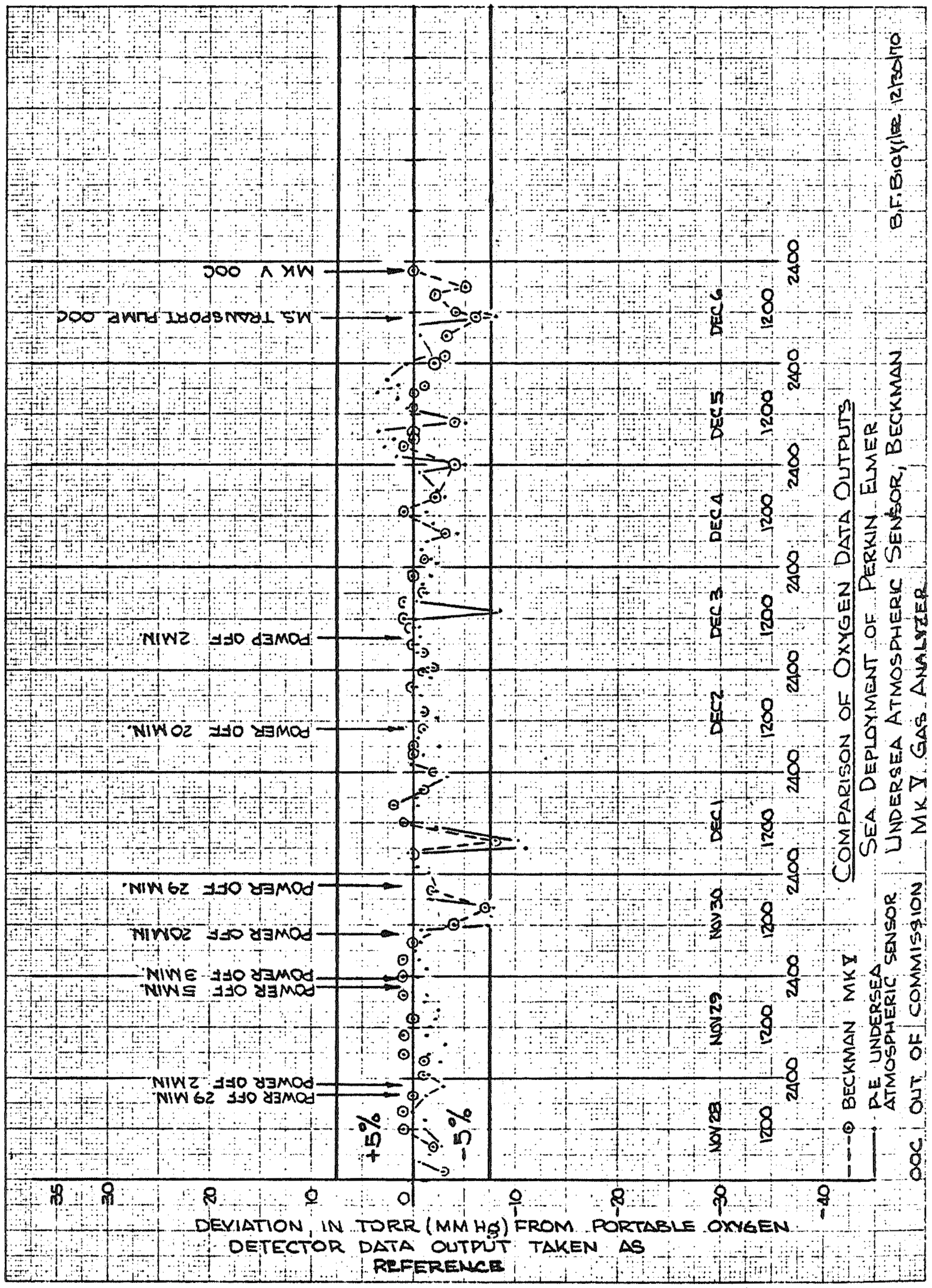
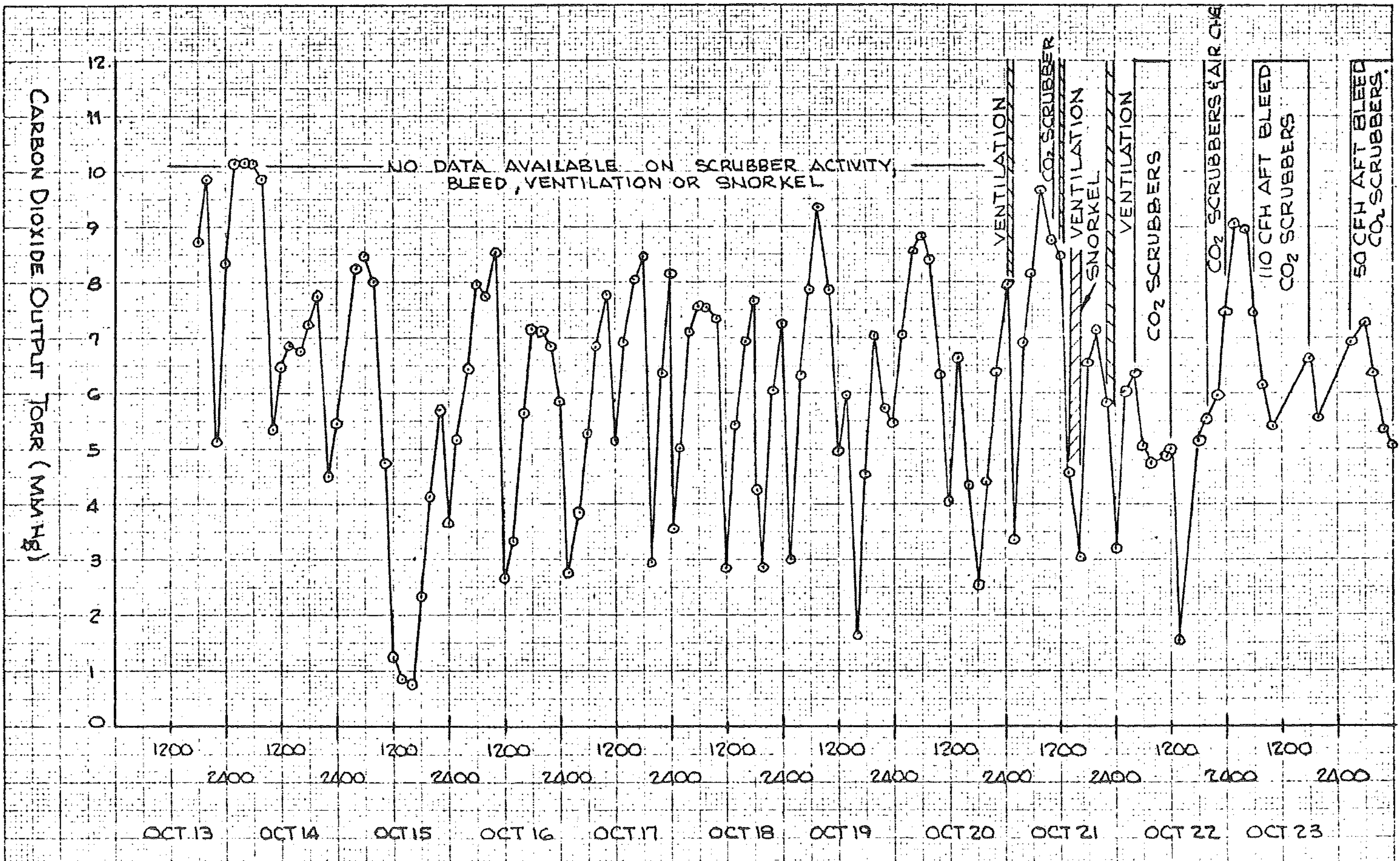

COMPARISON OF OXYGEN DATA OUTPUTS
SEA DEPLOYMENT OF PERKIN ELMER
UNDERSEA ATMOSPHERIC SENSOR, BECKMAN
MK V GAS ANALYZER
B.F. Bickler 12/30/70
---⊙ BECKMAN MK V
— P.E. UNDERSEA ATMOSPHERIC SENSOR
OOC OUT OF COMMISSION
DEVIATION, IN TORR (MM Hg) FROM PORTABLE OXYGEN DETECTOR DATA OUTPUT TAKEN AS REFERENCE
35
30
20
10
0
-10
-20
-30
-40
+5%
-5%
NOV 28
NOV 29
NOV 30
DEC 1
DEC 2
DEC 3
DEC 4
DEC 5
DEC 6
1200
2400
POWER OFF 29 MIN.
POWER OFF 2 MIN.
POWER OFF 5 MIN.
POWER OFF 3 MIN.
POWER OFF 20 MIN.
POWER OFF 29 MIN.
POWER OFF 20 MIN.
POWER OFF 2 MIN.
M.S. TRANSPORT PUMP OOC
MK V OOC

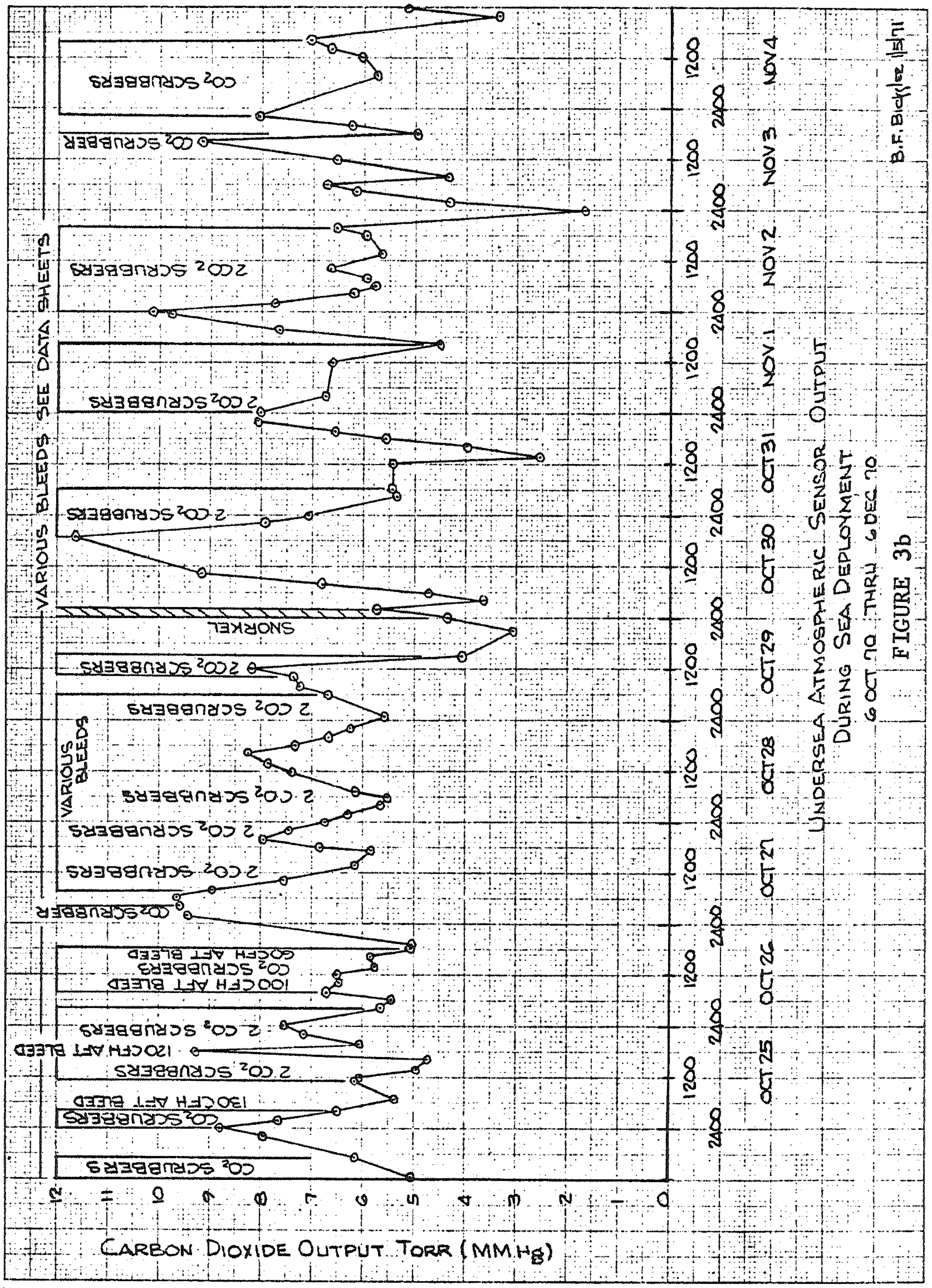
FIGURE 2e



Undersea Atmospheric Sensor Output
During Sea Deployment
6 OCT 70 THRU 6 DEC 70

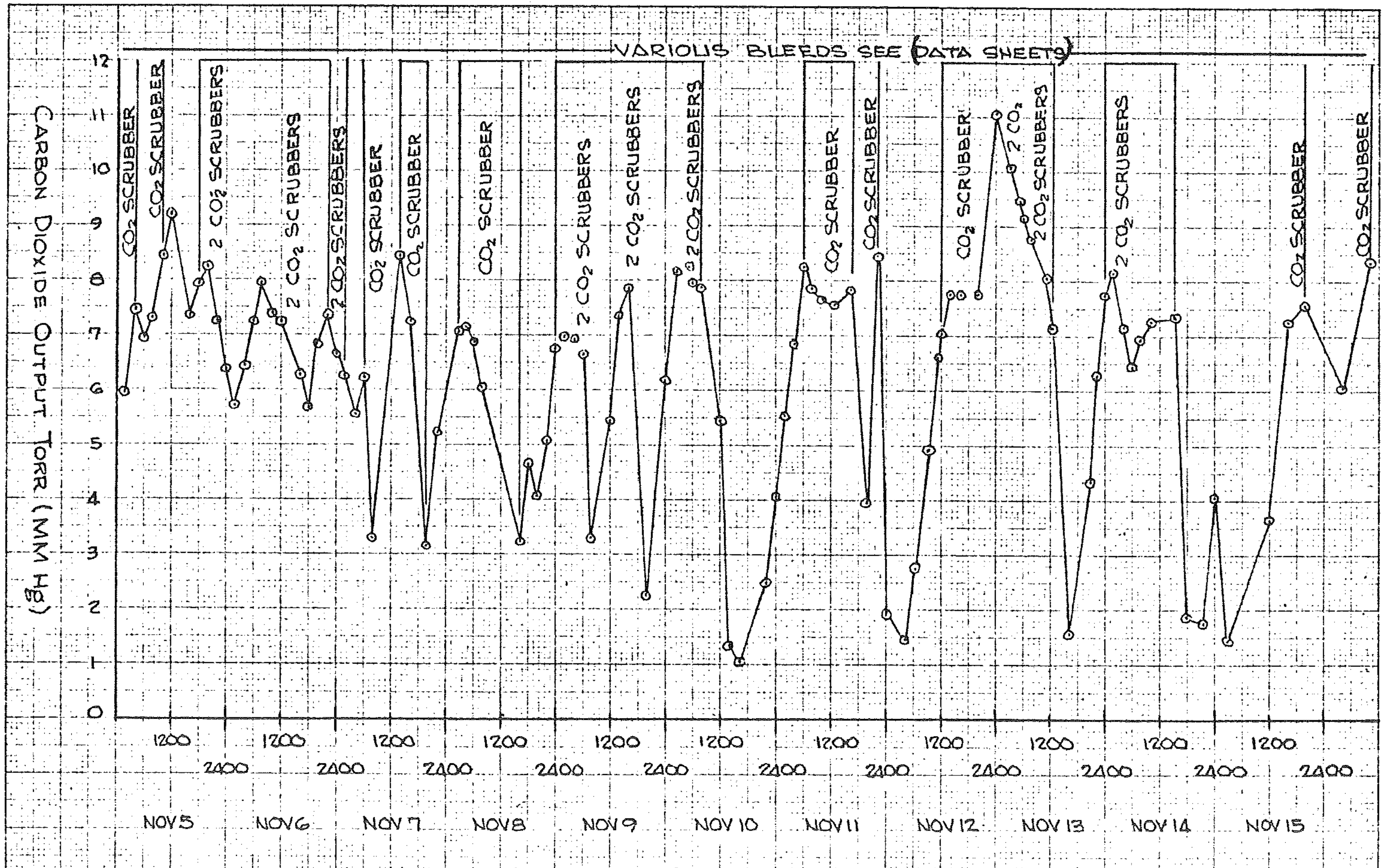
FIGURE 3a

B.F. Bichler 1/5/71



Undersea Atmospheric Sensor Output
During Sea Deployment
6 Oct 70 thru 6 Dec 70

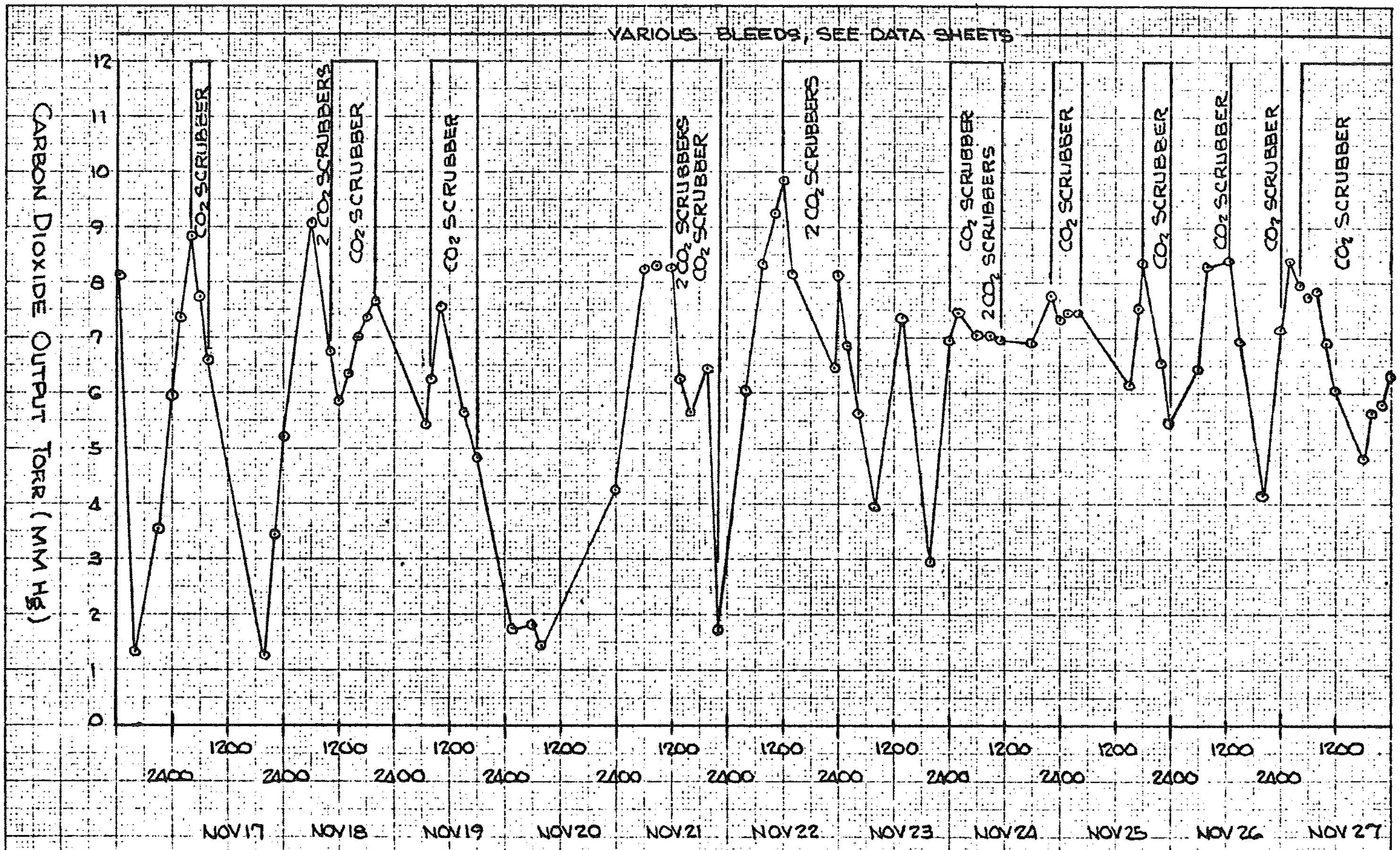
FIGURE 3b



UNDERSEA ATMOSPHERIC SENSOR OUTPUT
DURING SEA DEPLOYMENT
6 OCT 70 THRU 6 DEC 70

FIGURE 3c

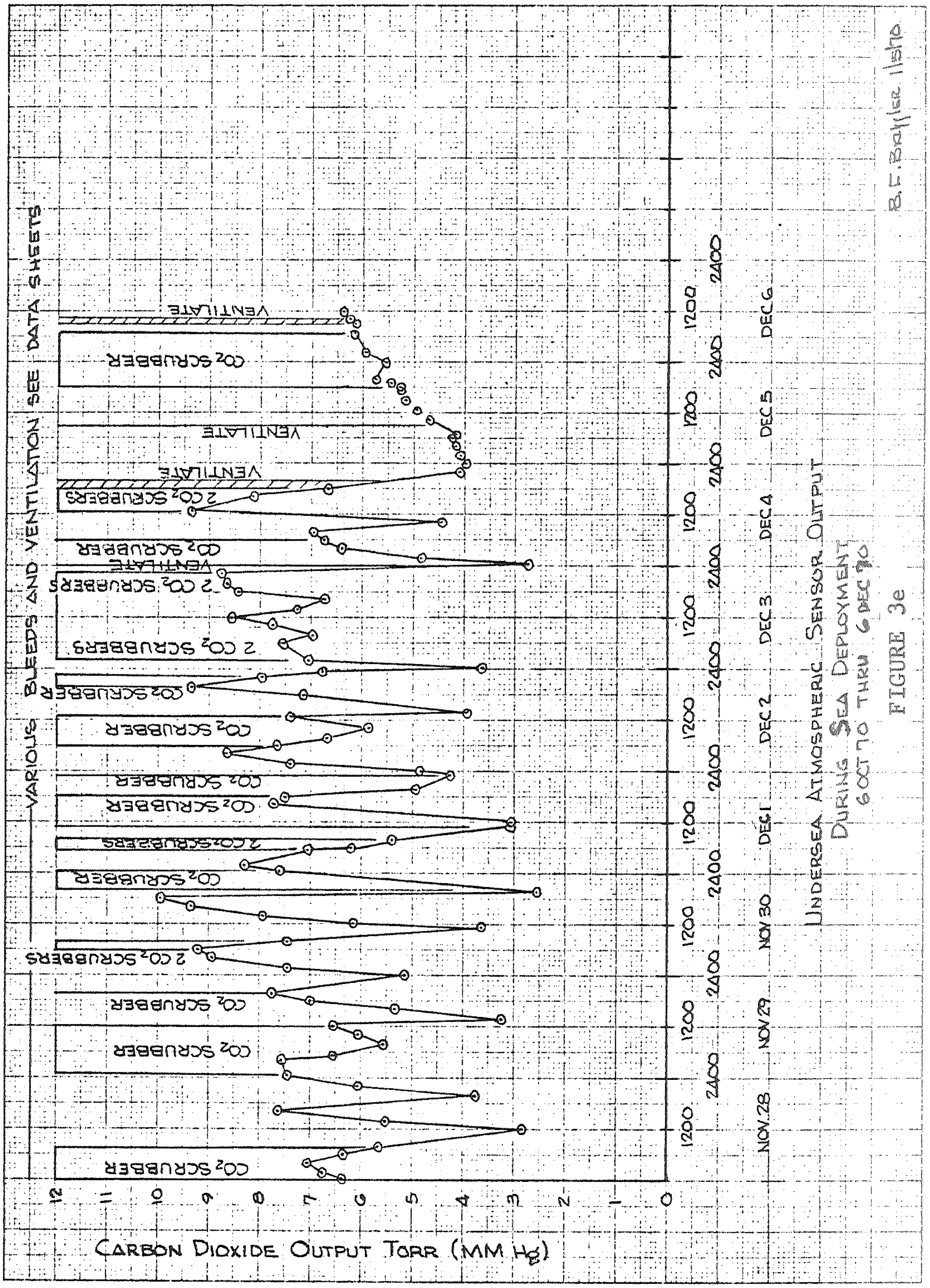
B.F. Bickler 1/5/71



UNDERSEA ATMOSPHERIC SENSOR OUTPUT
DURING SEA DEPLOYMENT
6 OCT 70 THRU 6 DEC 70

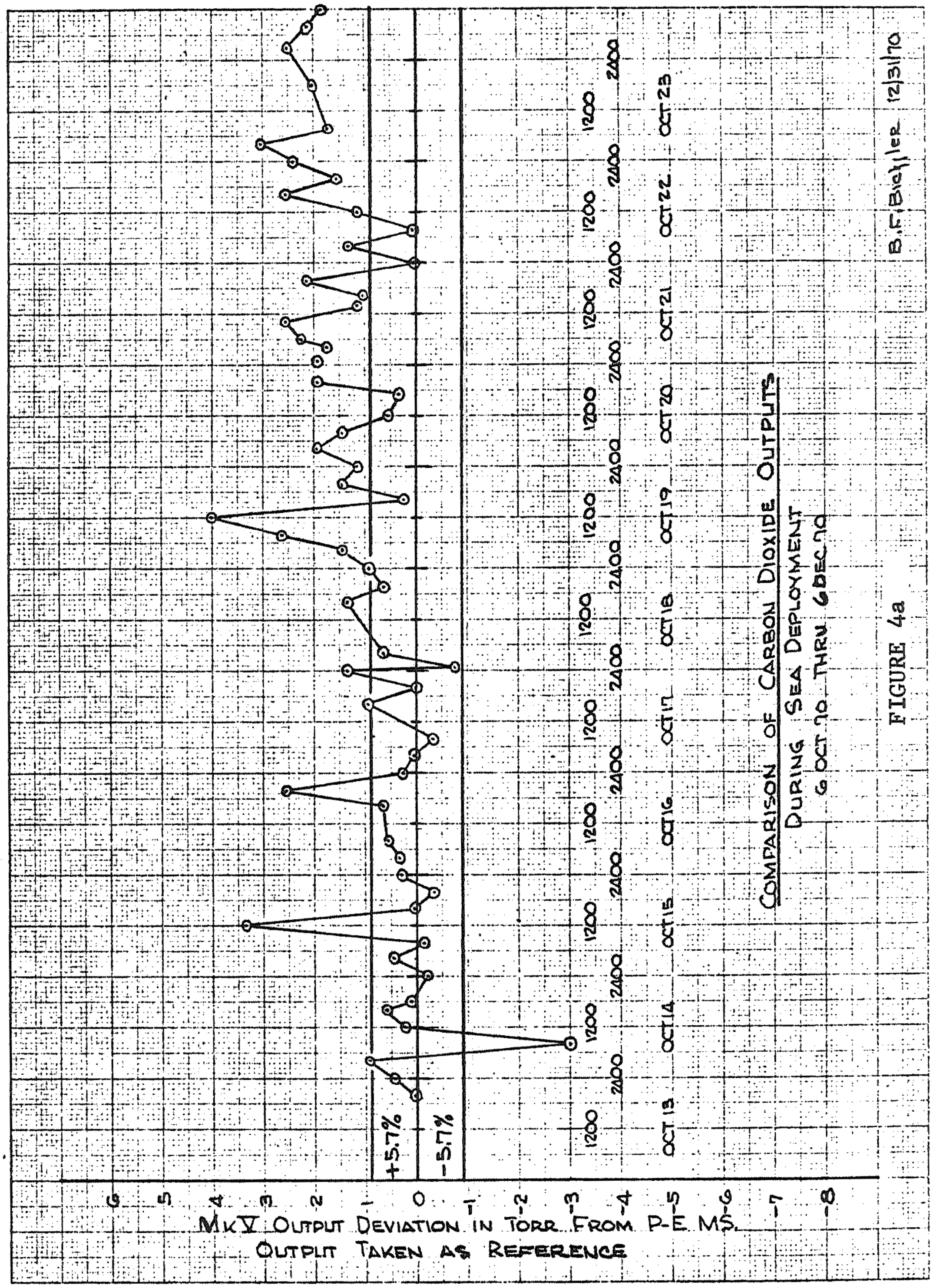
FIGURE 3d

B.F. Bickley 1/5/71



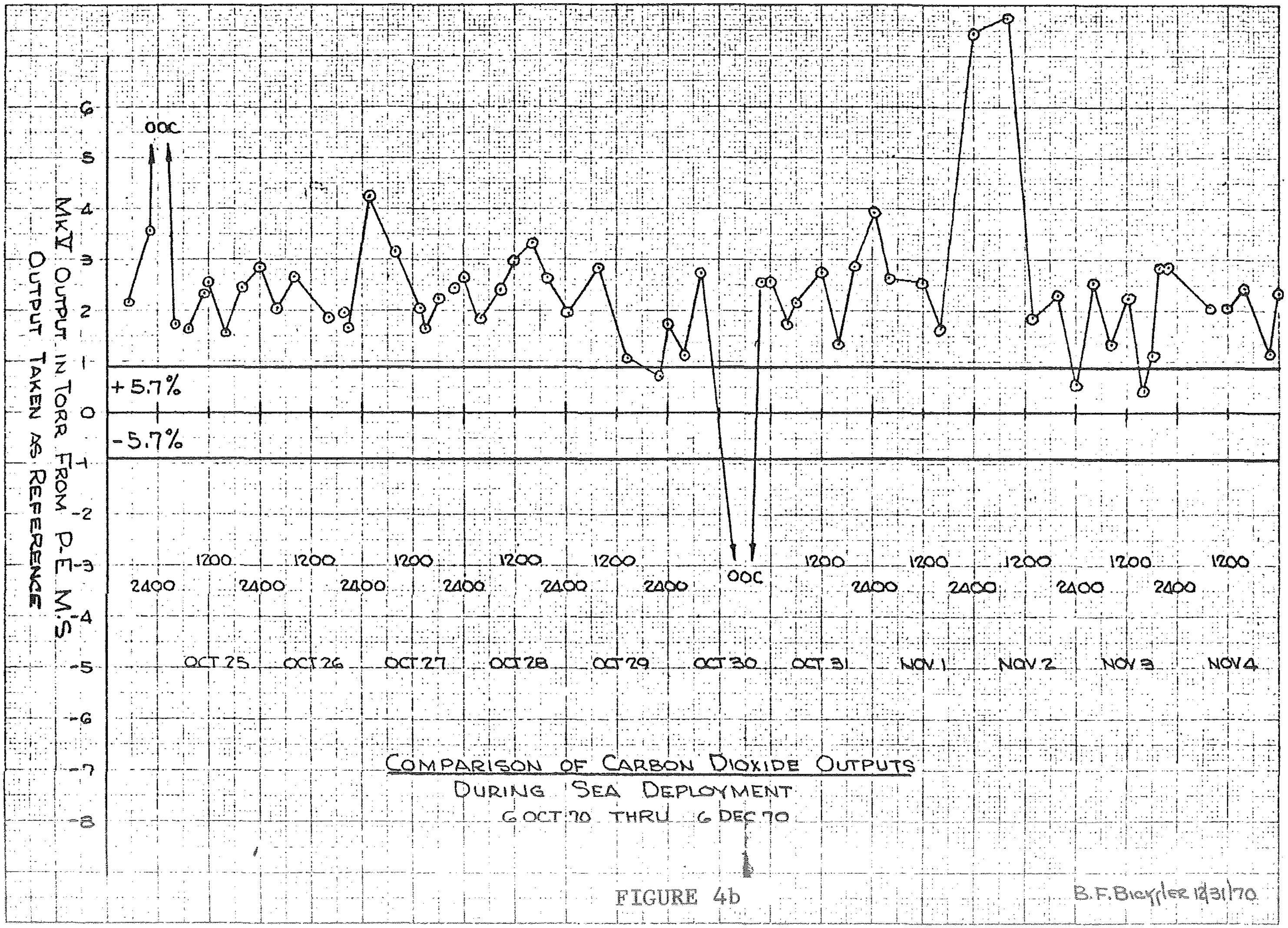
Undersea Atmospheric Sensor Output
During Sea Deployment
6 Oct 70 thru 6 Dec 70

FIGURE 3e



Comparison of Carbon Dioxide Outputs
During Sea Deployment
6 Oct 70 Thru 6 Dec 70

FIGURE 4a



Comparison of Carbon Dioxide Outputs
During Sea Deployment
6 OCT 70 THRU 6 DEC 70

FIGURE 4b

B.F. Bickler 12/31/70

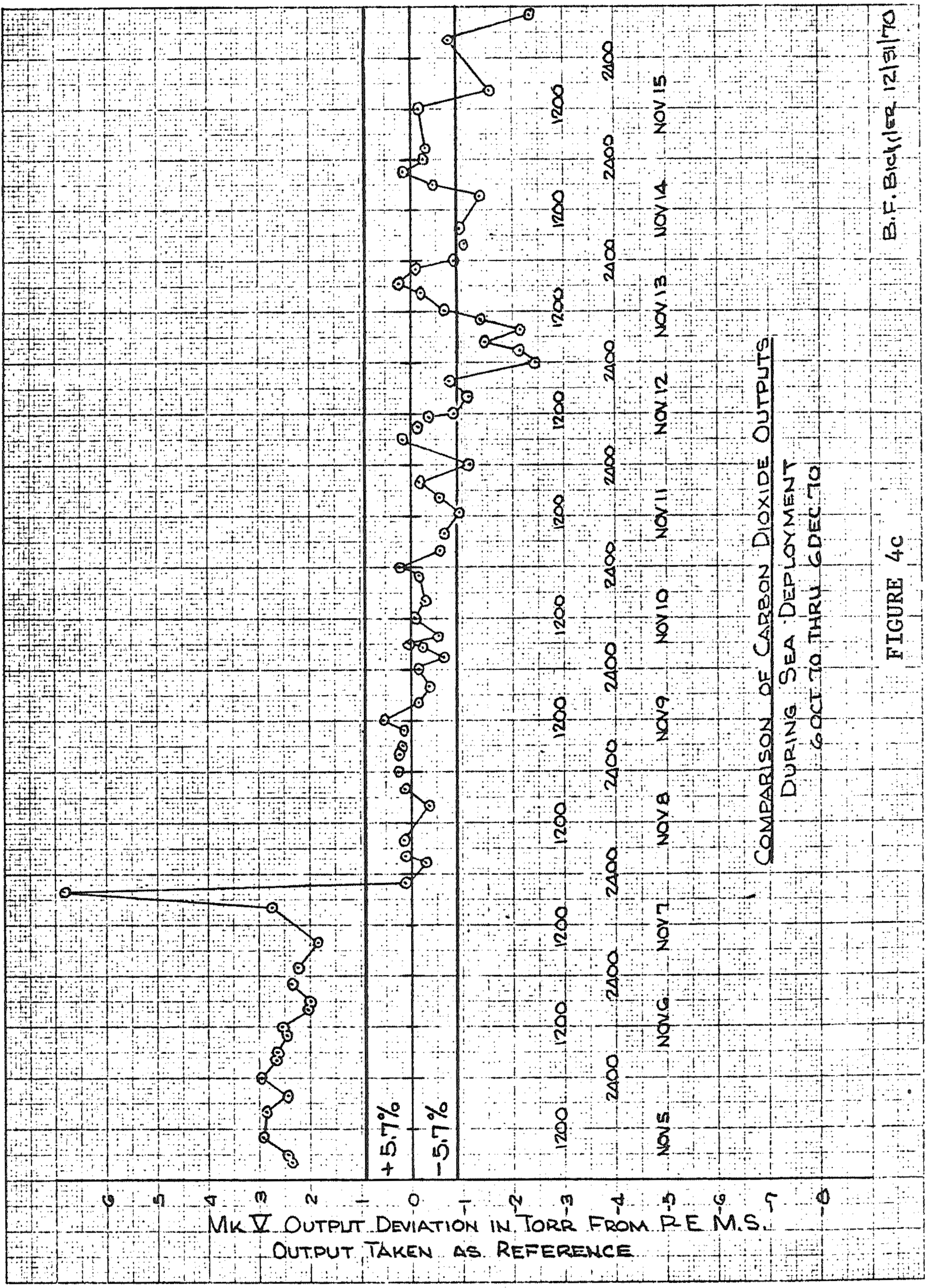
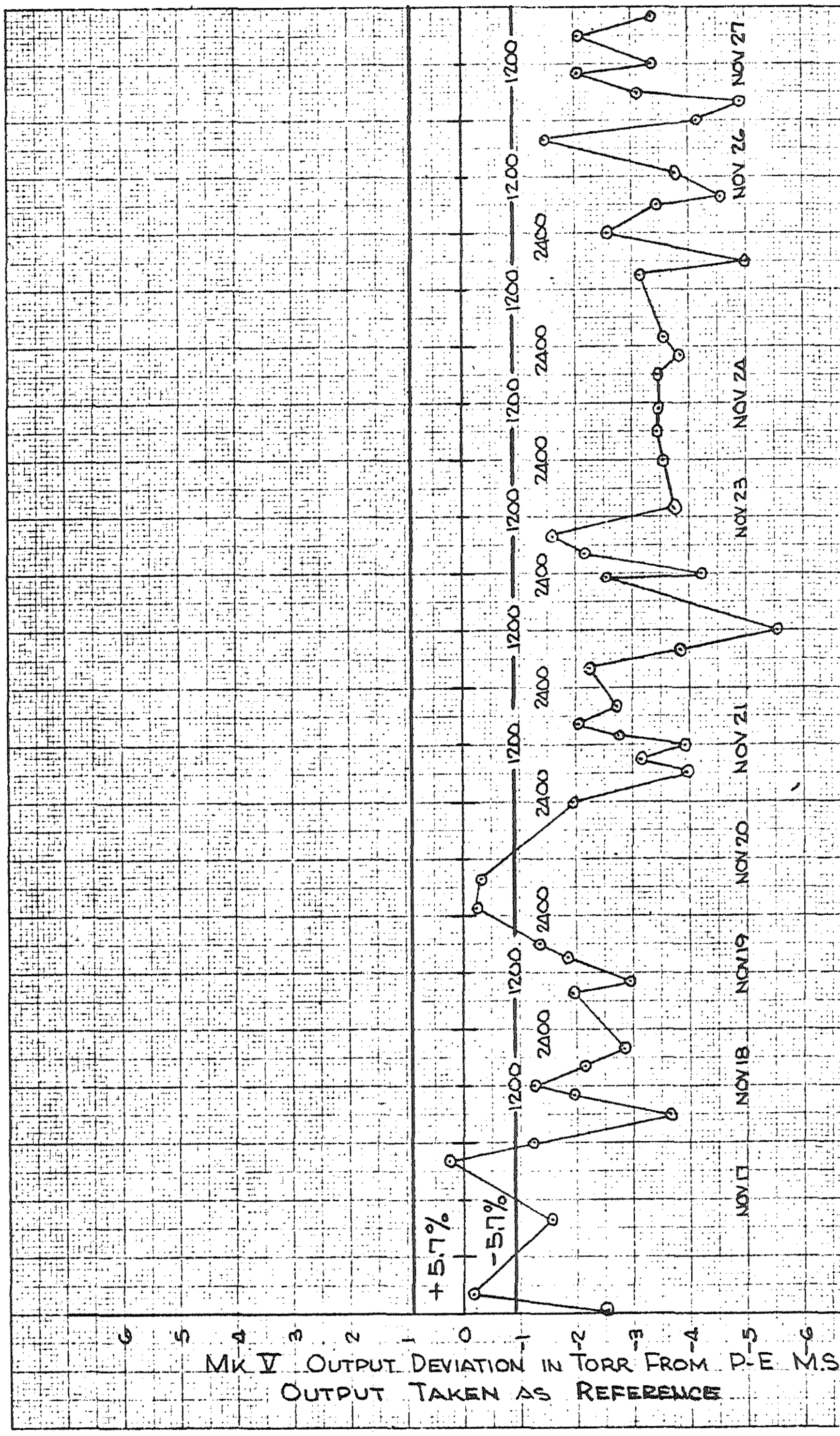

COMPARISON OF CARBON DIOXIDE OUTPUTS
DURING SEA DEPLOYMENT
6 OCT 70 THRU 6 DEC 70
B.F. Bickler 12/31/70
+5.7%
-5.7%
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
MK V OUTPUT DEVIATION IN TORR FROM R.E.M.S.
OUTPUT TAKEN AS REFERENCE
NOV 5
NOV 6
NOV 7
NOV 8
NOV 9
NOV 10
NOV 11
NOV 12
NOV 13
NOV 14
NOV 15
1200
2400

FIGURE 4c



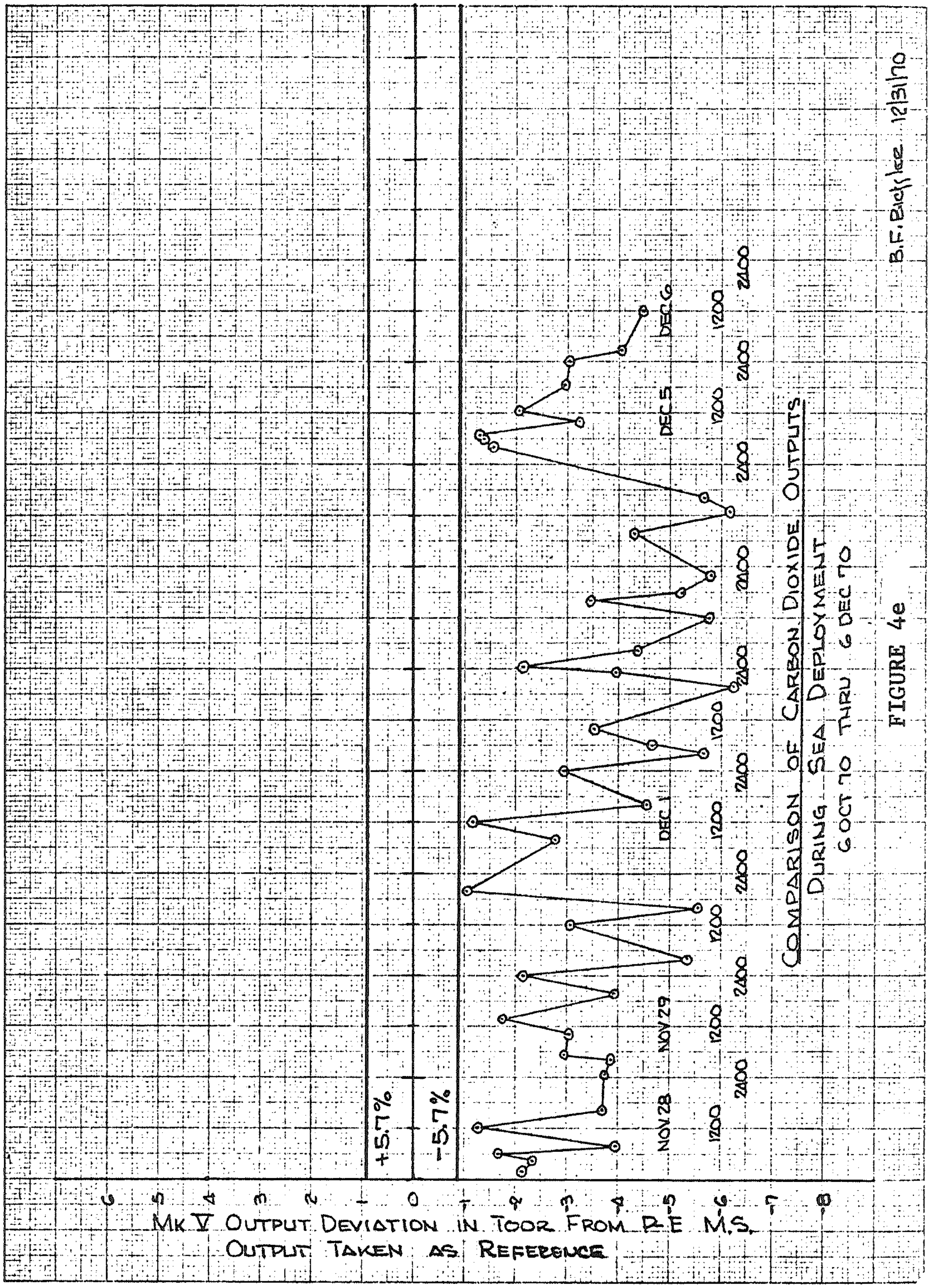
COMPARISON OF CARBON DIOXIDE OUTPUTS

DURING SEA DEPLOYMENT

6 OCT 70 THRU 6 DEC 70

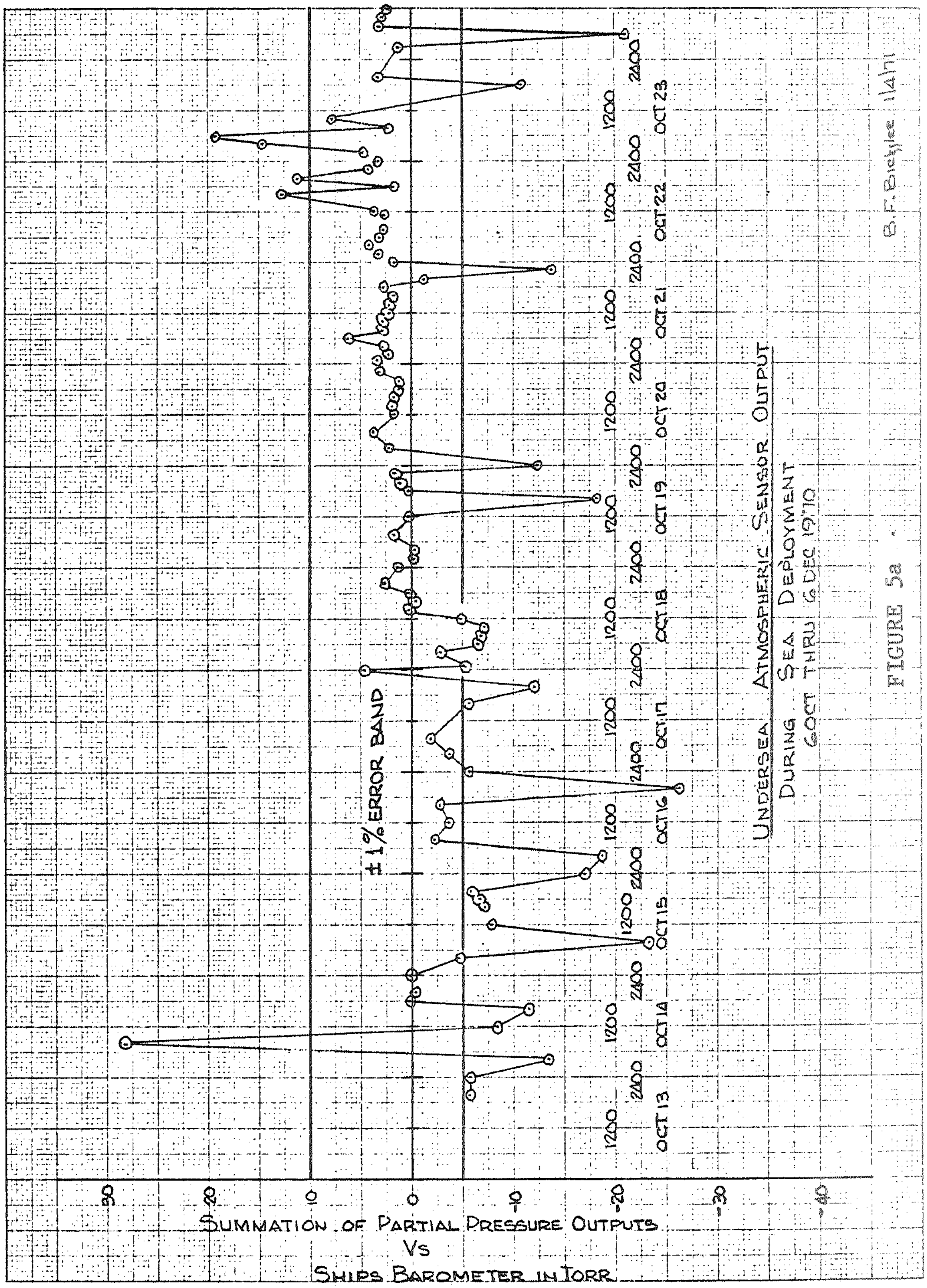
FIGURE 4d

B.F. Bichler 12/31/70



COMPARISON OF CARBON DIOXIDE OUTPUTS
DURING SEA DEPLOYMENT
6 OCT 70 THRU 6 DEC 70

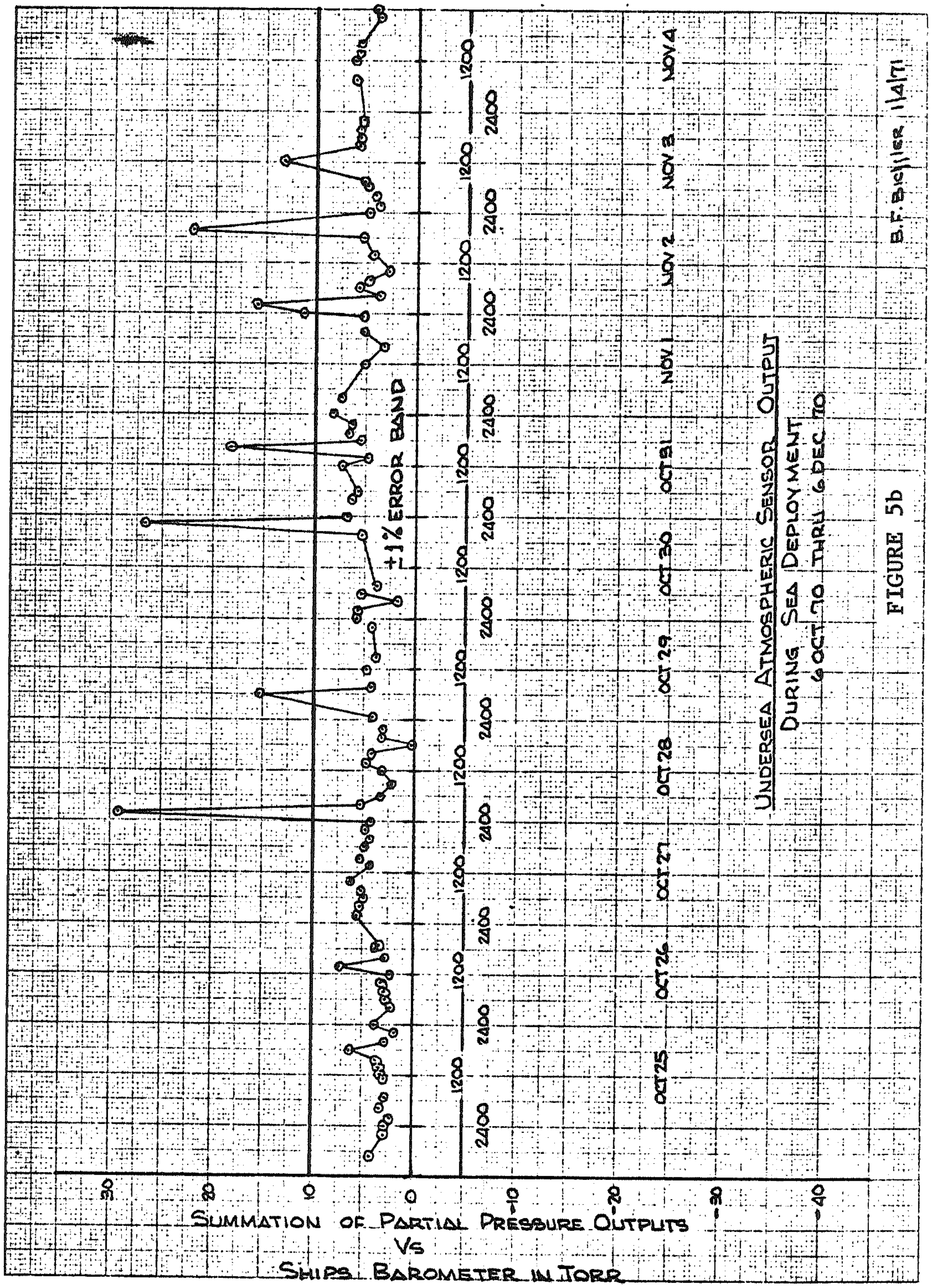
FIGURE 4e



Undersea Atmospheric Sensor Output
During Sea Deployment
6 Oct thru 6 Dec 1970

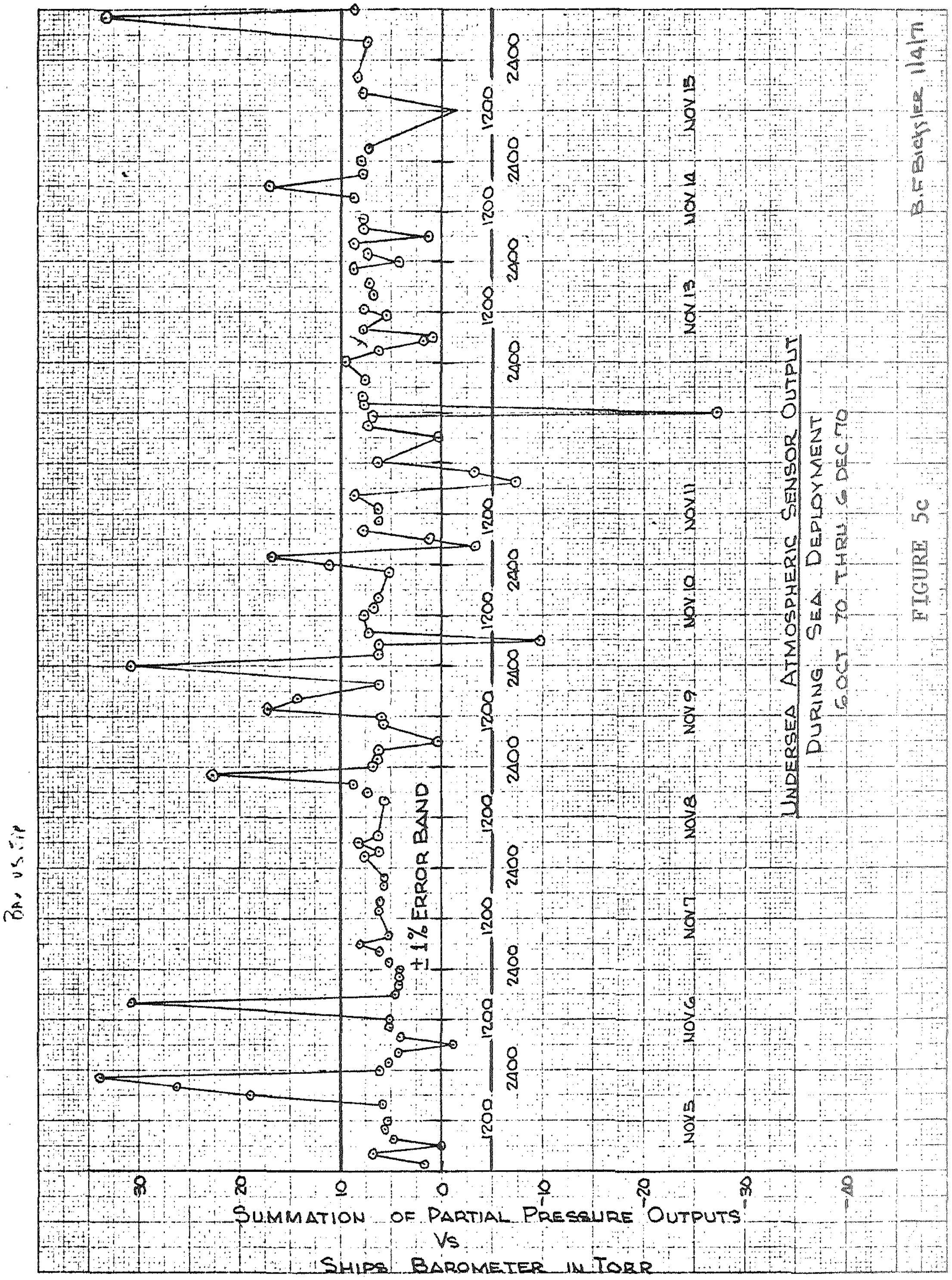
FIGURE 5a

B.F. Bickley 11/4/71



Undersea Atmospheric Sensor Output
During Sea Deployment
6 Oct 70 thru 6 Dec 70

FIGURE 5b



UNDERSEA ATMOSPHERIC SENSOR OUTPUT
DURING SEA DEPLOYMENT
6 OCT 70 THRU 6 DEC 70

FIGURE 5c

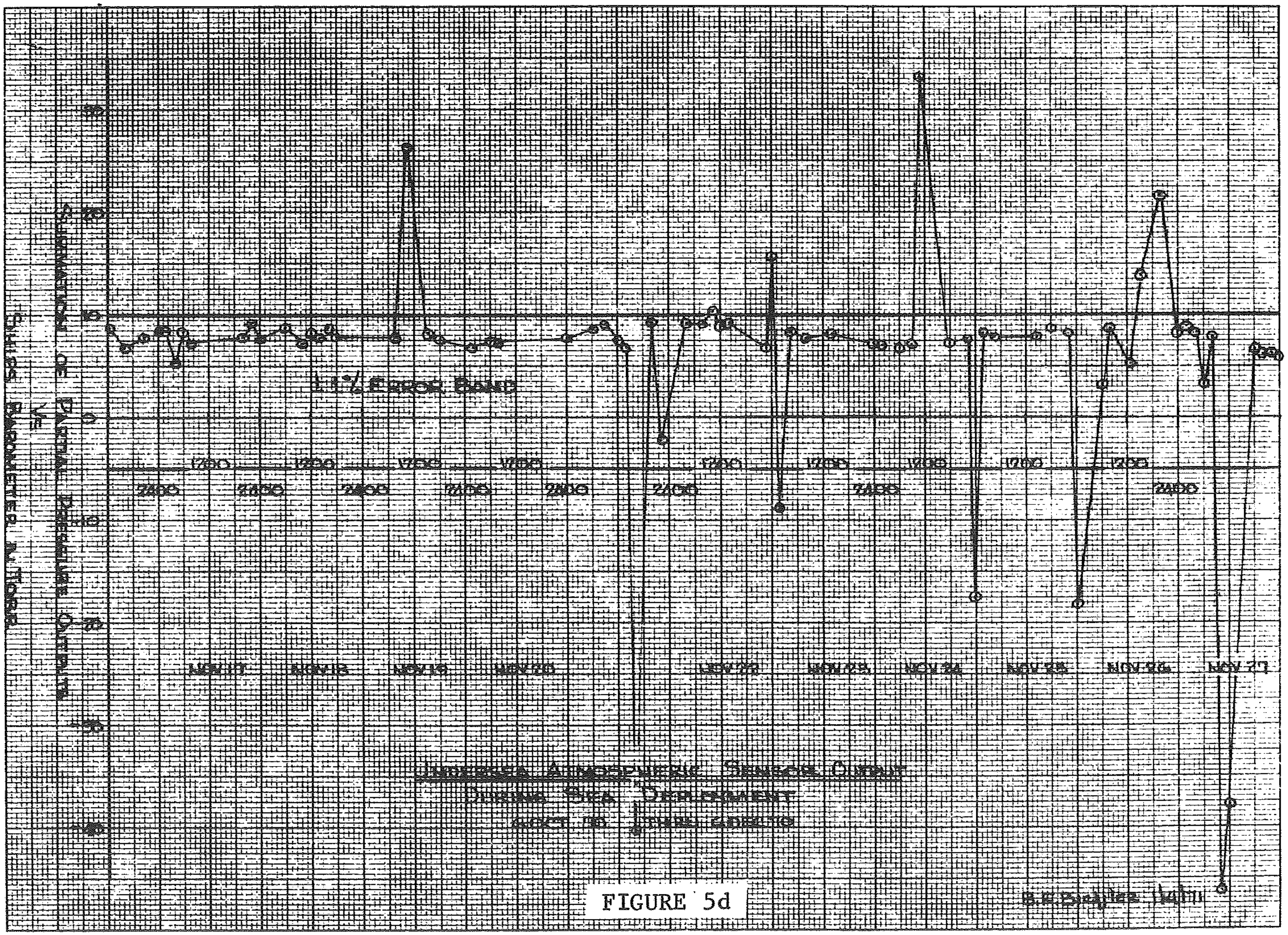
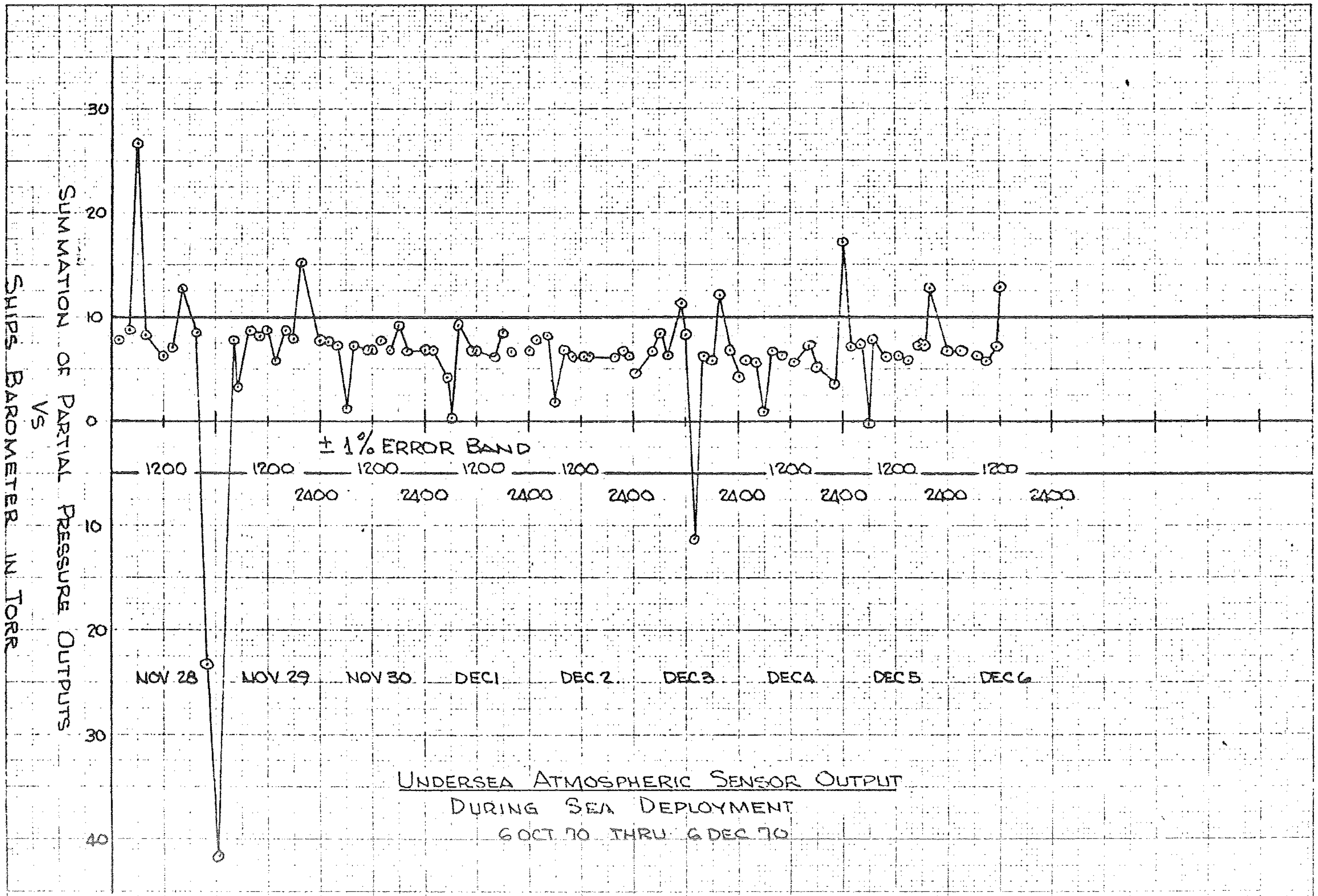

Summation of Partial Pressure Outputs
Vs
Ships Barometer in Torr
30
20
10
0
10
20
30
40
±1% Error Band
2400
1200
Nov 17
Nov 18
Nov 19
Nov 20
Nov 22
Nov 23
Nov 24
Nov 25
Nov 26
Nov 27
Unbiased Atmospheric Sensor Output
During Sea Deployment

FIGURE 5d



Undersea Atmospheric Sensor Output
During Sea Deployment
6 Oct 70 thru 6 Dec 70

FIGURE 5e

B.F.Bickler 1/4/70

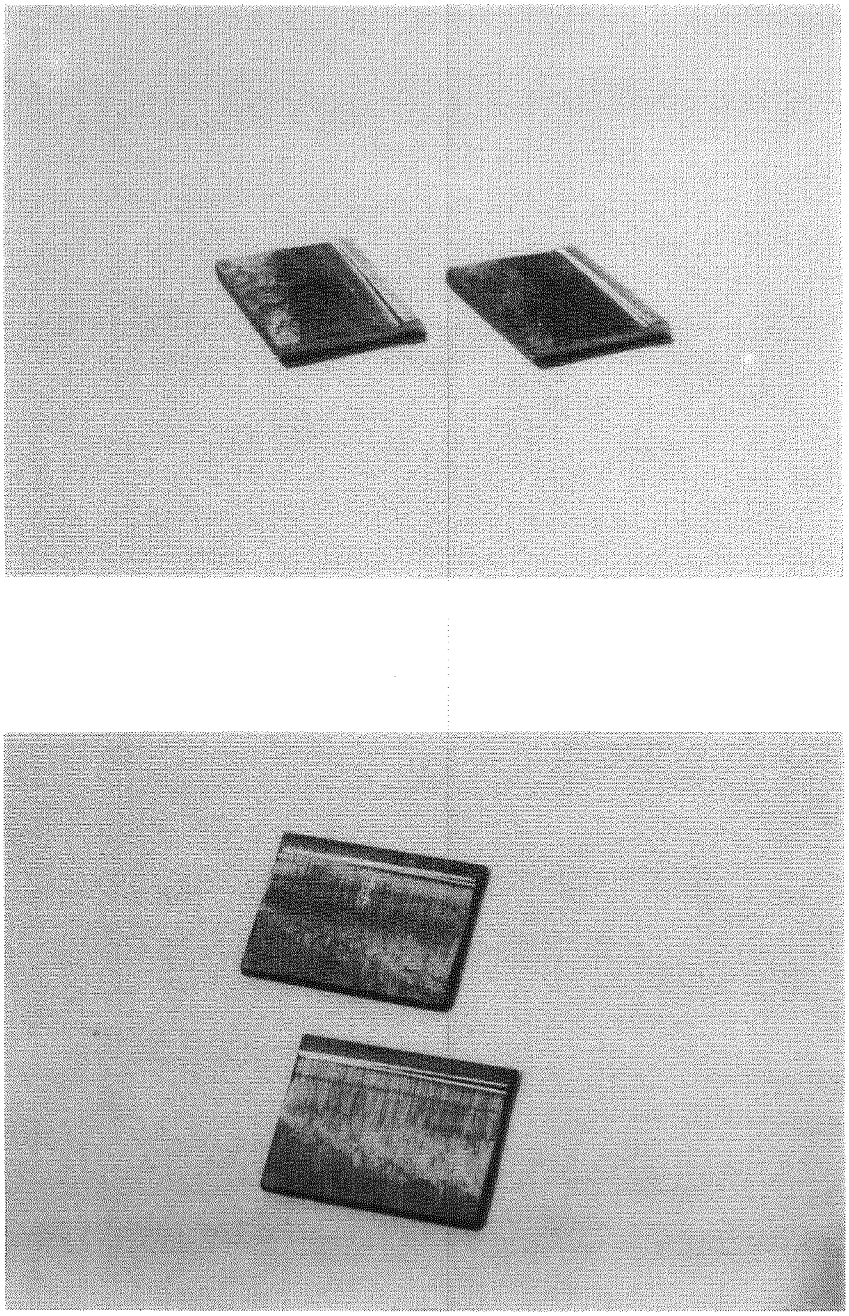


FIGURE 6.- Two Carbon Vanes From Gast Pump - Model 0531-102,347 - Showing Abrasion During Operation

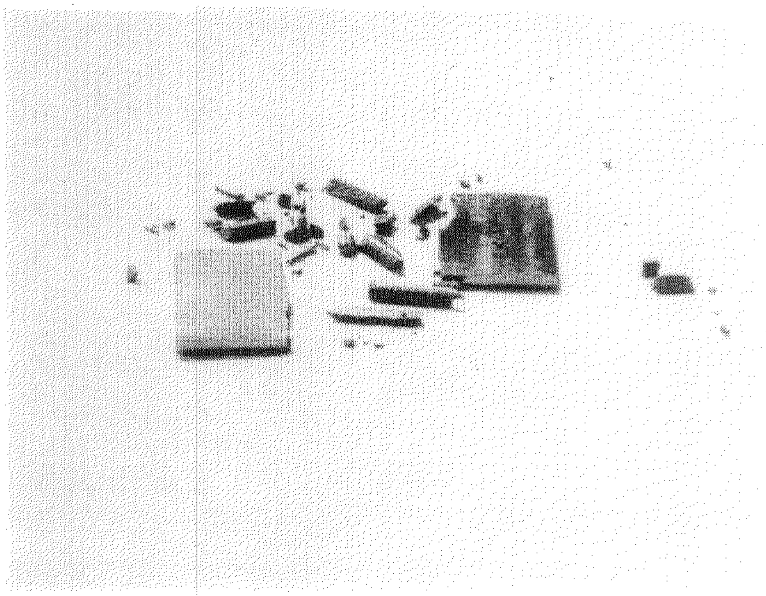


FIGURE 7.- Two Carbon Vanes From Gast Pump - Model 0531-102, 347 - Showing Failure and Abrasion

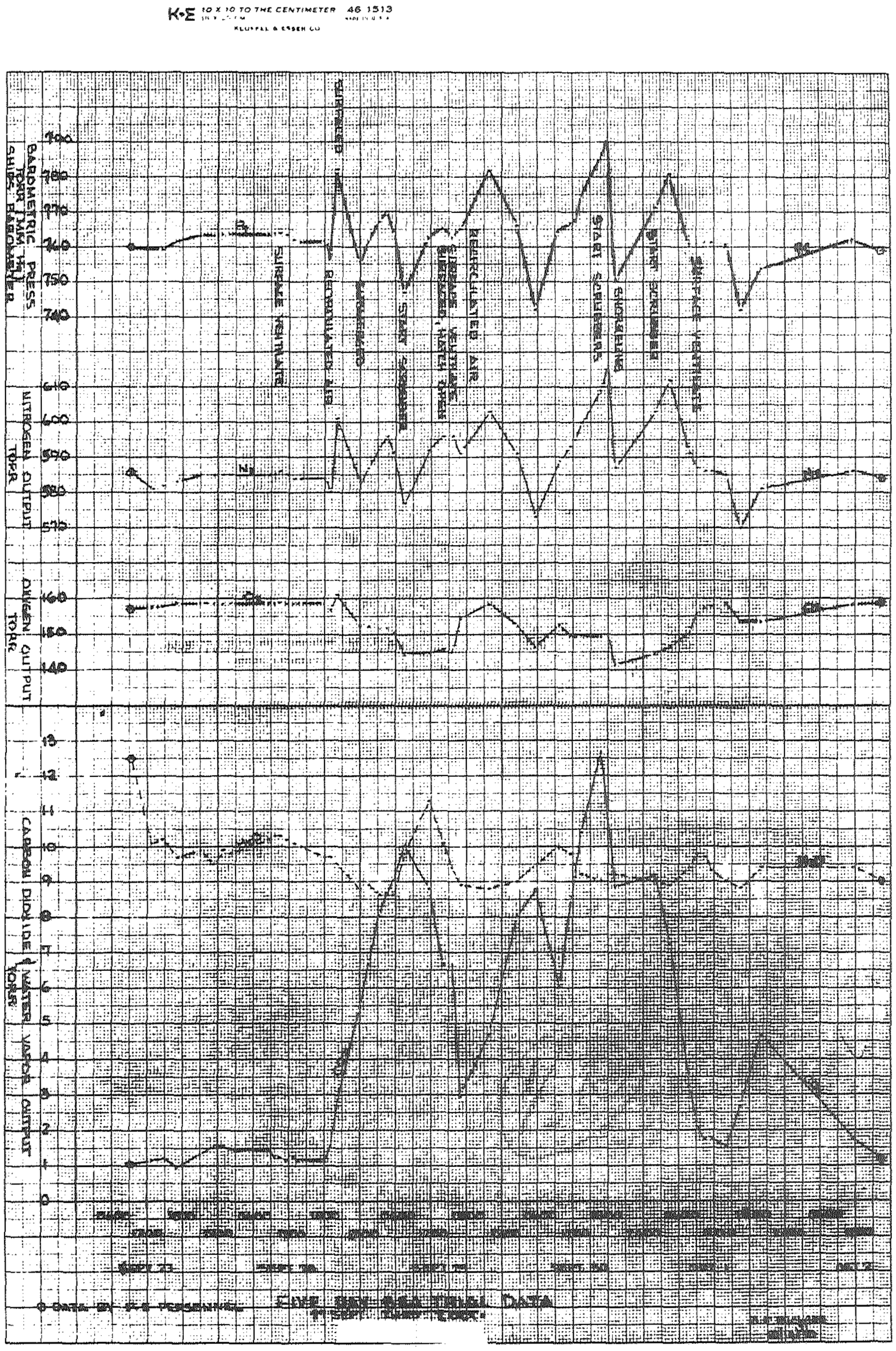
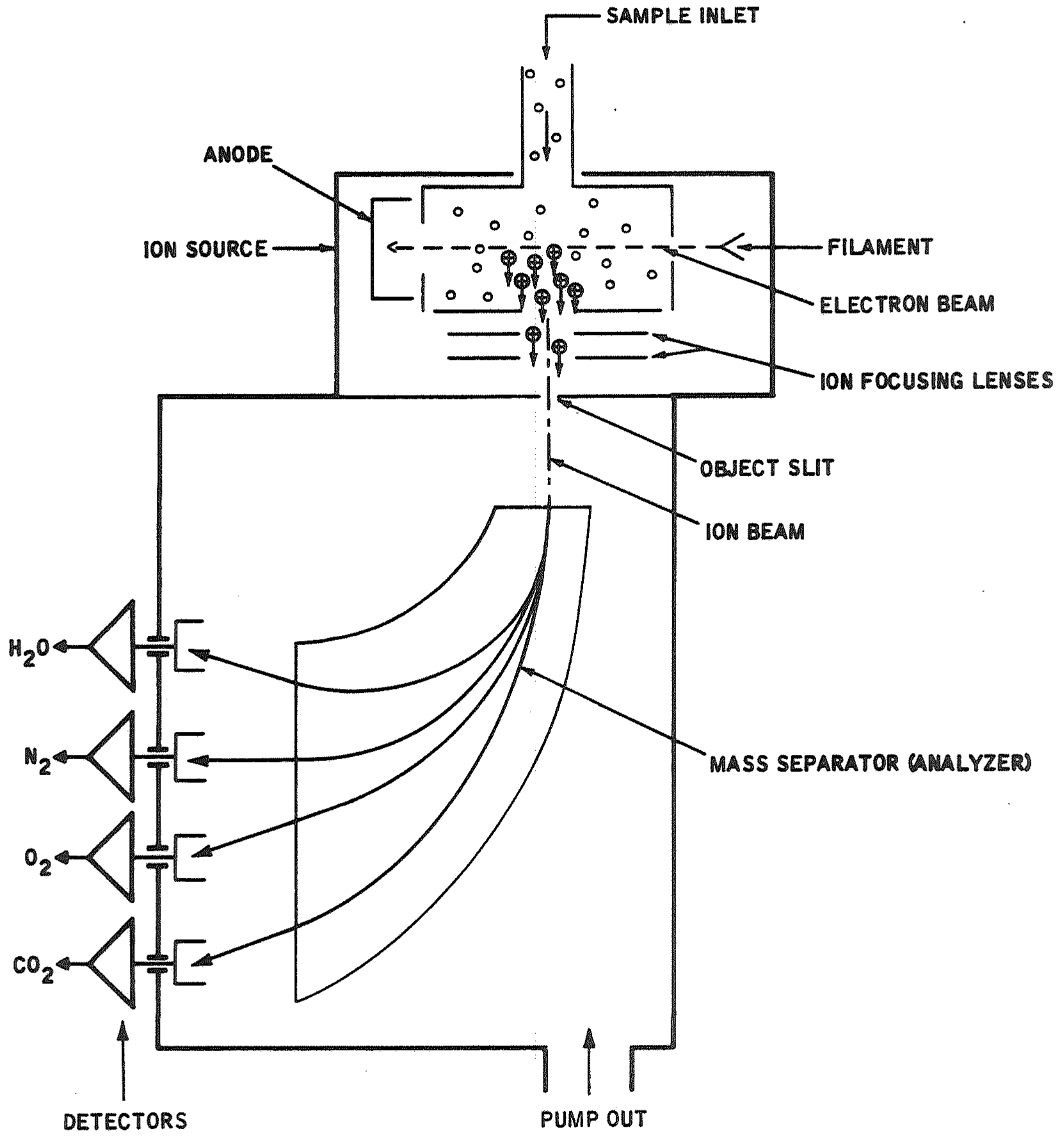

K+E 10 X 10 TO THE CENTIMETER 46 1513
KEUFFEL & ESSER CO.
BAROMETRIC PRESS TORR (MM Hg) SHIPS BAROMETER
790
780
770
760
750
740
NITROGEN OUTPUT TORR
610
600
590
580
570
OXYGEN OUTPUT TORR
160
150
140
CARBON DIOXIDE & WATER VAPOR OUTPUT TORR
13
12
11
10
9
8
7
6
5
4
3
2
1
0
SURFACE VENTILATE
SURFACED
RECIRCULATED AIR
SUBMERGED
START SCRUBBER
SURFACE VENTILATE
SURFACED, HATCH OPEN
RECIRCULATED AIR
START SCRUBBERS
SNORKELING
START SCRUBBER
SURFACE VENTILATE
N2
O2
FIVE DAY SEA TRIAL DATA

FIGURE 8

FIGURE 9. **Basic Two Gas ATM Sensor**



A-105-A2

FIGURE 10. Principles of Mass Spectrometer Operation

FIGURE 11. Two Gas Atmosphere Analyzer Assembly

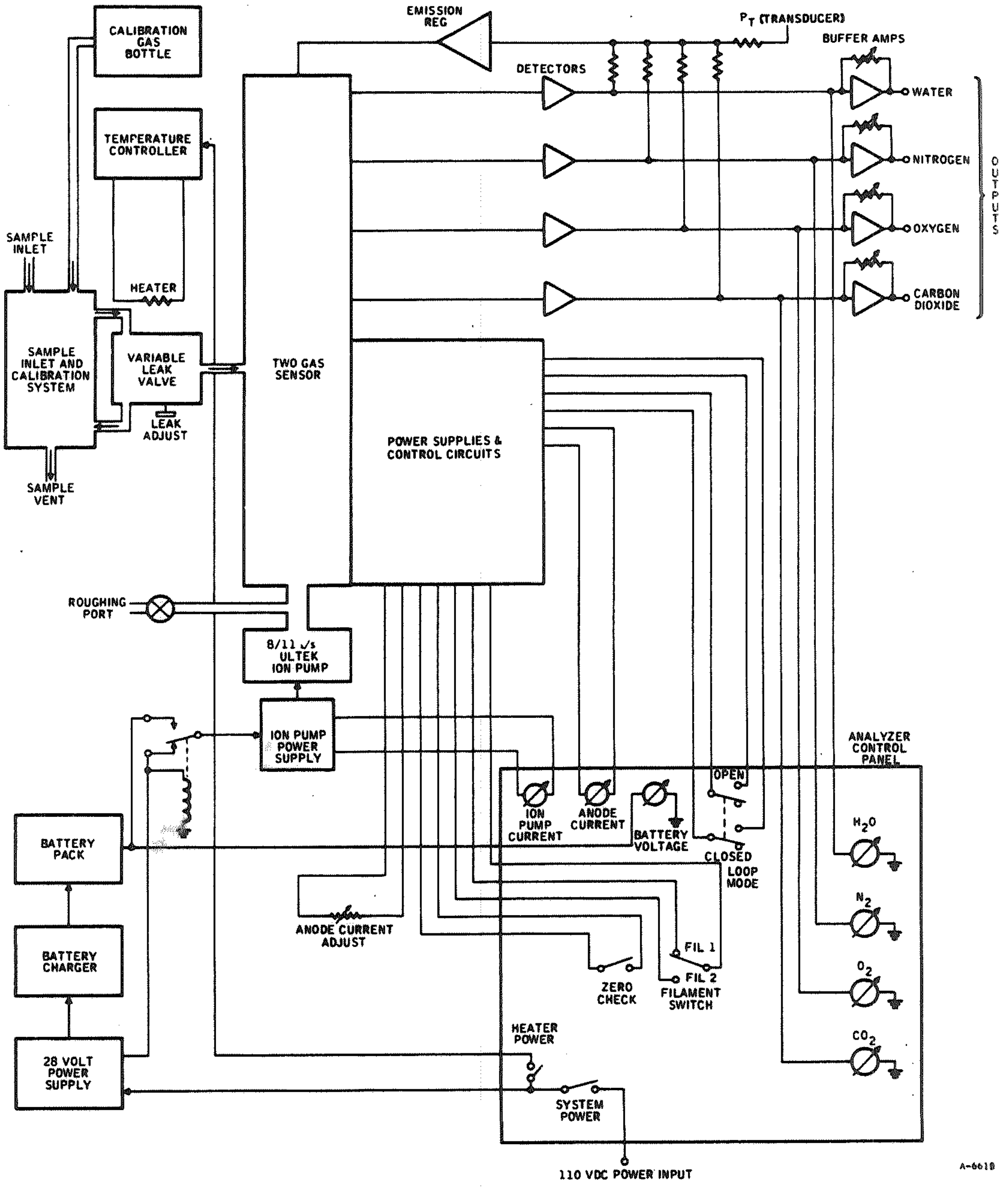


FIGURE 12. Atmospheric Sensor System Block Diagram

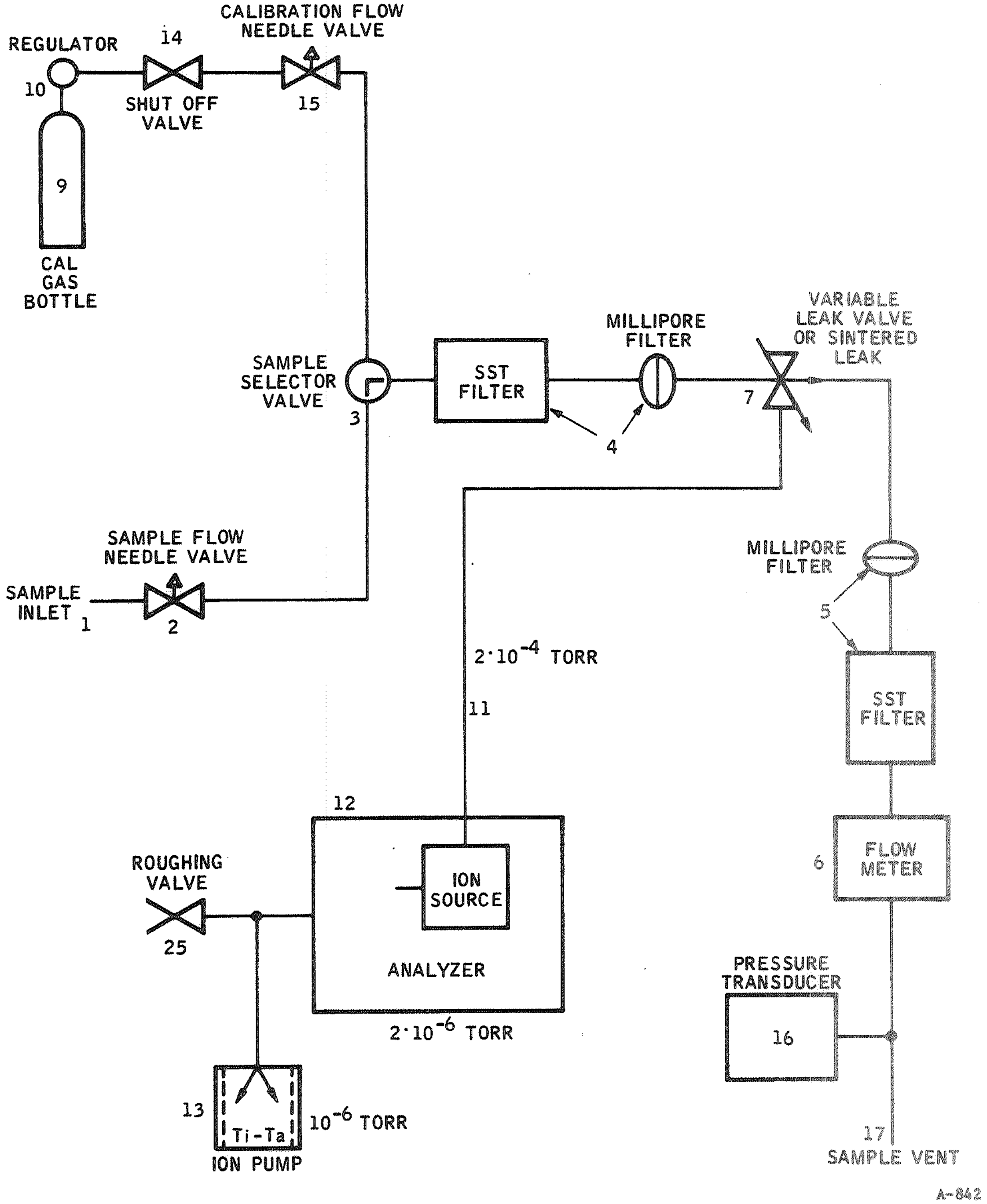


FIGURE 13. Sample and Calibration Inlet System Schematic Flow Diagram

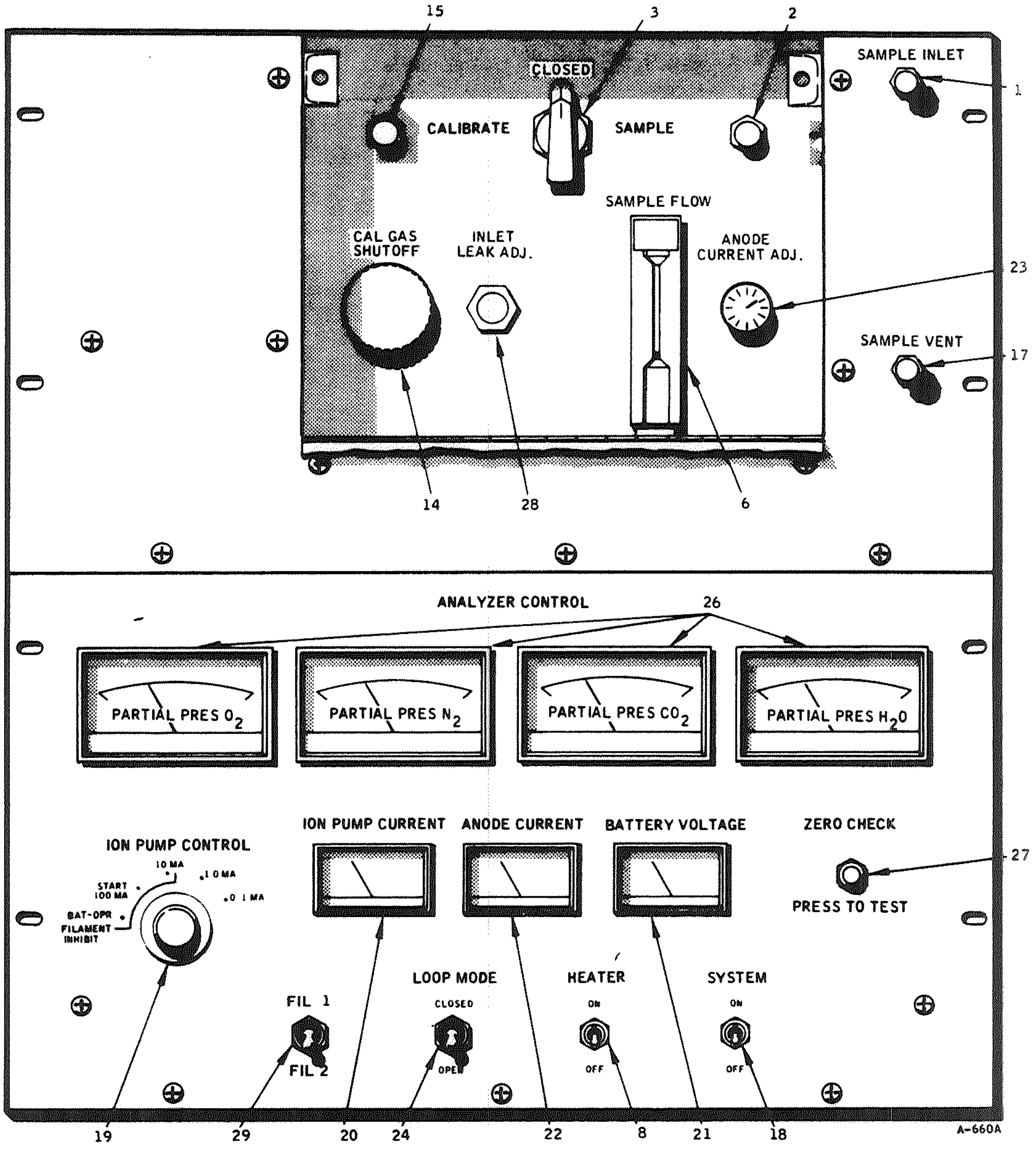


FIGURE 14. Atmospheric Sensor Front Panel

FIGURE 15. **90-Day Space Station Simulator Atmospheric Sensor System**

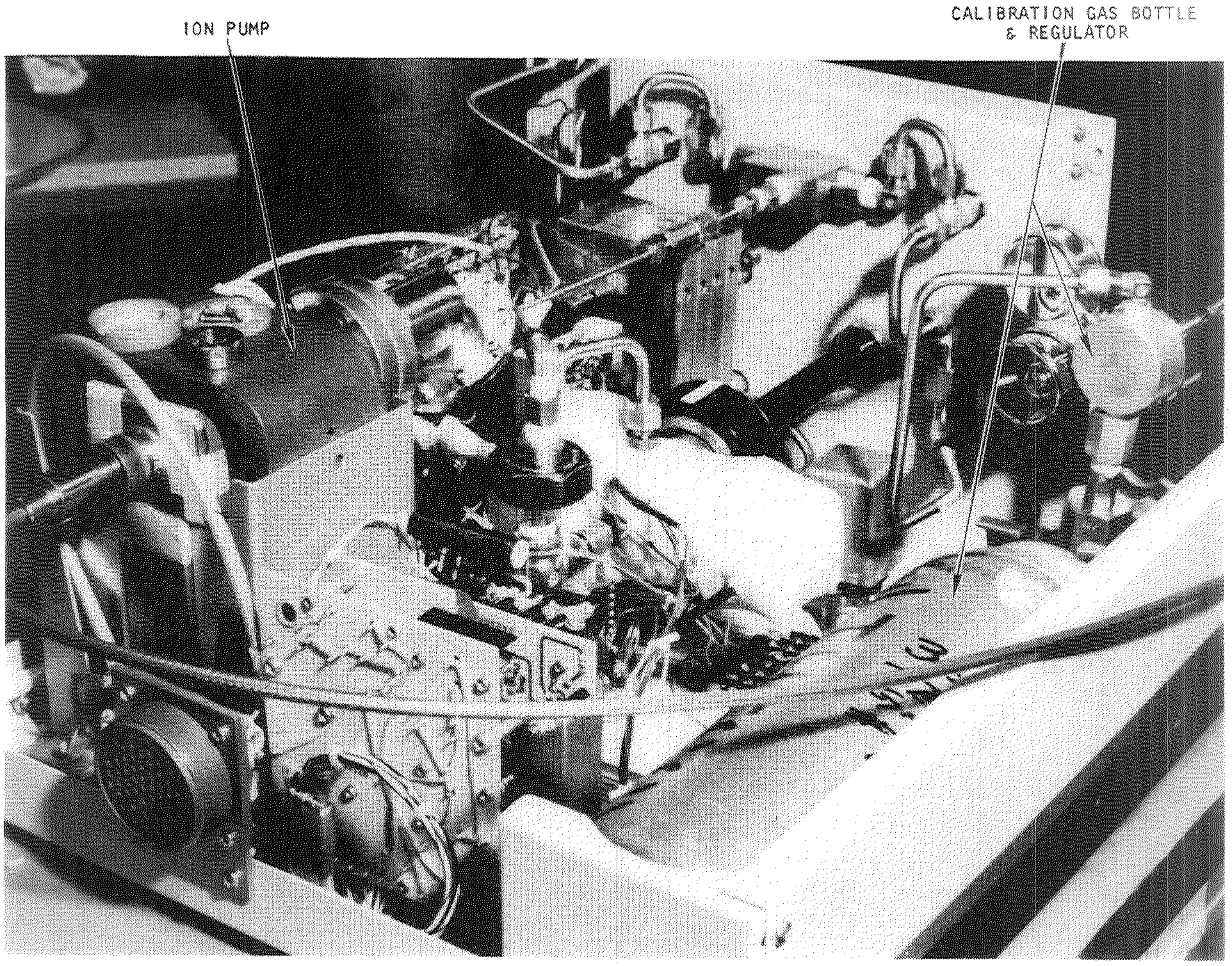


FIGURE 16. Atmospheric Sensor - Upper Bay

FIGURE 17. **Atmospheric Sensor - Lower Bay**

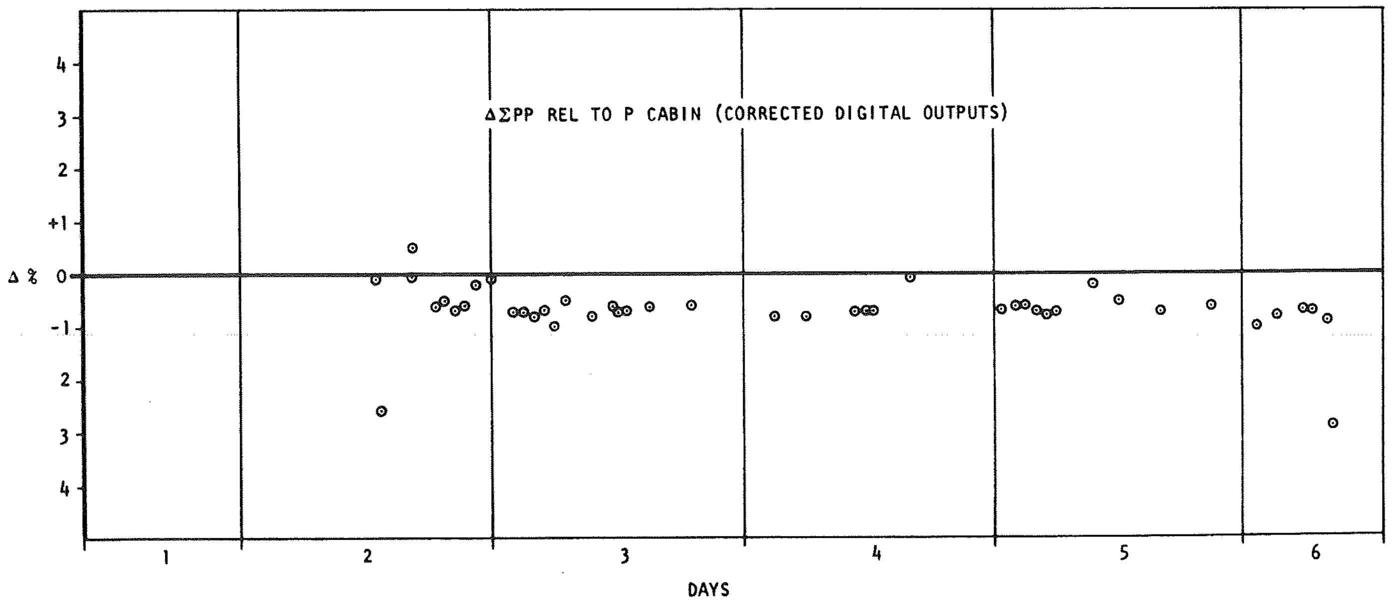


FIGURE 18. Comparison of the Summation of Partial Pressures to the Total Pressure During the Five Day Test

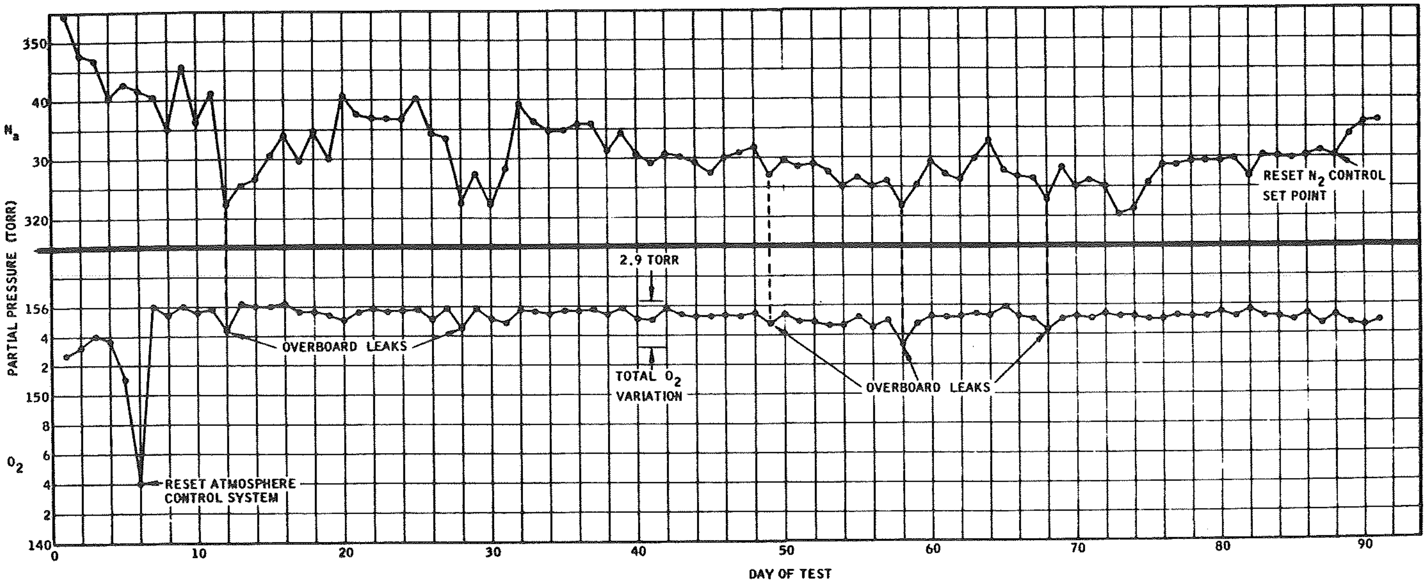


FIGURE 19. Oxygen and Nitrogen Partial Pressures During the 90 Day Test

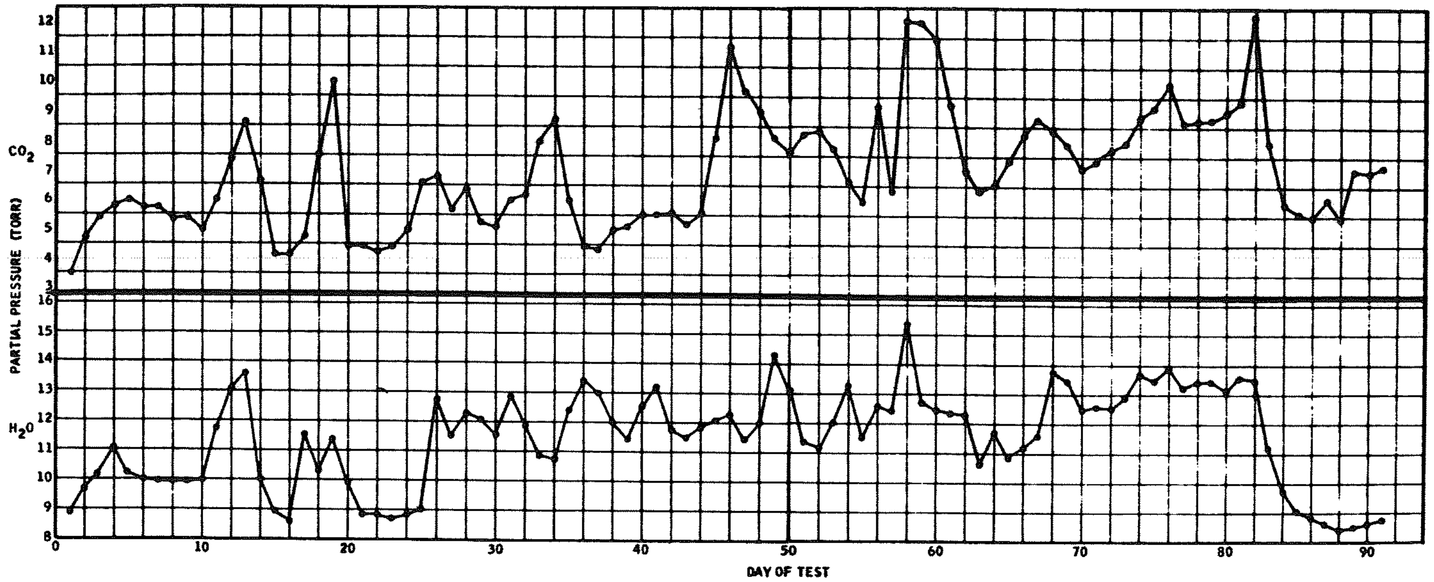


FIGURE 20. Carbon Dioxide and Water Vapor Partial Pressures During the 90 Day Test

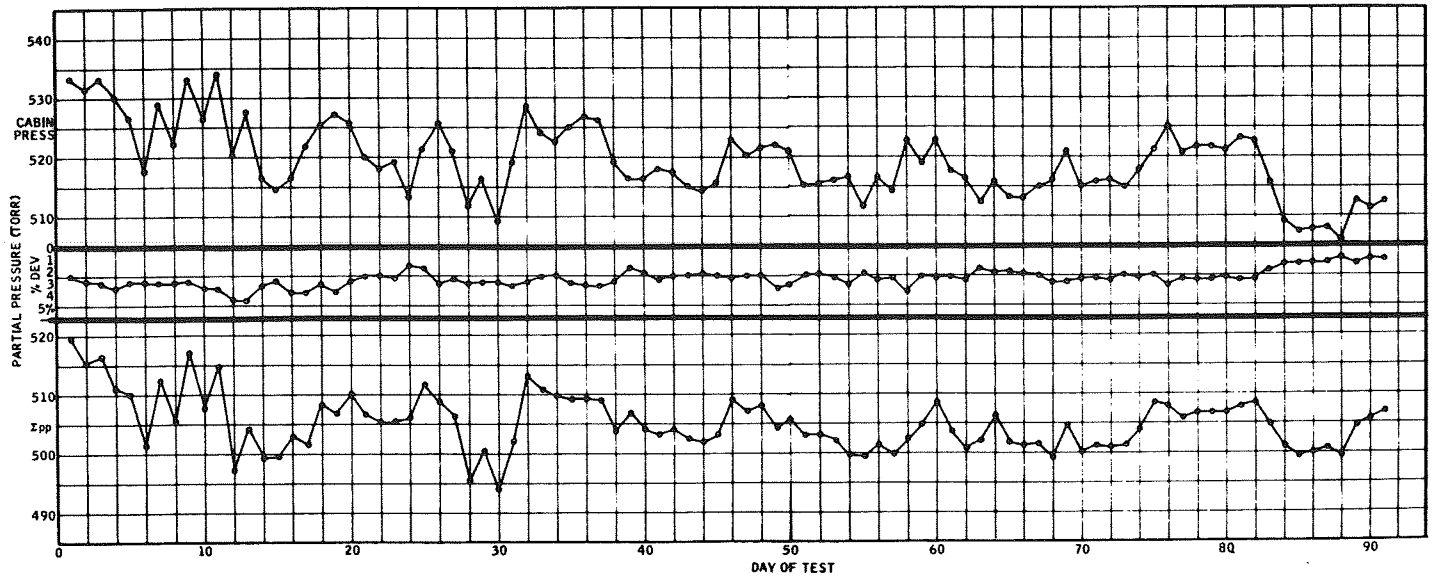


FIGURE 21. Comparison of the Summation of Partial Pressures to the Total Pressure During the 90 Day Test

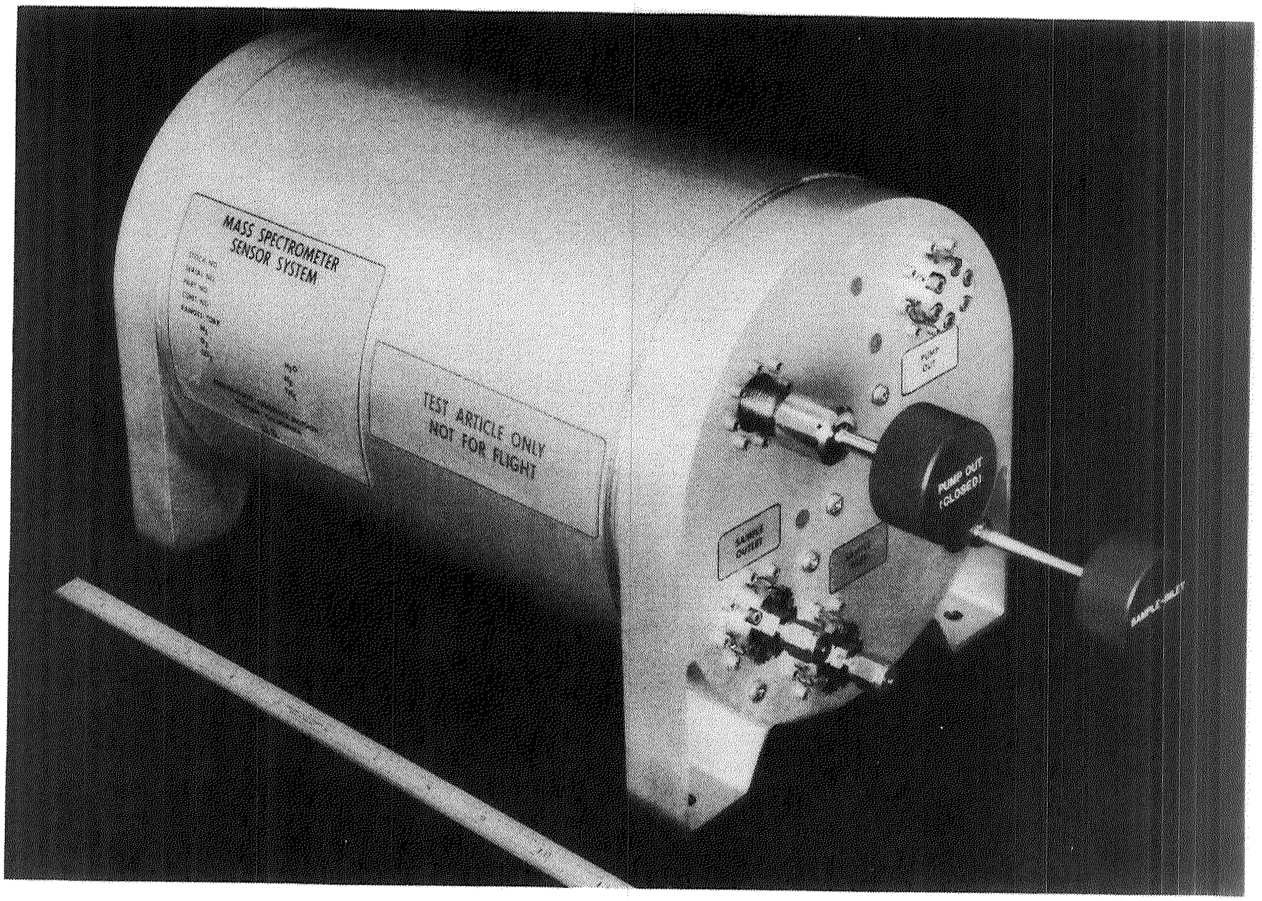


FIGURE 22. Flight Qualified Mass Spectrometer Atmospheric Sensor System for Atmospheric and Respiratory Monitoring

FIGURE 23. Undersea Atmospheric Sensor (UAS)

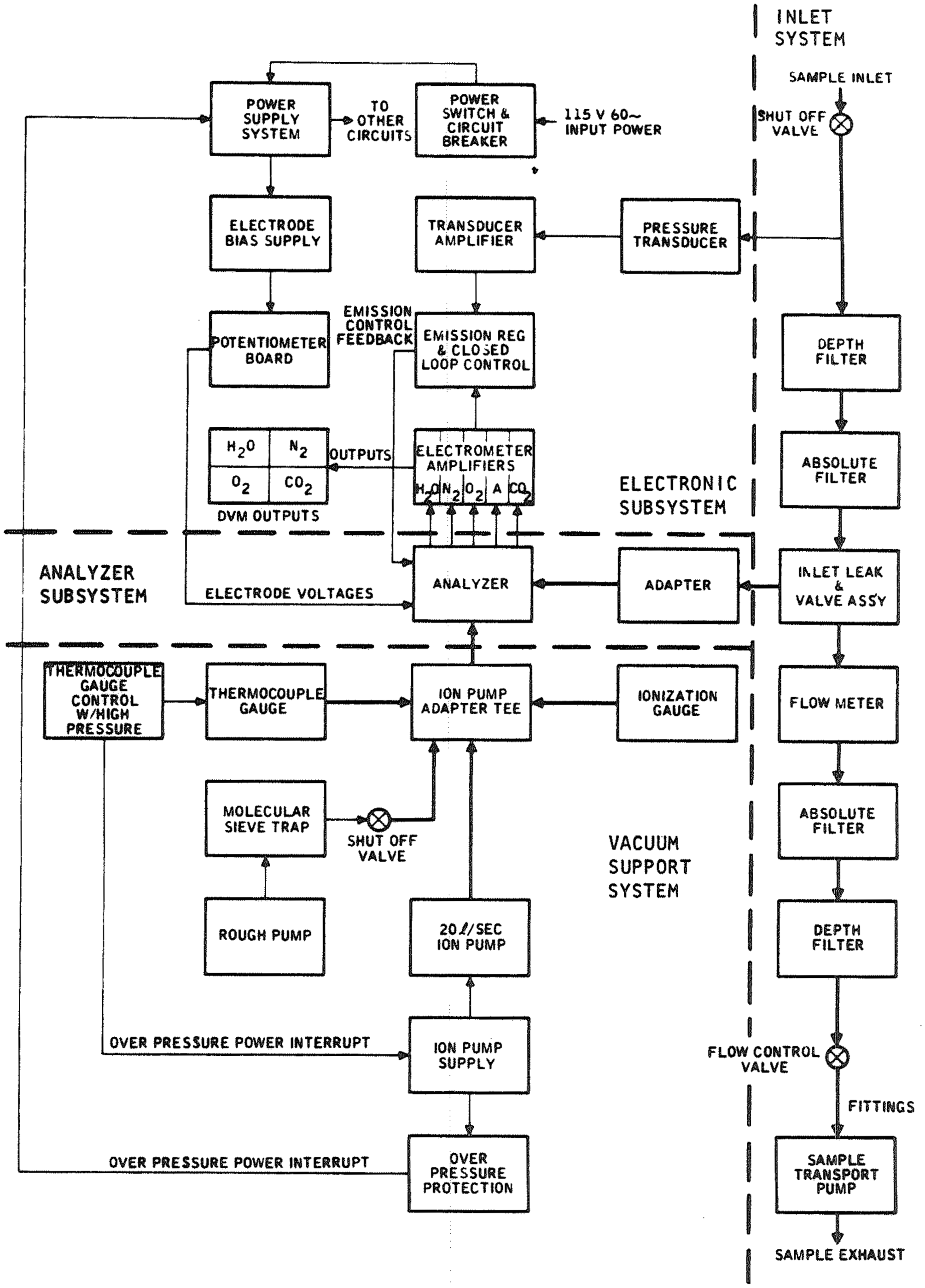


FIGURE 24. Block Diagram - Undersea Atmosphere Sensor (UAS)

FIGURE 25. UAS (With Panel Covers Installed)

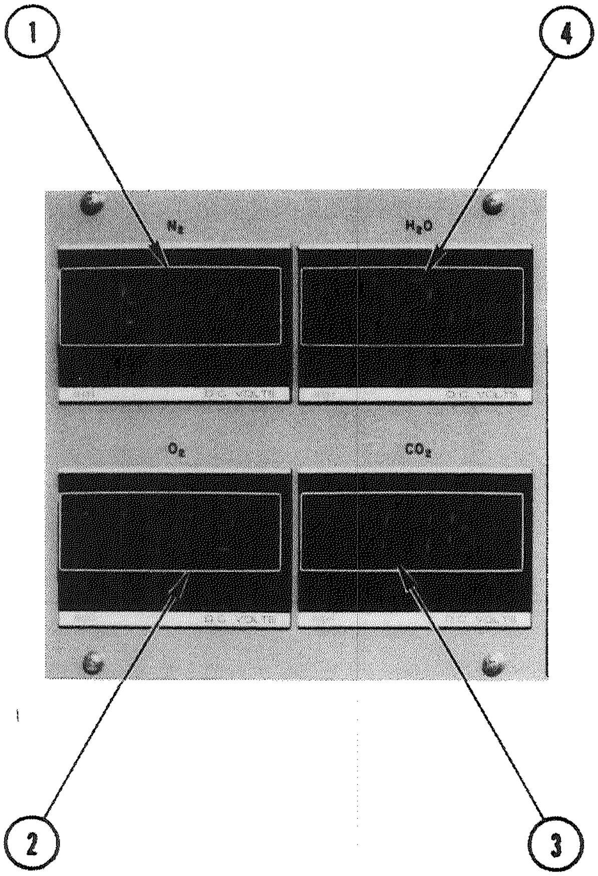


FIGURE 26a. Identification of System Controls

FIGURE 26b. Identification of System Controls

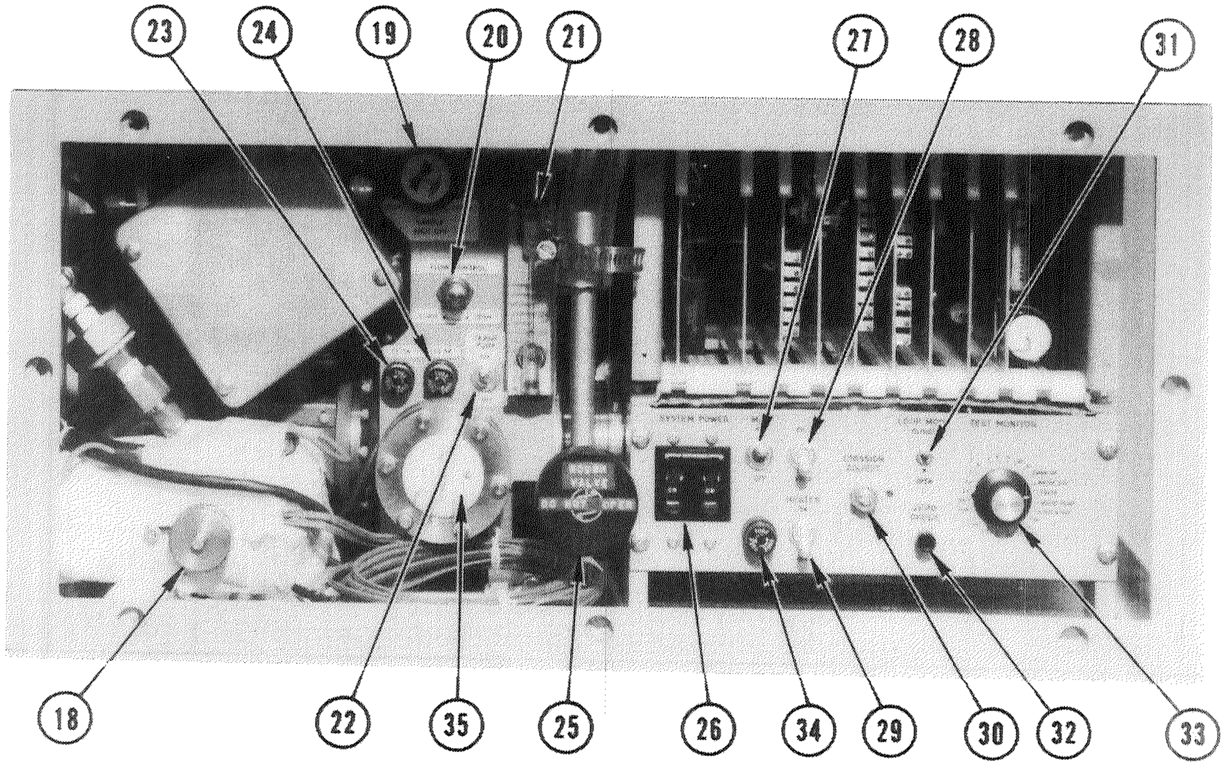


FIGURE 26c. Identification of System Controls

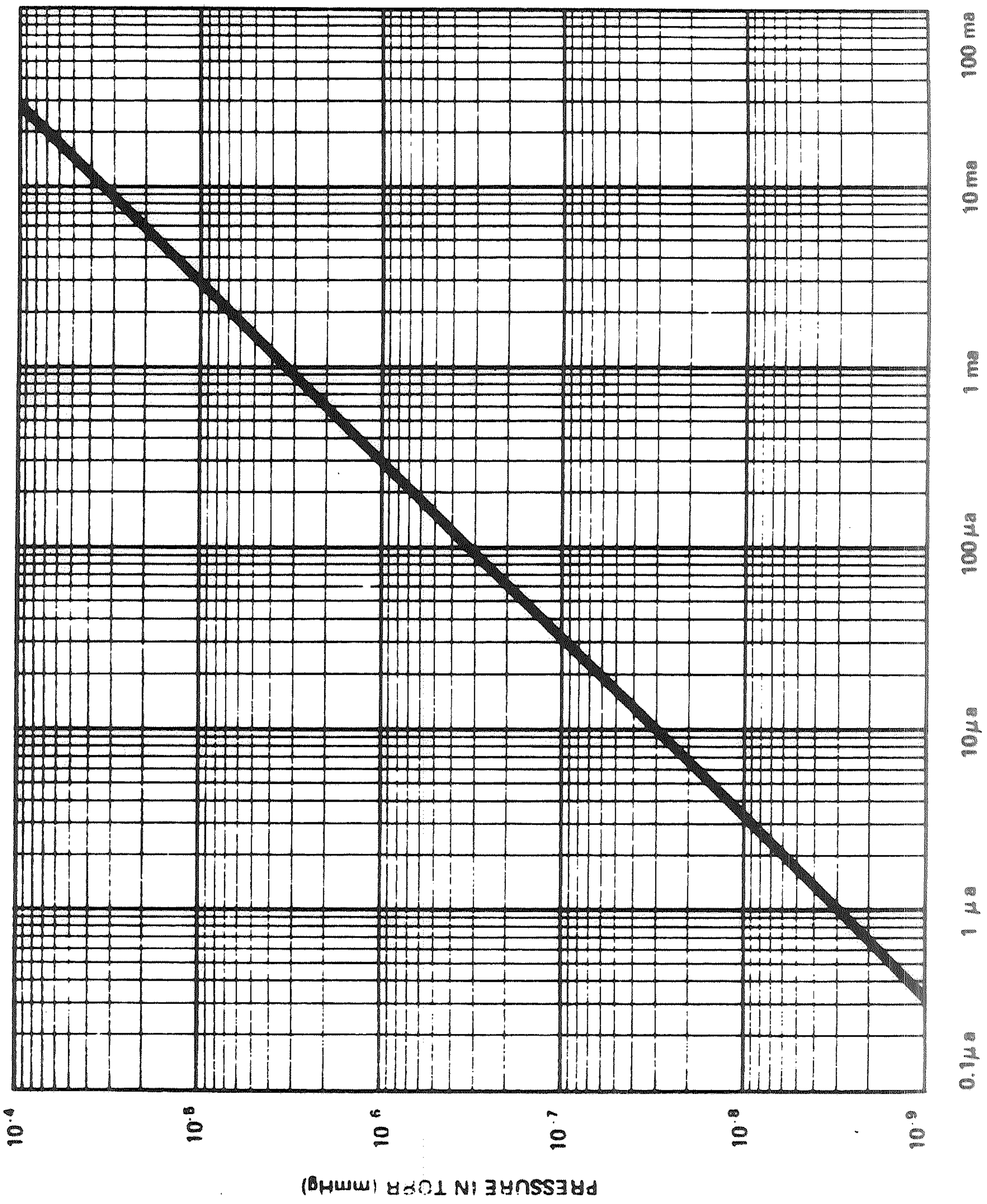


FIGURE 27

Pump Current (20 l/s Ultek Ion Pump)