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NAVSEA TASK 92-002 & 92-003



NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. <u>12-94</u>

EVALUATION OF MAKO 5436 HIGH PRESSURE BREATHING AIR COMPRESSOR

> GEORGE D. SULLIVAN April 1994

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#### UNCLASSIFIED SECURITY CLASSIFICATION OF THIS PAGE

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1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED         2a. SECURITY CLASSIFICATION AUTHORITY         2b. DECLASSIFICATION/DOWNGRADING SCHEDULE         4. PERFORMING ORGANIZATION REPORT NUMBER(S)	<ul> <li>1b. RESTRICTIVE MARKINGS</li> <li>3. DISTRIBUTION/AVAILABILITY OF REPORT DISTRIBUTION STATEMENT A: Approved for public</li> </ul>
<ul> <li>2a. SECURITY CLASSIFICATION AUTHORITY</li> <li>2b. DECLASSIFICATION/DOWNGRADING SCHEDULE</li> <li>4. PERFORMING ORGANIZATION REPORT NUMBER(S)</li> </ul>	3. DISTRIBUTION/AVAILABILITY OF REPORT DISTRIBUTION STATEMENT A: Approved for public
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE 4. PERFORMING ORGANIZATION REPORT NUMBER(S)	DISTRIBUTION STATEMENT A: Approved for public
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	release; distribution is unlimited
NEDU Report #12-94	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZ. 6b. OFFICE SYMBOL Navy Experimental Diving Unit (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Panama City, Florida 32407-5001	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION6b. OFFICE SYMBOL (If applicable OOCNaval Sea Systems CommandOOC	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, D.C. 20362-5101	10. SOURCE OF FUNDING NUMBERS         PROGRAM       PROJECT NO.       TASK NO.       WORK UNIT         ELEMENT NO.       92-002       ACCESSION NO.         92-003       92-003
12. PERSONAL AUTHOR(S) Mr. David Sullivan 13a. TYPE OF REPORT FINAL	14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT
16. SUPPLEMENTARY NOTATION	April 1994 16
17.       COSATI CODES       18. SUBJECT TERMS         FIELD       GROUP       SUB-GROUP         MAKO 5436 Hig	(Continue on reverse if necessary and identify er) h Pressure Breathing Air Compressor
19. ABSTRACT (Continue on reverse if necessary and In response to NAVSEA tasking, Navy Experimental Di Pressure Breathing Air Compressor from April 1994 t compressor, when operating at 5000 PSI, met Navy di results NEDU recommends that the compressor be plac VAVSEA OOC.	identify by block number) ving Unit (NEDU) evaluated the MAKO 5436 High o May 1994. This test was to determine if the ving community requirements. Based on the test ed on the Aopproved for Navy Use list published by
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION

DD FORM 1473. 84 MAR 83 APR edition may be used until exhausted. <u>SECURITY CLASSIFICATION OF THIS PAGE</u> All other editions are obsolete. UNCLASSIFIED

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#### I. INTRODUCTION

In response to NAVSEA tasking<sup>1</sup> a MAKO HIGH PRESSURE AIR COMPRESSOR, MODEL 5436, ELECTRIC DRIVE was tested<sup>2</sup> by Navy Experimental Diving Unit (NEDU). The unit was previously tested (NEDU Test No. 91-04) and approved by NAVSEA for inclusion in the ANU list<sup>3</sup> at an operating pressure of 211 bar (3000 psig). The purpose of this test was to re-evaluate the unit at 345 bar (5000 psig) and:

A. Determine if the compressor provides compressed air at the required pressures, flow rates, quality and cleanliness required by the U.S. Navy<sup>4</sup>.

B. Determine the adequacy of the manufacturer's information, instructions and guidance for the safe operation and overall management of the compressor.

#### II. EQUIPMENT DESCRIPTION

#### A. GENERAL

The MAKO, MODEL 5436 high pressure, breathing air compressor (Figure 1) is of a four stage, four cylinder, single acting, "vee" configuration.

A forced lubrication system is utilized. Lubricating oil is supplied under pressure to the main bearings via a filter and crankshaft passages. Oil is forced through the bearing clearance and thrown off the rotating crankshaft to ensure an adequate supply to cylinders, pistons, and crossheads. The third and fourth stages are lubricated through a dedicated mechanical lubricator. Sight glasses allow observation of compressor sump oil level and the feed rate of the third and fourth stage mechanical lubricator. The mechanical lubricator tank is supplied by the compressor oil sump. The compressor requires approximately 45 liters (11.8 gallons) of lubricating oil, and the cylinder lubricator requires 1.0 liter (2.1 pint) of oil.

Compressor cooling is by water through a closed radiator type system. Water from this system is pumped through the jackets and passages of the compressor and returned to the radiator for heat removal.

The drive unit for this test was a 460 Volt, 3 Phase, 75 Horsepower, Reliance A/C motor. It is equipped with a slide motor plate and "V" belt pulley. Rotational torque is transferred to the compressor by five "V" belts. Electric motors purchased for use with this compressor shall comply with Navy standards for sealed insulation units<sup>5</sup>.



Figure 1 5436 High Pressure Air Compressor

The MAKO compressor unit consists of a compressor block, auto drain monitoring system, and a drive motor mounted on a steel frame secured to a concrete floor.

The compressor air system consists of an interstage separator, auto drain system, and auto drain reservoir. The interstage separators are installed between the 2nd and 3rd, and the 3rd and 4th stages. Internal operation of the interstage separators is through a nozzle which separates water and oil from the compressed air. The interfilter requires routine maintenance (periodic draining).

The auto drain system blows down the separators at 15 minute intervals. This is accomplished by an electric timer which deactivates a solenoid valve that controls the pressure on a bank of piston type valves isolating the separators from the reservoir. Residual oil and water vapors not drained by the auto-drain system are removed by a down stream filter purification system.

The MAKO 5436 compressor has a rated capacity of 2548 liters per minute (90 scfm) free air delivered at 345 bars (5,000 psi).

A pressure maintaining/non-return valve set at 145 bars (2,100 psi) is provided. This ensures that pressure build-up occurs during start up and initial compressor air delivery. This achieves constant, optimum moisture separation, fourth stage piston ring expansion/cylinder sealing, and prevents compressed air return from the storage flasks to the compressor during unit shut down. All four stages of the compressor are protected by safety relief valves.

The MAKO, MODEL 5436 comes with one Breathing Air Module Owner's Manual<sup>5</sup> which is divided into the following sections;

- 1. Leading Particulars
- 2. General Description
- 3. Installation
- 4. Commissioning or Recommissioning
- 5. Operation & Routine Maintenance
- 6. Valve Servicing
- 7. Fault Guide
- 8. Illustrated List of Parts

#### III. TEST PROCEDURE

There are various methods of testing compressor capacities, stability, and reliability. For this compressor evaluation<sup>2</sup>, NEDU chose to continuously run the compressor for extended periods charging a 178.39 liter floodable volume (6.3 cuft) cylinder bank from 0 bars to 345 bars (0 to 5,000 psig).

The compressor was a permanently installed part of the NEDU EDF air system. A Cole Palmer Model 8502-14 temperature monitor and Yellow Springs Instruments 700 Series thermistor probes were attached for measuring compressor discharge and ambient temperatures. Figure 2 provides a diagram of the test equipment set up.

Appendix A shows the recorded data from the Test Log. The unit was operated in an interior work area, open to ambient temperature and humidity. The testing included subjective evaluation of the system operation but did not include detailed mechanical review of the individual components of the system.

The compressor was operated using one external final separator. No other purification systems were used. A total of 25 test hours were expended. The following parameters were recorded:

- 1. Date
- 2. Time
- 3. Meter Test Hours
- 4. Ambient Temperature
- 5. Compressor Air Discharge Temperature
- 6. Ambient Humidity
- 7. Cylinder Charging Time
- 8. Compressor Water Pressure
- 9. Compressor 3rd Stage Temperature
- 10. Compressor Oil Pressure
- 11. Compressor Stage Pressures
- 12. Final Discharge Pressure
- 13. Compressor free air capacity flow rate

Appendix A is recorded data from the Test Log.

#### IV. OBSERVATIONS/RECOMMENDATIONS

## A. AIR DELIVERY

Compressor capacity was determined to be 2,763.66 liters per minute (97.6 cfm) by calculating the average time to charge a 178.39 liter (6.3 cuft) floodable volume cylinder from 0 to 345 bars (0 to 5,000 psig). Calculations are shown in Appendix A.

### B. AIR SAMPLING

Air samples were taken from the compressor discharge at the 1 and 25 hour running time. The samples were sent to the Coastal Systems Station (CSS) Laboratory, Code 5130, for purity analysis. Analysis of air samples are listed in Appendix B.

#### C. OIL LUBRICATION

At the beginning of the test, the compressor oil sump level indicated full. Oil level was checked every 30 minutes using the oil level sight glass. Oil consumption was logged in Appendix A. During the 25 hours, a total of 0.94 liters (1 quart) of oil was added to the compressor. The oil used during the test was Anderol 750 compressor oil. MAKO Technical Manual<sup>6</sup> CAUTION states:

"The following synthetic oils are approved:

Reavellite Anderol 500

The above oils have been found to give better and more consistent valve life on high pressure valves (i.e. third and fourth stages)."

### D. MAINTENANCE

No factory maintenance was scheduled during this test.

# E. PRIME MOVER

This task requested NEDU to test the compressor only. Commands procuring primemovers for these compressors must ensure that they meet Navy specifications. The prime mover, if electric, should be a sealed insulation system (service A use) in accordance with MIL- $M-17060 E^{6}$ , Amendment 1.

# F. CADMIUM FITTINGS

General Specifications<sup>7</sup> state that cadmium coated fittings cannot be used in systems that exceed 400 degrees Fahrenheit or if the cadmium could come in contact with petroleum products. At this time the only authorized HP compressor lubricant by the Navy is the petroleum based 2190 TEP (a petroleum based product). Recommend cadmium coated fittings be replaced with a suitable substitute.



Figure 2 NEDU Test No. 93.35 Equipment Configuration

# V. CONCLUSIONS

A. The high pressure air compressor delivers air which meets U.S. Navy standards<sup>4</sup> at an average rate of 2,763.66 liters per minute (97.6 cfm) per Appendix A. This meets the manufacturer's specification.

B. The unit is sturdy, reliable and readily maintained.

C. Based on the results of testing, the MAKO 5436 high pressure air compressor system is recommended for inclusion on the Authorized for Navy Use List<sup>3</sup>.

D. The vendor and NAVSEA should be contacted prior to purchase to ensure the unit meets the user's needs.

## VI. REFERENCES

1. NAVSEA Task 92-002; <u>Evaluation of Commercially Available Divers Air</u> <u>Compressors</u>

2. <u>MAKO 5436 High Pressure Air Compressor Evaluation 5000 PSIG (Unmanned)</u> Test Plan 93-35 (Limited Distribution), Navy Experimental Diving Unit, September 1993

3. NAVSEAINST 10560.2B Diving Equipment Authorized for U. S. Navy Use

4. NAVSEA 0994-LP-001-9010 U.S. Navy Diving Manual Volume 1, Rev. 3, Paras 5.3.2. Air purity standards, and 6.7.2.1. Air Compressors

5. <u>Breathing Air Module (5436) Manual</u>, Mako Compressors, Inc. 1634 SW 17 Street Ocala, Florida 34474

6 MIL-M-17060 E Amendment 1, <u>Sealed Insulated Systems</u>, (service A use). Navy specification for compressor power source

7. Navy Publication No. S9AA-AA-SPN-010/GENSPEC, <u>General Specifications for</u> <u>Ships of the Navy</u>, Cadmium Fittings, January 19, 1987

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		4TH	2100	2350	4100	2100	2100	2200	3200	2100	3100	4000	
	LESSOR R STAGES SI	3RD	1050	1100	1280	1090	1090	1100	1200	1050	1150	1250	
	COMPR CYLINDEH PS	2ND	220	250	260	250	250	250	260	250	260	260	
		IST	40	44	44	44	44	44	44	44	44	44	
	OIL PRESS		35	33	35	34	33	33	33	33	33	33	
	COMP TEMP °F		110	135	158	150	145	150	155	140	160	165	
	WATER PRESS		35	35	35	35	35	35	35	35	35	35	
	GED IDER E	RATED PSI	-	1	I	5000	,		5000	•	-	-	
i i	CHAR CYLIN SIZ	RATED CUFT	3	•	,	6.3			6.3		•		
	TION	END PSI				5000	1		5000		•		а - - -
	/LINDER 3 INFORMA	END TIME	,	•	,	1012		,	1132		,		
	C) CHARGING	START TIME	-	•	0950	ŀ		1110	,	•	1	1	
	CYL FILL TIME			ı		:22	,	•	:22				
	AMBI HUMID %		67	65	67	79	79	75	73	70	71	73	
	ţĻ. I	COMP DSCHG °F	54	56	113	105	601	118	122	66	611	119	
	TEMP	AMBI TEMP°F	7,8	78	17	78	80	81	80	82	81	82	
29, 1994	METER HOURS		431.4	431.6	432.1	432.6	433.1	433.6	434.1	434.6	435.2	435.6	
DATE: APRIL :	Тиме	/	0845	0060	0630	1000	1030	1100	1130	1200	1230	1300	Dealor Charles

0830 Checked oil levels 0845 Started compressor testing 1300 Secured compressor testing

minutes. Therefore, the charging rate is:  $\frac{178.39 \times 341.14}{22} = 2766.21 \text{ LPM}$  (97.6CFM) The mean time for pressurizing an 178.39 liter (6.3 cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is:  $\frac{22 + 22}{2} = 22$ 

Appendix-A-1

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		3	11	T	1	1	1	1		-		1	1	T	T	r	-	1	Y
		4TH	2100	4200	2100	4900	2100	3600	4800	2200	4100	2100	4000	2100	3200	2200	2100	5000	
	R STAGES	3RD	1050	1300	1050	1300	1050	1200	1300	1100	13()0	1050	1250	1050	1200	1100	0011	1300	
	CYLINDEJ P	2ND	240	260	250	260	250	260	260	250	260	250	260	250	260	250	250	260	
		IST	40	44	44	45	44	44	44	44	44	44	44	44	44	44	44	44	
	OIL PRESS		36	33	35	34	34	34	34	34	33	33	33	33	33	33	33	32	
	COMP TEMP °F		95	145	145	155	140	150	160	145	165	150	165	155	160	150	155	170	
	WATER PRESS		35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	
	GED (DER E	RATED PSI		-	5000	-	•	-	•	-	-	,	5000		1		3	'	
	CHAR CYLIN SIZ	RATED CUFT			6.3	•		•		,	,	,	6.3	ľ	,	'	,		
	TION	END			5000	-	-			,		-	5000				·	'	
	ylinder g informa	END TIME		,	0750	,	,	,	,	'		,	1224	t		-	,		
	C CHARGIN	START TIME	-	0728	×	,					4		1202	,		-			
	CYL FILL TIME				:22	1	,	ľ	,				:22	'			,	,	
	AMBI HUMID %		100	95	16	16	16	8	86	82	81	62	82	81	80	78	73	76	
	1.00	COMP DSCHG° F	59	103	96	114	101	115	118	109	117	110	117	113	118	110	114	121	
وموادعاتها والمحافظ المحافظ المحافظ المحافظ المحافظ	TEMI	AMBI TEMP°F	69	70	70	70	70	72	73	73	52	74	76	76	9L	78	64	80	e
1994	METER HOURS		435.6	436.0	436.5	437.0	+37.5	438.0	438.5	1.961	4.30.5	0.014	40.5	441.0	441.5	442.0	42.5	443.0	compressor oil lev compressor testing compressor testing
DATE: MAY 2,	TIME		0700	0725	0800	0830	0060	0630	1000	1030	0011	0£11	1200	1230	1300	1330	1400	1430	0645 Checked 0700 Started c 1445 Secured
						1.00.00													

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The mean time for pressurizing an 178.39 liter (6.3 cuti) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is:  $\frac{22+22}{2} = 22$  minutes. Therefore, the charging rate is:  $\frac{178.39}{2} \times 341.14 = 2766.21 LPM$  (97.6 CFM)

Appendix-A-2

DATE MAY 3,	1994																
TIME	METER HOURS	TEMP	ъ	AMBI HUMID %	CYL FILL TIME	CY CHARGING	LINDER I INFORMAT	NOL	CHAR CYLIN SIZI	GED DER E	WATER PRESS	COMP TEMP °F	OIL PRESS		COMPRI CYLINDER PS	ESSOR STAGES I	
		AMBI TEMP°F	COMP DSCHG°F			START TIME	END TIME	END PSI	RATED CUFT	RATED PSI				IST	2ND	3RD	4TH
0200	443.3	73	53	06	-	1	,	ř	,		35	100	37	40	240	1050	2100
0730	443.8	73	107	92	,	4	,		,		35	· 155	35	44	260	1200	3200
0800	4,44,4	73	66	94	,	0816		5000	6.3	5000	35	140	34	43	250	1050	2100
0830	444.9	76	109	72	:22	,	0838	,			35	150	34	43	250	1150	2300
0060	445.3	76	117	85			'	,	1× 1	-	35	160	34	44	260	1300	4400
0660	445.9	77	114	86						,	35	140	33	43	250	1150	3000
0001	446.4	78	108	80		-	-			-	35	150	33	43	250	1100	2150
1030	6.044	62	116	81	-	1			,	ŗ	35	160	33	43	260	1200	3200
1100	t-77.4	79	110	83		1			,	'	35	150	33	43	250	1100	2200
1130	447.9	78	112	81	1		,	'	1	'	35	145	33	44	250	1100	2300
1200	418.4	78	104	87		'	,	'		,	35	150	33	44	350	1050	2100
1230	448.9	78	611	89	,	,		'			35	170	33	44	260	1300	4800
1300	449.4	78	116	89	1		,	,		ľ	35	150	33	4	250	1150	3000
1330	6.644	78	95	87	2		'	'	-	'	35	145	33	44	250	1050	2100
1400	450.4	78	117	89	ŗ					'	35	160	33	44	260	1250	4200
1430	450.9	78	107	66			'	'	,	'	35	150	33	44	250	1050	2100
1450	451.2	SECURED		,	i	·	'	,	-	'			,		ſ	,	-
0650 Checke 0655 Started 1450 Secured	id compressor oil compressor testin d compressor testi	level Ig ing						•									

The mean time for pressurizing an 178.39 liter (6.3 out) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is: 22 minutes. Therefore, the charging rate is:  $\frac{128.39}{22}$  # 341.14 = 2766.21 LPM (97.6 CFM)

Appendix-A-3

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	S	4TH	2100	2100	,		3600	2100	4900	2100	3800	2100	4600	3800	2600	3200	
	COMPRESSOR LINDER STAG PSI	ID 3RI	105	102	, 		50 120	50 105	50 130	00 102	30 125	50 105	50 130	50 125	20 112	50 120	
	CYL	2N	24	24			26	25	36	25	26	35	26	26	25	26	
		IST	40	42	,	•	44	44	4	44	44	44	44	44	44	44	
	OIL		35	33		•	35	35	33	33	33	33	33	33	33	33	
	COMP TEMP °F		110	· 135	-		155	145	170	160	170	155	175	170	160	165	
	WATER PRESS		35	35	,	-	35	35	35	35	35	35	35	35	35	35	
	GED (DER JE	RATED PSI			-		,	-	,	5,000			,	,	,	•	
	CHAR CYLIN SIZ	RATED CUFT	-	ì	-		: •	-		6.3	,	,	1	•	,	h	
	TION	END PSI	-	-	3	•	•	-	-	5,000				-	,	•	
	YLINDER 3 INFORMA	END TIME	-	,	•		,			0958	ł	,	,		,	•	
	C' CHARGIN	START TIME		1	-	-	*	-	9£60			. ,	-		L	r	
	CYL FILL TIME		-	,	ł			-	-	:22	-	ĸ	-	-	ŀ	-	
	AMBI IIUMID %		88	89			73	52	57	63	70	68	65	68	68	67	
	o ولن	COMP DSCHG°F	51	66	-	-	105	100	117	105	118	109	123	121	117	119	sure regulator refill compressor
	TEMI	AMBI TEMP°F	71	73	ł		75	79	79	80	67	80	81	82	81	81	vel tre regulator failure (tepaired back-pres; ; (25 hours) Anderol 750 oil to
1661	METER HOURS		451.2	451.4			452.0	452.4	452.9	453.4	453.9	454.4	454.9	455.4	456.0	456.4	d compressor oil le compressor testing I due to back-pressu compressor testing - compressor testing 2.94 liters (1 quart)
DATE: MAY 4,	TIME		0650	0700	0730	0800	0830	0060	0930	1000	1030	1100	1130	1200	1230	1300	0645 Checke 0650 Started 0710 Secured 0817 Started 1300 Secured 1305 Added

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The mean time for pressurizing an 178.39 liter (6.3cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is: 22 minutes. Therefore, the charging rate is:  $\frac{178.39}{22}$  =  $\frac{341.14}{22}$  = 2766.21 LPM (97.6CFM)

Appendix-A-4

Memorandum

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

, ARS

Subject: Analysis of air sample marked MAKO 543 $\phi'$  Evaluation Test # 93-35 1 hour Sample.

In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

#### Standard Components

Component	Level	Limit
Oxvgen	21.0%	20 <b>-</b> 22% <sup>2</sup>
Nitrogen	78.1%	NONE <sup>2</sup>
Argon	0.9%	NONE <sup>2</sup>
Carbon Dioxide	335 PPM	1000 PPM <sup>2</sup>
Total Hydrocarbons <sup>1</sup>	1.6 PPM	25 PPM <sup>2</sup>
Carbon Monoxide	1.6 PPM	$20 \text{ PPM}^2$
Methane	1.6 PPM	1000 PPM <sup>2</sup>
Acetone	<0.1 PPM	200 PPM <sup>2</sup>
Benzene	<0.1 PPM	$1 \text{ PPM}^2$
Chloroform	<0.1 PPM	$1 \text{ PPM}^2$
Ethanol	<0.1 PPM	100 PPM <sup>2</sup>
Freon 113	<0.1 PPM	100 PPM <sup>2</sup>
Freon 11	<0.1 PPM	100 PPM <sup>2</sup>
Freon 12	<0.1 PPM	100 PPM <sup>2</sup>
Freon 114	<0.1 PPM	100 PPM <sup>2</sup>
Isopropyl Alcohol	<0.1 PPM	1 PPM <sup>2</sup>
Methanol	<0.1 PPM	$10 \text{ PPM}^2$
Methyl Chloroform	<0.1 PPM	30 PPM <sup>2</sup>
Methyl Ethyl Ketone	<0.1 PPM	$20 \text{ PPM}^2$
Methyl Isobutyl Ketone	<0.1 PPM	$20 \text{ PPM}^2$
Methylene Chloride	<0.1 PPM	25 PPM <sup>2</sup>
Toluene	<0.1 PPM	$20 \text{ PPM}^2$
Trimethyl Benzenes	<0.1 PPM	3 PPM <sup>2</sup>
Xylenes	<0.1 PPM	50 PPM <sup>2</sup>
Other Components		

Component

Level

<0.1 PPM

Limit

NONE

C4+

APPENDIX B-1-1

NONE

<sup>1</sup>Expressed as methane equivalents.
<sup>2</sup>Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
<sup>3</sup>OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Dearo Den

Glen Deason Chemist

#### Memorandum

06 MAY 1994

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample marked MAKO 5436 Evaluation Test # 93-35, 25 hour Sample.

In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

#### Standard Components

Component	Level	Limit
Oxygen Nitrogen Argon Carbon Dioxide	21.0% 78.1% 0.9% 322 PPM	20-22% <sup>2</sup> NONE <sup>2</sup> NONE <sup>2</sup> 1000 PPM <sup>2</sup>
Total Hydrocarbons <sup>1</sup> Carbon Monoxide Methane	1.7 PPM 2.4 PPM 1.7 PPM	25 PPM <sup>2</sup> 20 PPM <sup>2</sup> 1000 PPM <sup>2</sup>
Acetone Benzene Chloroform Ethanol Freon 113 Freon 11 Freon 12 Freon 114 Isopropyl Alcohol Methanol Methyl Chloroform Methyl Ethyl Ketone Methyl Isobutyl Ketone Methyl Isobutyl Ketone Methylene Chloride Toluene Trimethyl Benzenes Xylenes	<0.1 PPM <0.1 PPM	$\begin{array}{cccc} 200 & \text{PPM}^2 \\ 1 & \text{PPM}^2 \\ 1 & \text{PPM}^2 \\ 100 & \text{PPM}^2 \\ 1 & \text{PPM}^2 \\ 10 & \text{PPM}^2 \\ 20 & \text{PPM}^2 \\ 20 & \text{PPM}^2 \\ 20 & \text{PPM}^2 \\ 25 & \text{PPM}^2 \\ 20 & \text{PPM}^2 \\ 3 & \text{PPM}^2 \\ 50 & \text{PPM}^2 \end{array}$
er Components		

<u>Othe</u>

Component	Level	Limit

NONE

C4+

<0.1 PPM

NONE

<sup>1</sup>Expressed as methane equivalents.
<sup>2</sup>Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
<sup>3</sup>OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

le. Glen Deason

Chemist