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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 5-89

DESIGN REVIEW, TEST AND EVALUATION OF FOUR ANALOX HYPERBARIC ENVIRONMENTAL CONTROL MONITORS
0055S CARBON DIOXIDE MONITOR
CARBON DIOXIDE HYPERBARIC MONITOR
401A TEMPERATURE MONITOR
401B HUMIDITY MONITOR

CDR K. M. ZWINGELBERG, MC, USN

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Submitted:	Reviewed:	Approved:
K.M. ZWINGELBERG	H.J.C. SCHWARTZ	JAMES E. HALWACHS
CDR, MC, USN	CAPT, MC, USN	CDR, USN
Task Leader	Senior Medical Officer	Commanding Officer

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
The unmanned test and evaluation of the Analox 0055S CO_2 monitor for use in the standard U.S. Navy double-lock recompression chamber and the Analox CO_2 Hyperbaric, 401A Temperature, and 401B Humidity Monitors for use in U.S. Navy deep diving systems (DDS) are presented. Tests were conducted under the auspices of the Navy Experimental Diving Unit to determine suitability for shore-based and shipboard Navy hyperbaric systems. Testing included standard engineering, design, safety, and human factors reviews. These reviews were followed by bench testing to various military standards and a simulated operational test of durability. Both CO_2 monitors were evaluated as adequate for their intended U.S. Navy uses. The 401A Temperature Monitor functioned well except during extremes (30°) of simulated shipboard tilt, where variances of up to 4.4° F were noted. The Analox 401B Humidity Monitor was also evaluated as acceptable in tests performed, however, the lack
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tests; evaluation; hyperbaric chamber

19. (Continued)

of a hyperbaric humidity standard prevented hyperbaric testing of this instrument.

CONTENTS

ILLUSTRATIONS

ABBREVIATIONS

ATA	atmospheres absolute
CO_2	carbon dioxide
DDS	Deep Diving Systems
DLRC	double-lock recompression chamber
ECS	environmental control system
EDF	Experimental Diving Facility
FSD	full scale deflection
FSW	feet-of-seawater
G-Force, g's	gravitational forces
HeO_2	helium-oxygen
IAW	in accordance with
ℓ/min	liters per minute
MIL-STD	Military Standard
NAVFAC	Naval Facilities Engineering Command
NAVMAT	Naval Material Command
NAVSEAINST	Naval Sea Systems Command Instruction
NEDU	Navy Experimental Diving Unit
NFPA	National Fire Protection Association
PTC	personnel transfer capsule
SEV	surface equivalent value
°C	degrees Celsius
°F	degrees Fahrenheit
%	percentage
YSI	Yellow Springs Instruments

I. INTRODUCTION

Hyperbaric chambers in the U.S. Navy are currently used for surface decompressions, medical treatments, saturation living, and personnel transfers. Operational and medical requirements have greatly extended the time divers may live in chambers. Two- and three-day medical treatments are common and saturation dives in excess of 30 days have occurred at the Navy Experimental Diving Unit (NEDU). Environmental Control Systems (ECS) for chambers have been commercially produced and ensure long-term chamber habitability and personnel comfort.

This report describes the unmanned test and evaluation process used to evaluate four ECS monitors:

a. Analox 0055S Carbon Dioxide Monitor.

b. Analox Carbon Dioxide Hyperbaric Monitor.

c. Analox 401A Temperature Monitor.

d. Analox 401B Humidity Monitor.

All monitors are products of Scottish Anglo Environmental Protection Limited, Unit 1, 1A Church Street, Guisborough, Cleveland, TS 14 6HG. The 0055S CO_2 Monitor is intended for use on standard double-lock (air) recompression chambers. The CO_2 Hyperbaric, 401A Temperature, and 401B Humidity Monitors are intended for use on helium-oxygen Deep Diving Systems (DDS).

II. METHODS

A three phase test and evaluation process was used. Phase I encompassed a standard engineering design and safety review. Phase II consisted of bench testing procedures to determine suitability of the monitors for shore and shipboard hyperbaric chamber use. Phase III was simulated operational testing of the monitors to delineate specific operational and durability limitations.

A. ENGINEERING AND SAFETY REVIEW

Personnel with expertise in electronics, human factors, and technical equipment support at NEDU reviewed the three monitors based on accepted design criteria, performance standards, electrical requirements, and various safety codes. In the course of this review, the monitors were examined along with their operations and maintenance manuals. Additionally, manufacturer testing documentation and tests substantiated or performed by outside test and evaluation facilities were also reviewed.

Temperature, relative humidity, and carbon dioxide (CO_2) monitors are chamber life support components. The ECS monitors were not considered in the category of combat hardened equipment. They were evaluated for durability in the normal hyperbaric, ship or shore based, marine environment. Standards which were applied to these monitors are listed below:

Standards Reviewed:

MIL-STD-454H	Standard General Requirements for Electronic Equipment, 30 July 1982.
MIL-STD-167	(Ships) Mechanical Vibrations of Shipboard Equipment, 20 December 1954.
SE-019-049-2H	SRB Vibration, Acoustic, Shock Design and Test Criteria (Ships), Marshall Space Flight Center Document No. SE-019-049-2H REV A, 17 November 76, Change #50.
MIL-STD-1472C	Human Engineering Design Criteria for Military Systems, Equipment and Facilities, 31 December 1974.
	Human Engineering Guide to Equipment Design VanCott, H.P. and Kinkade, R.G. (Eds), 1972.
MIL-STD-108E	Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment, 27 June 1958.
MIL-STD-810C	Environmental Test Methods, 15 June 1987.
NAVFAC DM-39	Hyperbaric Facilities Design Manual 39, July 1982.
NAVMAT P-9290	System Certification Procedures and Criteria Manual For Deep Submergence Systems, June 1976.
NFPA 99	National Fire Protection Association, 1987
ANSI C2 1987	National Electric Safety Code, 1987 Edition, August 1986
NEDU REPORT No. 3-50	Tilt Standards, Motion Standards, 1950
	NASA Lubricants List for O_2 Enriched Atmospheres, 15 November 1986
NAVSEAINST 9597.1A	Promulgation of List of Diving Equipments Which are Authorized for Navy Use (ANU)

B. BENCH TESTING PROCEDURES

Based on Phase I standards review, eight areas for further bench testing were identified. These areas encompass environmental evaluations for shock, vibration, heat, cold, off-gassing, moisture exposure, and operability during extremes of ship roll or tilt. Additionally, the monitors were evaluated for accuracy during an abbreviated 30-minute warm-up as opposed to the standard 4-hour warm-up.

Prior to each test, the monitors underwent a 4-hour warm up and standard calibration according to their operation and maintenance manuals unless an abbreviated warm-up test was being conducted. The Analox 0055S CO_2 monitor was calibrated with primary standard gases 0.000%, 0.517%, and 1.450% CO_2 in air or nitrogen backgrounds, accuracy to ± 0.01% (Matheson Gas Products, East Rutherford, N.J.). The Analox CO_2 Hyperbaric monitor also used Matheson primary standards with 0.000%, 0.0487%, and 0.517% CO_2 in air or nitrogen background.

Temperature measurements were secondarily compared to a Bureau of Standards verified Precision Filled Refrigerating Calibrator (Model D 50 RC; Jofra Inc., Rego Park, NY) through a calibrated YSI dry heat probe (Model 705, Yellow Springs Instruments, Inc., Yellow Springs, Ohio), and a Digitec electronic temperature monitor (Model 2780A, United Systems Corporation, Dayton, Ohio). Relative humidity during moisture exposure testing was measured by a Federal Republic Test Society certified horse hair hygrometer (Model No. 3310-20, Cole-Parmer Instrument Company, Chicago, Illinois 60648). Accuracy ± 3 % relative humidity.

Repetitive monitor readings during bench testing were taken a minimum of 30 seconds apart. If test criteria simply required a working monitor after the exposure then the monitor reading was allowed to equilibrate with the room environment prior to comparison to its specified standard.

1. Shock

Shock testing was conducted IAW Environmental Test Methods (1), (c.f.3, Section 516.2, Procedure V, Bench Handling Test). This test assessed the durability of the equipment to routine shipboard shock experienced during installation and maintenance. The monitors are placed on a wood work bench tilted on edge to 45° and allowed to fall, right, left, front and back four times each. The test is done without power to the motors and a passing test requires the monitor to operate normally after the 16 shock exposures.

2. Vibration

Vibration testing was conducted at Marshall Space Flight Center, Huntsville, Alabama. The test procedures were according to shipboard transporation Test Criteria (2). The shaker platform (Model KI No. K4523, Kimball Industries Inc., Monrovia, CA) and Electrodynamic Shaker (Model 4000-24, Unholtz-Dickie Corporation, Wallingford, CT) are pictured in Figure 1. The test consists of a resonant frequency search from 5-300 hertz in each of the three defined spacial planes. This was followed by an exposure of 15 minutes at the observed resonant frequencies in each of the three spacial planes. The monitors were operating during the test.

3. <u>Heat</u>

Thermal stress was tested to 71°C (160° F) for 48 hours IAW reference (1) procedures I, Section 501.1.

4. <u>Cold</u>

Freezing stress was tested to -20° C (-4° F) for 24 hours IAW reference (1) procedures I, Section 501.1. The temperature of -20° C was the coldest temperature attainable due to technical constraints but was judged by NEDU engineers as a suitable freezing stress for these components.

5. <u>Off-gassing</u>

Offgas testing of PTC components of the Analox CO_2 Hyperbaric, 401A Temperature, and 401B Humidity Monitors were conducted at the Naval Coastal Systems Center Gas Analysis Laboratory. The off-gassing test chamber was pressurized to 10 psig and the sample was allowed to equilibrate for 4 hours at 130° F (54.4° C) before an analysis for specific and total hydrocarbons was completed.

6. <u>Salt Atmosphere Exposure</u>

Salt fog exposure was conducted on the PTC components of the Analox CO_2 Hyperbaric, 401A Temperature, and 401B Humidity monitors. This exposure was conducted under guidelines as delineated in reference (1), Section 516.2-5 procedure V. Total exposure was 48 hours in an NEDU constructed salt atmosphere chamber. Clear plastic was used to construct an environmentally isolated chamber of volume 24 liters. Aeration of a 130 square centimeter salt water basin placed on the floor of the chamber was sufficient to raise the relative humidity to 96° and to cause droplet formation on the plastic roof of the chamber. Temperature was held at 24-27° C (75-81° F).

7. <u>Roll and Tilt</u>

The accuracy and reliability of the four monitors during at sea conditions was tested in two ways. First, the monitors were evaluated for variation in reading with tilt angles of 10, 20, and 30 degrees; right, left, forward, and back (3). Secondly, the monitors were placed on a platform which was disturbed to approximate the roll and pitch experienced during shipboard operations. The accuracy of monitor readings were compared with the level, motionless reference values for the given monitor.

C. OPERATIONAL TESTING

The Analox 0055S CO_2 monitor is an infra-red analyzer intended for use on standard air recompression chambers. Simulated operational testing of the 0055S CO_2 monitor was conducted in March of 1987 during the testing of chamber CO_2 scrubbers for use in standard double-lock recompression chambers. For specific methods of that study see references (4 and 5). Chamber CO_2 levels obtained during that study were recorded manually from a calibrated Analox 0055S CO_2 monitor and compared to results obtained using a fixed detector mass spectrometer, Gas Analyzer (Model MGA 1100 Perkin Elmer, Pamona, CA). Accuracy of the mass spectrometer is ± 0.25% full scale deflection (FSD). Seventy readings were taken over 12 days of testing with gas flow rates to the 0055S CO_2 monitor between 200 and 460 cc's per minute. Readings were generally one hour apart. The manufacturer stated accuracy on the 0055S CO_2 monitor is ± 0.5% FSD.

The Analox CO_2 Hyperbaric Monitor is also an infra-red analyzer but has its sensor located inside a standard double-lock recompression chamber, a saturation chamber complex, or a PTC. Since the sensor is located at depth in the chamber or PTC, the microprocessor unit also references the total hyperbaric pressure and gives an LED readout in milli-atmospheres. The manufacturer stated accuracy of this unit is ± 0.5% FSD. Operational testing was done concurrently with PTC CO_2 scrubber testing. For details of the set-up see reference (6). The Analox CO_2 Hyperbaric monitor was compared to the Perkin-Elmer fixed detector mass spectrometer. The mass spectrometer percentage CO_2 reading was depth corrected by comparison to a Heise 2,000 foot depth gauge (Model 711 series, Dresser Industries, Newtown, CT 06470). Accuracy of the Heise gauge is ± 0.1% FSD. These two depth corrected surface equivalent values (SEV) were then recorded every 4 minutes by a computer (Hewlett-Packard HP-1000). Graphic comparison displays, as shown in Figure 2, were then plotted from the computer for 3- to 6-hour runs during simulated helium-oxygen dives to 200, 500, and 850 feet of sea water (FSW) in NEDU's Experimental Diving Facility (EDF) unmanned chamber.

The Analox 401A Temperature Monitor is comprised of a pressure sensor mounted in the chamber or diving bell with a remote, control room readout. It was tested under simulated operational conditions along with the CO_2 Hyperbaric monitor (7). Continuous readings at 4-minute intervals were recorded for the 401A Temperature monitor and for its secondary reference, the YSI dry heat probe monitored with a Digitec electronic temperature monitor. The combined accuracy of this standard is ± 2° F. Temperatures were monitored during numerous simulated 200, 500, and 850 FSW unmanned EDF dives. Once again, a comparison graphic display was generated of the secondary standard and the Analox 401A Temperature monitor and is shown in Figure 3. The manufacturer stated accuracy of the 401A is ± 0.1% FSD.

The Analox 401B Humidity Monitor consists of a chamber or bell mounted optical sensor with a remote readout. The Analox monitor was compared to a Federal Republic Test Society certified horse hair hygrometer, accuracy ± 3 % relative humidity. Technical constraints have precluded testing with EDF chambers at depth, all humidity tests were conducted on the surface at 1ATA. Hyperbaric testing has been performed by Scottish Anglo Environmental Protection LTD and certified by Surveyor to Lloyd's Register of Shipping, R. W. Pickup, to meet requirements of Offshore Marine Engineering Limited order number 11443, see Appendix A. For further information on testing of the 401B Humidity Monitor see reference 8.

III. RESULTS

A. ENGINEERING AND SAFETY

Standards reviews completed by NEDU Electronics, Technical Support and Human Factors evaluators identified eight areas where further testing was felt warranted. These areas were subsequently tested in the Bench Testing phase. All four Analox monitors configured in their standard manufactured configuration were found electrically safe for use in the hyperbaric, ship or shore based application.

The testing modification performed by Scottish Anglo Environmental Protection Ltd. of the Analox 0055S CO_2 monitor, serial #118/F did not provide the same level of electrical safety as was found with the standard manufacturer configuration represented by monitor serial #135.

Review of European certification was conducted on the monitors. All four monitors were certified in 1986 by the Lloyd's Register of Shipping according to British Standard 5000-500 in "The Rules and Regulations for Construction and Classification for Submersible and Diving Systems." The review encompasses design appraisal along with construction and testing under survey. Survey in this regard addresses electrical continuity, electrical leakage, and chemical off-gassing. Copies of certificates are contained in Annex A.

Human Factors evaluation found all monitors acceptable with an overall good rating. Specific areas for improvement were noted. The LED readout on the Analox CO_2 Hyperbaric monitor is in milli-atmospheres. A simple function change of moving the decimal point one place to the left would allow relabeling of the LED to percent surface equivalent value (% SEV) which is a unit more familiar to U.S. Navy divers. The function labels and pushbuttons on all monitors are at the small end of acceptable size, but in the interest of miniturization seem to be an acceptable trade-off. The monitors were easy to read with adequate size LED readouts. Alarms were consistently effective with both visual and auditory signals. Operation and maintenance manuals were judged acceptable by NEDU technical support staff. For further specifics on Human Factors evaluation refer to Annex B.

B. BENCH TESTING

1. Shocks

All four monitors completed the 16 bench handling shocks without breakage. All continued to operate and showed readings within manufacturer stated accuracies.

2. Vibration

The Analox 0055S CO_2 monitor showed resonant frequencies at 31.83 hertz in the front to back axis as shown in Figure 4 and at 124.3 hertz in the up and down axis when mounted in a standard 19-inch mounting rack. No damage or electrical failures occurred during 15-minute 0.75 g dwell times at these resonant frequencies. Soft paper pads were placed under and atop the back portion of the monitor to obliterate the 1/4" gap between the monitor and the rear braces of the 19" rack.

This standard 19-inch mounting rack configuration was also used during vibration testing of the Analox CO_2 Hyperbaric, 401A Temperature, and 401B Humidity monitors. The mounted monitor arrangement showed resonant frequencies at 28.7 hertz in the front to back axis, 261.3 hertz in up and down axis, and 16.5 hertz in the right to left axis referenced as you would look at the monitor displays. No damage or electrical failures occurred during 15 minutes of 0.75 g, dwell times at these three frequencies and axes.

The Analox PTC sensors for CO_2 , Temperature, and Humidity; along with the PTC pressure sensor showed no resonant frequencies in any axis.

3. Heat

In accordance with Environmental Test Methods (1) all Analox monitors underwent 48 hours of heat exposure to a minimum of 55° C (131° F). This is the highest recommended operating level according to the manufacturer. One attempt to expose the 0055S CO_2 Monitor to 71° C (160° F) resulted in a malfunction of the monitor's chopper motor. When exposed without power for 48 hours at 55° C and then energized, the 0055S CO_2 Monitor functioned well and within its ± 1% accuracy. These readings were obtained after a 4-hour warm-up and with the ambient temperature 110° F. The CO_2 Hyperbaric, 401 A Temperature and 401B Humidity Monitors also underwent 48 hours of 55° C temperature exposure. Likewise, these monitors were without power during the heat exposure. Following the exposure, all monitors were energized and allowed a 4-hour warm-up. The 401A temperature and 401B Humidity Monitors both functioned within the combined accuracies of themselves and the standards ± 2° F and ± 3% relative humidity. The CO_2 Hyperbaric Monitor read up to 0.036% SEV high, an error of 3.6% FSD. After recalibration, the CO_2 Hyperbaric Monitor easily returned to stated ± 0.5% FSD accuracy. During the testing of these monitors a temperature fluctuation transiently occurred to 78° C (172° F).

4. Cold

After 24 hours at -15°C (5°F) the Analox 0055S CO_2 Monitor showed readings within ± 0.5% FSD in the 0.5% CO_2 range and at ± 5.5% FSD in the 1.5% CO_2 range. The 0055S had only been allowed 1 1/2 hours of warm-up, not the 4 hours recommended by the manufacturer. The CO_2 Hyperbaric, 401A Temperature, and 401B Humidity Monitors underwent a similar subfreezing exposure for 24 hours at -20°C (-4°F). Cold exposures were all performed without power to the monitors. They were allowed to gradually rewarm to room temperature over 1 hour and then energized for a standard 4-hour warm-up. Both the 401A Temperature and 401B Humidity Monitors showed readings within acceptable combined accuracies when compared to their standards, ± 2° F and ± 3% relative humidity. The CO_2 Hyperbaric Monitor again showed a slight error, reading low by 3.7% of FSD. This was easily corrected by recalibration which brought the monitor again within the ± 0.5% FSD expected accuracy.

5. Off-gassing

Gas analysis on the PTC Temperature and Humidity Sensor HPP5 along with the PTC carbon dioxide analyzer, serial #018, Model HYP showed no excessive off-gassing. Both sensors were judged safe for use in a man-rated, closed environment at temperatures up to 130° F (54.4° C), see Appendix C.

6. Salt Atmosphere Exposure

The NEDU salt atmosphere chamber attained in excess of 90% RH with a temperature of 80.8° F (27.1°C). Sufficient salt atmosphere existed for droplet formation to occur on the upper surface of the chamber and a thin salt coat to precipitate on the sensors. All PTC components for the Analox CO_2 Hyperbaric, 401A Temperature and 401B Humidity Monitors successfully completed a 48-hour salt atmosphere exposure without failure.

7. Roll and Tilt

The Analox 0055S CO_2 and CO_2 Hyperbaric Monitors showed no appreciable alteration in accuracy with disturbed motion nor with tilt to 30° in any direction. The 401A Temperature Monitor showed swings of up to 4.4° F from reference and baseline levels when tilted to 30° in various directions. This variance stabilized when the Temperature Monitor was placed through simulated shipboard motion where readings were within ± 1° F of the reference standard. The 401B Humidity Monitor showed no appreciable alterations in readings with disturbed motion or tilt to 30°. Throughout this phase of testing the 401B Humidity Monitor consistently read 1 to 2% above the reference horse hair hygrometer.

8. Thirty-Minute Warm-Up

The Analox 0055S CO_2 Monitor performed with ± 2% FSD accuracy when given a 1/2 hour vice the manufacture recommended 4-hour warm-up. The other Analox Monitors were not tested for rapid, "cold," start-up characteristics.

C. SIMULATED OPERATIONAL TESTING

The Analox 0055S CO_2 Monitor was calibrated on 23 March 1986. It was recalibrated on 25 March and then had no further calibrations through 3 April 1986. The monitor lost power for approximately 2 minutes on the 26th and 27th of March at 0600 and 0700 daily. These disruptions showed no apparent alterations in the monitor performance. Over 12 days 70 readings were taken manually from the 0055S CO_2 Monitor and compared with the Perkin-Elmer mass spectrometer. The combined reading accuracy of the Analox 0055S CO_2 monitor and mass spectrometer is ± 0.03% CO_2. The greatest variance seen between the two instruments was 0.021%.

The Analox CO_2 Hyperbaric monitor underwent simulated operational testing in the NEDU EDF as previously described. The combined reading accuracy of the Analox CO_2 Hyperbaric monitor, Heise depth gauge, and Perkin-Elmer mass spectrometer is ± 0.06% at 200 FSW and deteriorates to 0.17% at 850 FSW. In 6 runs on HeO_2 to depths as deep as 850 FSW the Analox CO_2 Hyperbaric monitor tracked well with the EDF references. The monitor was within expected accuracy throughout the 500 and 850 FSW runs. In two of three 200 FSW runs high SEV readings were recorded by the Analox CO_2 hyperbaric monitor near its upper range limit of 1% SEV. In this range the maximum combined variance between the Analox monitor and the mass spectrometer/heise gauge was 0.10% SEV, 40% greater variance than expected.

The Analox 401A Temperature monitor consistently read within 1° F of the Standardized Digitec reading from the YSI dry probe in eight out of nine hyperbaric runs over the temperature range 50 to 100° F. On one early run there was a constant 1-2° F offset between the two temperature monitoring systems.

IV. DISCUSSION.

Hyperbaric environmental control systems and monitors are intended to enhance the habitability and life support capabilities of Hyperbaric Chambers and Deep Diving Systems (DDS) during at-sea diving operations or medical treatments. The precision and sensitivity of life support controls becomes increasingly critical as chamber depth increases. The advent of sensors inside the chamber and PTC has enhanced the technical capabilities to monitor and control DDS environments. In this regard they are a welcome advance, but sophisticated electronic equipment with metal and synthetic construction requires close scrutiny in areas of electrical and material safety. Also of consideration is the interaction of divers with the equipment or human factors engineering.

The four Analox monitors were tested for use in either a ship or shore based application. It is expected that the monitors will be sheltered from the marine environment and in DDS monitors will be in an environmentally controlled compartment. Sensors used in DDS chambers and PTCs will be exposed to extremes of the marine and hyperbaric environment. This is the operational environment for which the monitors were tested. The monitors were not tested to the military standards for combat hardened equipment.

The Analox 0055S Carbon Dioxide Monitor performed acceptably in all phases of Test and Evaluation for use on U.S. Navy Double-Lock Recompression Chambers (DLRC). The Carbon Dioxide Hyperbaric Monitor likewise performed acceptably in all phases of test and evaluation for DDS application. With its in-chamber sensors the CO_2 Hyperbaric Monitor allows direct reading of chamber or PTC CO_2 levels without the system operators having to compute mathematical depth corrections. It would also be suited for use in the standard U.S. Navy DLRC.

The CO_2 Hyperbaric Monitor evaluated at NEDU had labeled readings in milli-atmospheres. Electronically it is simple to move the decimal point on the LED display one digit to the left. This will allow relabeling of the display as %SEV (percent surface equivalent value), a term more familiar to U.S. Navy divers.

The 401B Humidity Monitor also performed acceptably in all areas tested and evaluated. Due to the unavailability of a primary humidity standard in the hyperbaric environment, a controlled, simulated, operational test was not able to be performed. The Naval Coastal Systems Center is currently working on the difficulties in accurately measuring relative humidity in the hyperbaric environment. Once a reliable primary standard is identified, simulated operational testing at depth should be completed to verify if the 401B Humidity Monitor has accuracy comparable to other types and styles of humidity monitors available for use in hyperbarics.

The 401A Temperature Monitor adequately completed all phases of test and evaluation except for simulated shipboard roll and tilt. In this phase of testing the monitor varied by as much as 4.4° F from the reference temperature when placed in angles of tilt to 30°. No defect could be ascertained which might explain this surprising occurrence in a solid state monitor. The roll and tilt testing was performed after the heat and cold exposure but shock, shipboard vibration, off-gassing, and salt atmosphere exposures all were successfully completed after this defiency was noted.

Shipboard vibration with monitors mounted in a standard 19-inch rack showed all monitors to tolerate 0.75 g's of stress. One-quarter inch of padding/support was added to the back portion of the monitors to bring their frames in better apposition with the back braces of the 19-inch rack. This greatly decreased the slapping motion that resulted at low shipboard vibration frequencies.

All Analox monitors are rated for temperatures from freezing to 130° F (54.5° C). When exposed to such wide swings from room temperature, it is wise to recalibrate the monitors or an error of up to 4% of full scale deflection may occur.

V. CONCLUSIONS.

A. Both Analox CO_2 monitors were evaluated as acceptable for their respective applications in the DLRC or DDS.

B. The 401B Humidity Monitor was also evaluated as acceptable but still needs a simulated at-depth operational test when a primary hyperbaric humidity standard is available.

C. An apparent defect in the 401A Temperature Monitor resulted in a deviation of 4.4° F on the readout during monitor tilts to 30°.

D. When ordering and mounting Analox Monitors attention should be directed to labeling and mounting recommendations in this report.

E. Monitors may vary from accepted accuracies under extremes of temperature and should be recalibrated after such exposures.

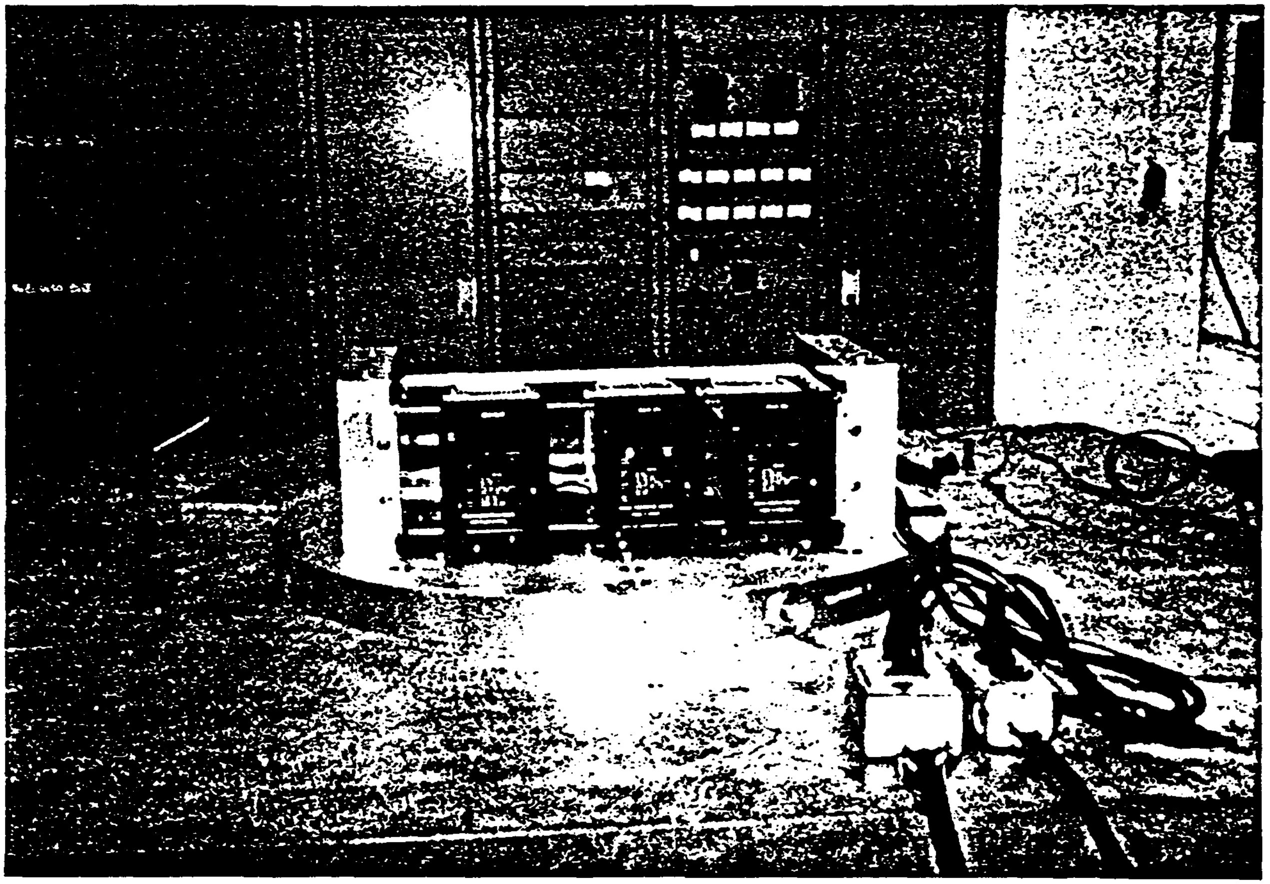

FIGURE 1. Vibration Test Platform at Marshall Space Flight Center Huntsville, Alabama.

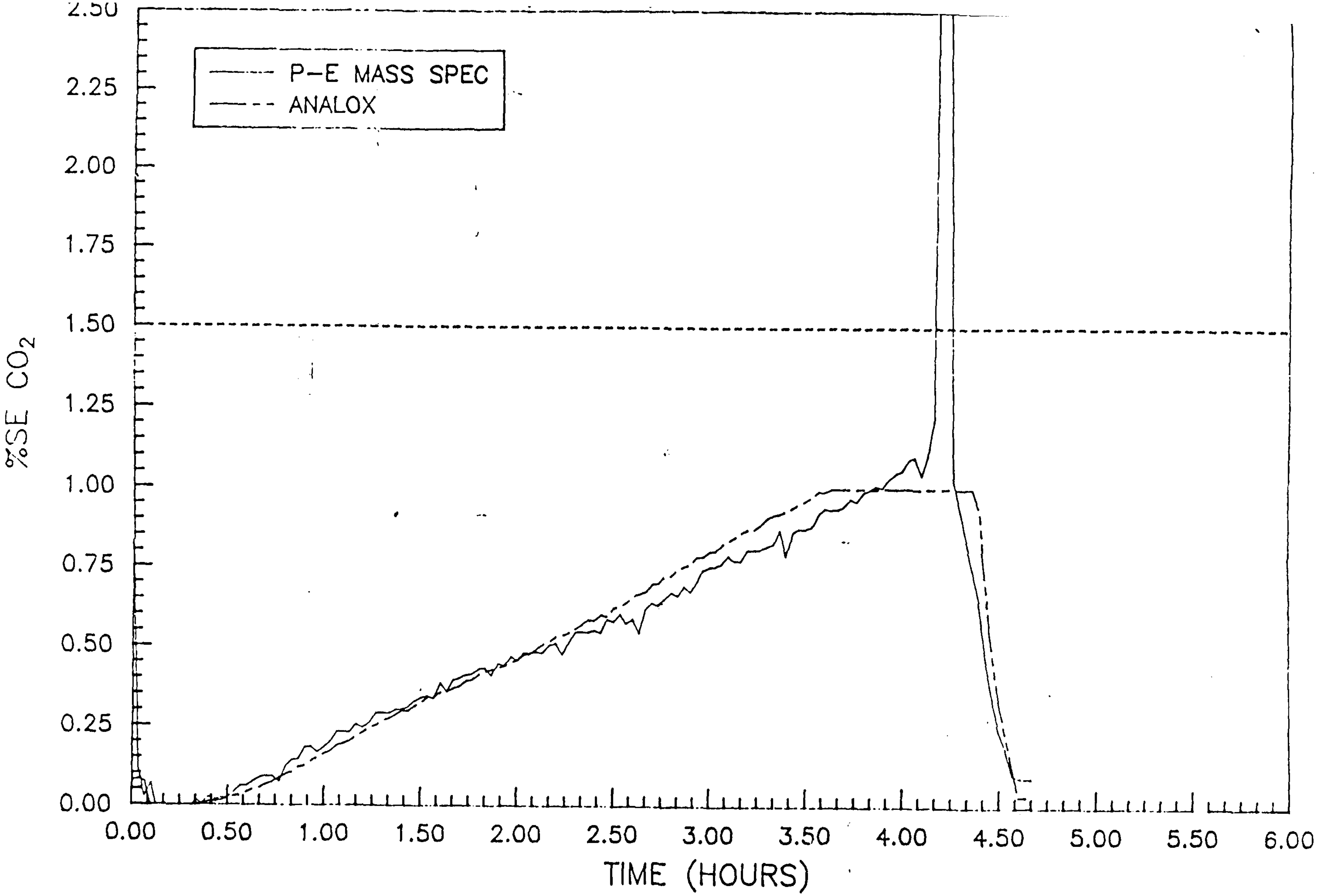

FIGURE 2. Percent Surface Equivalent Values for Analox CO_2 Hyperbaric Monitor Compared with Depth Corrected Perkin-Elmer Mass Spectrometer at 500 FSW Chamber Depth.

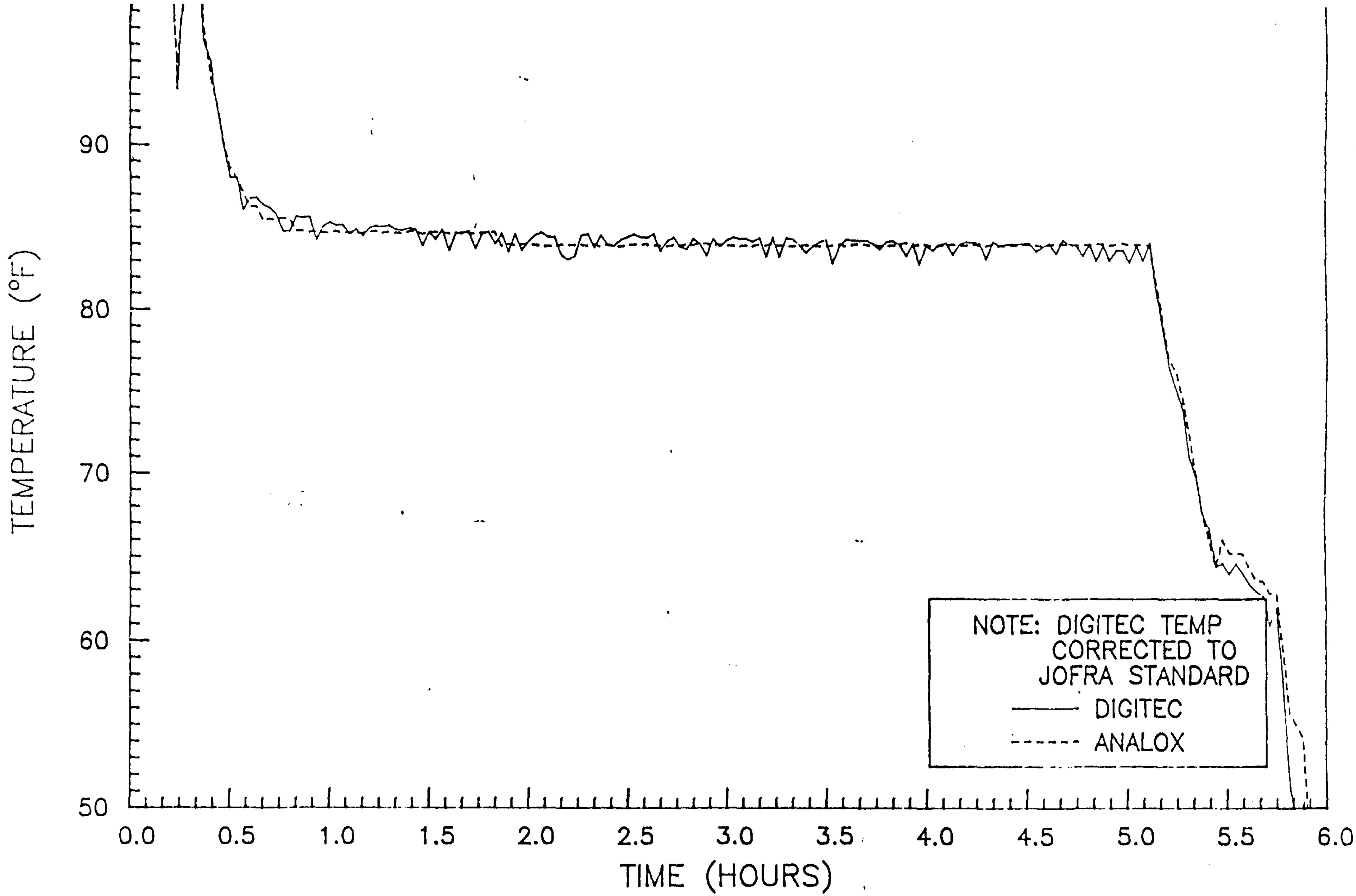

FIGURE 3. Temperature (°F) for the Analox 401A Temperature Monitor and YSI Digitec Control at 850 FSW Chamber Depth.

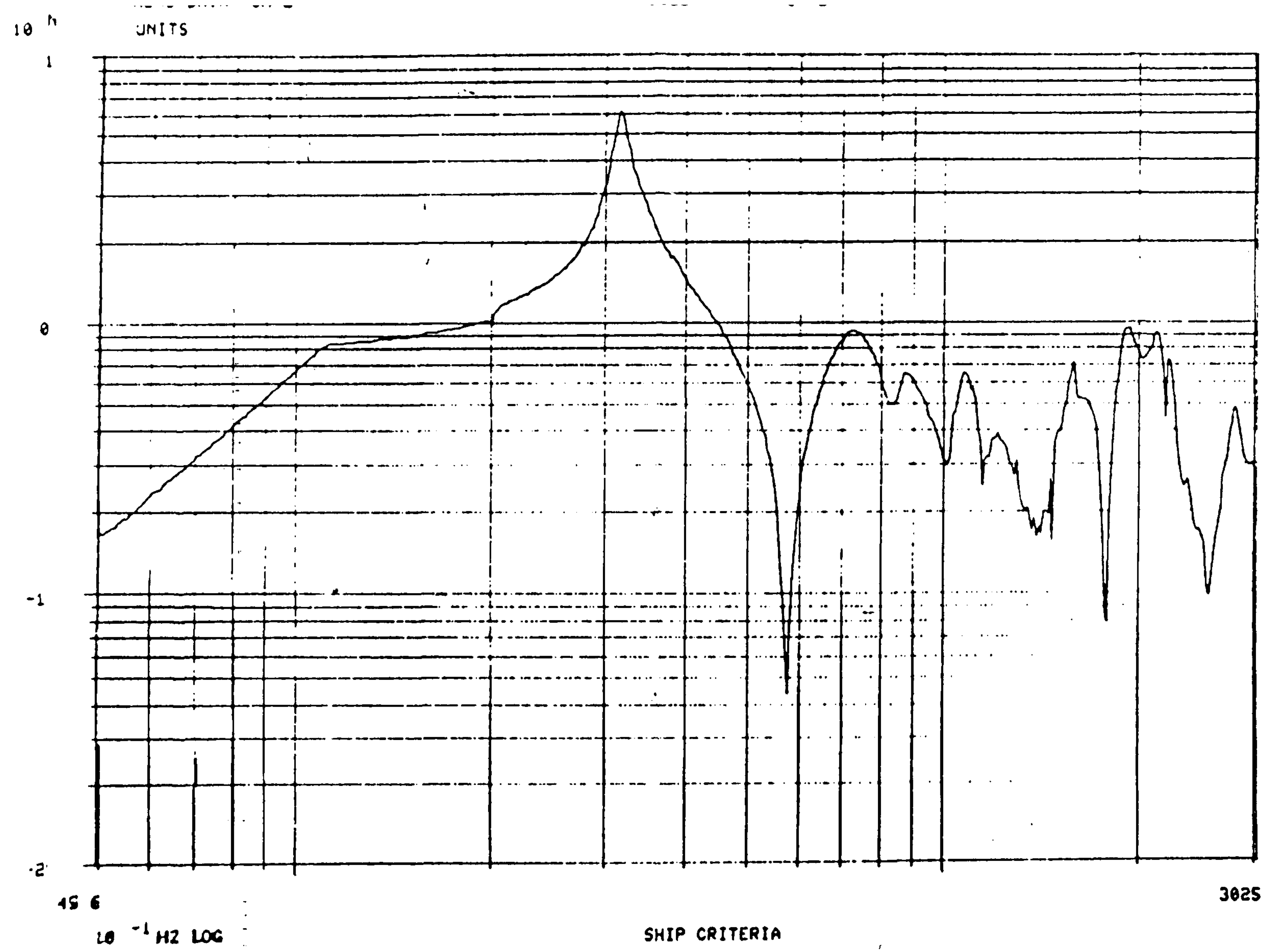

FIGURE 4. Resonant Frequency at 31.83 Hertz of Front to Back Vibration for the Analox 0055S CO_2 Monitor During 5-300 Hertz Resonant Frequency Search Sweep.

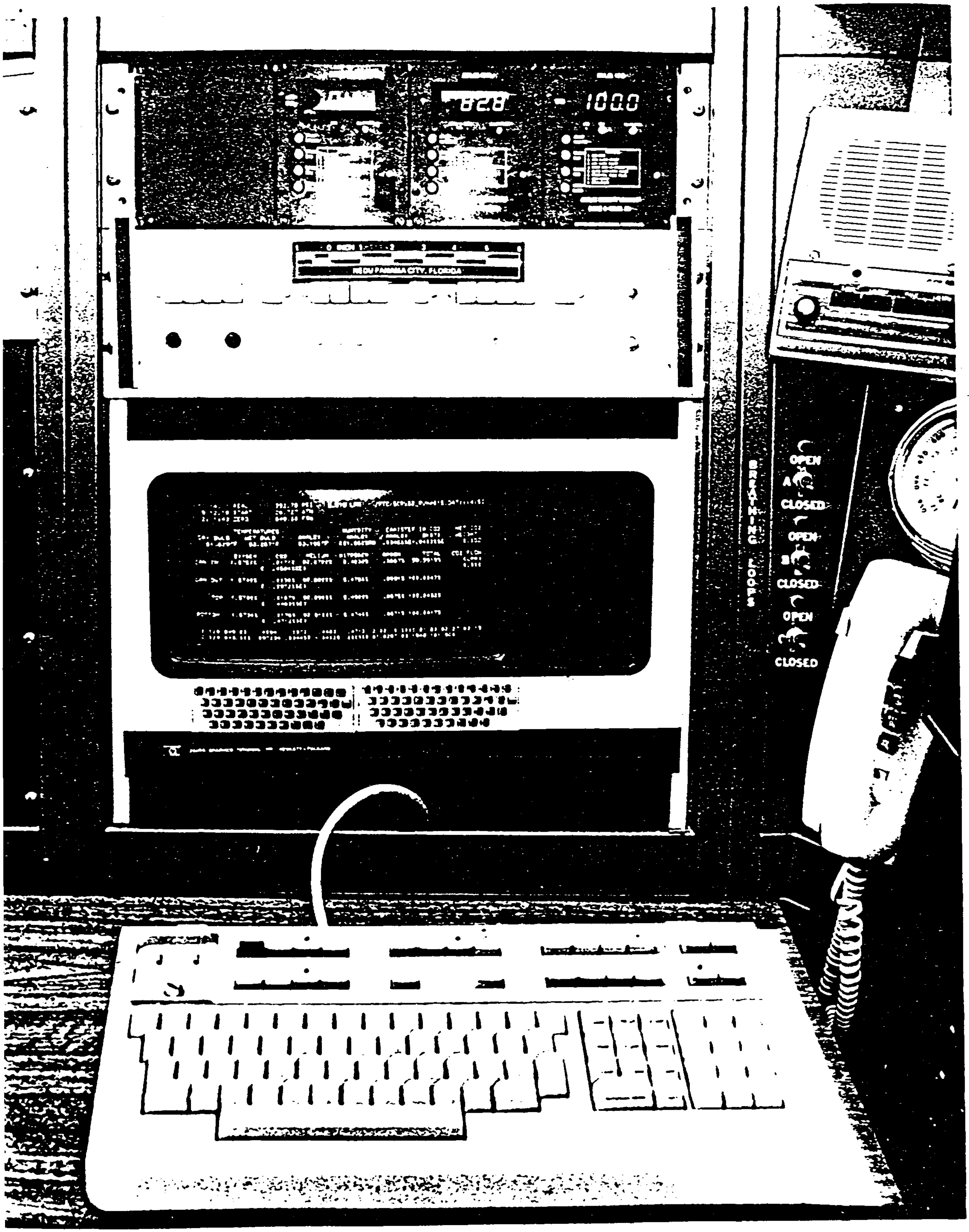

FIGURE 5. The Three Analox Deep Diving System Monitors Mounted in a 19-Inch Mounting Rack at the NEDU's Experimental Diving Facility.

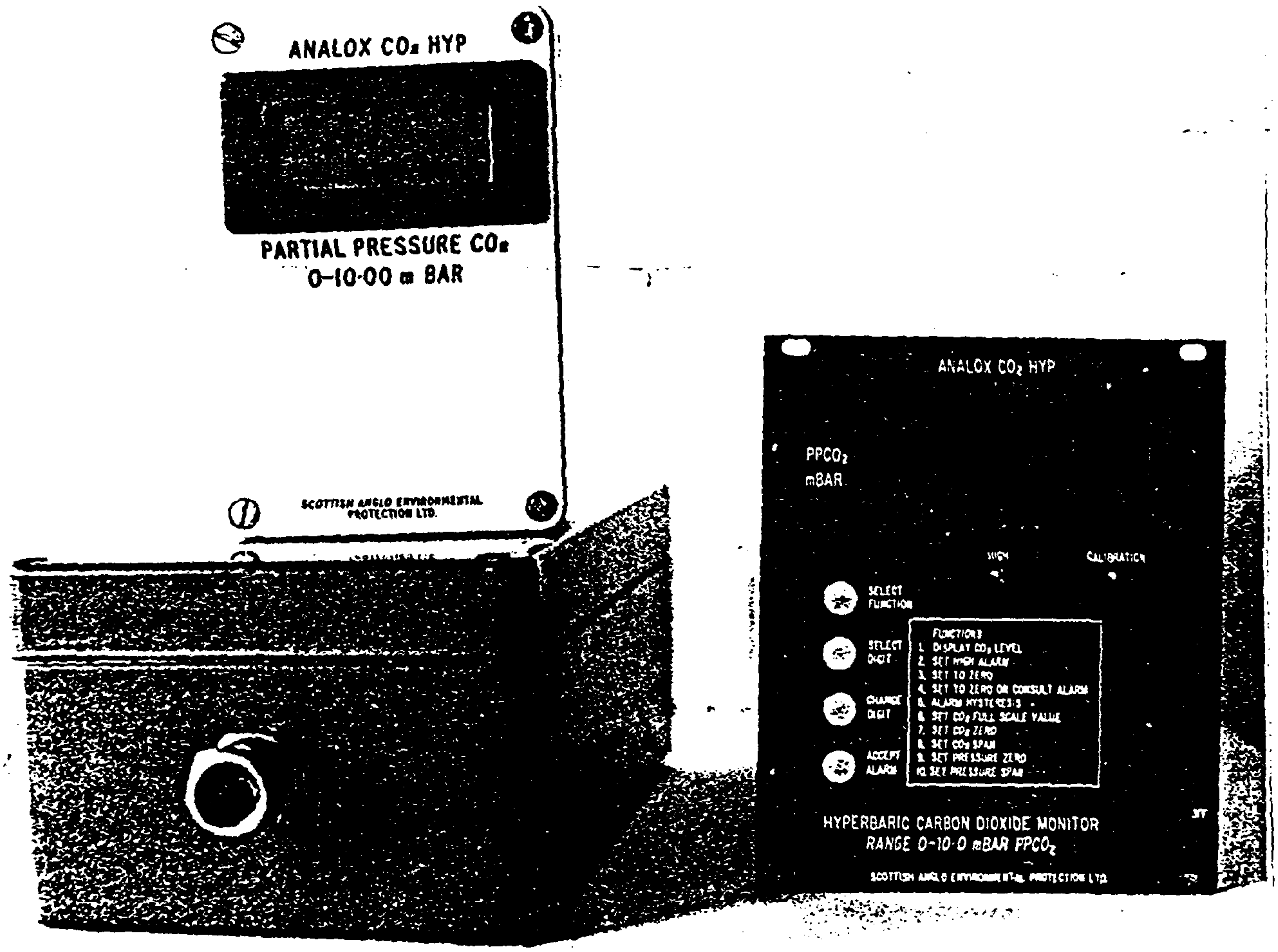

FIGURE 6. Analox CO_2 Hyperbaric Monitor with Remote Diving Bell (PTC) Readout and In-Chamber Sensor/Pump.

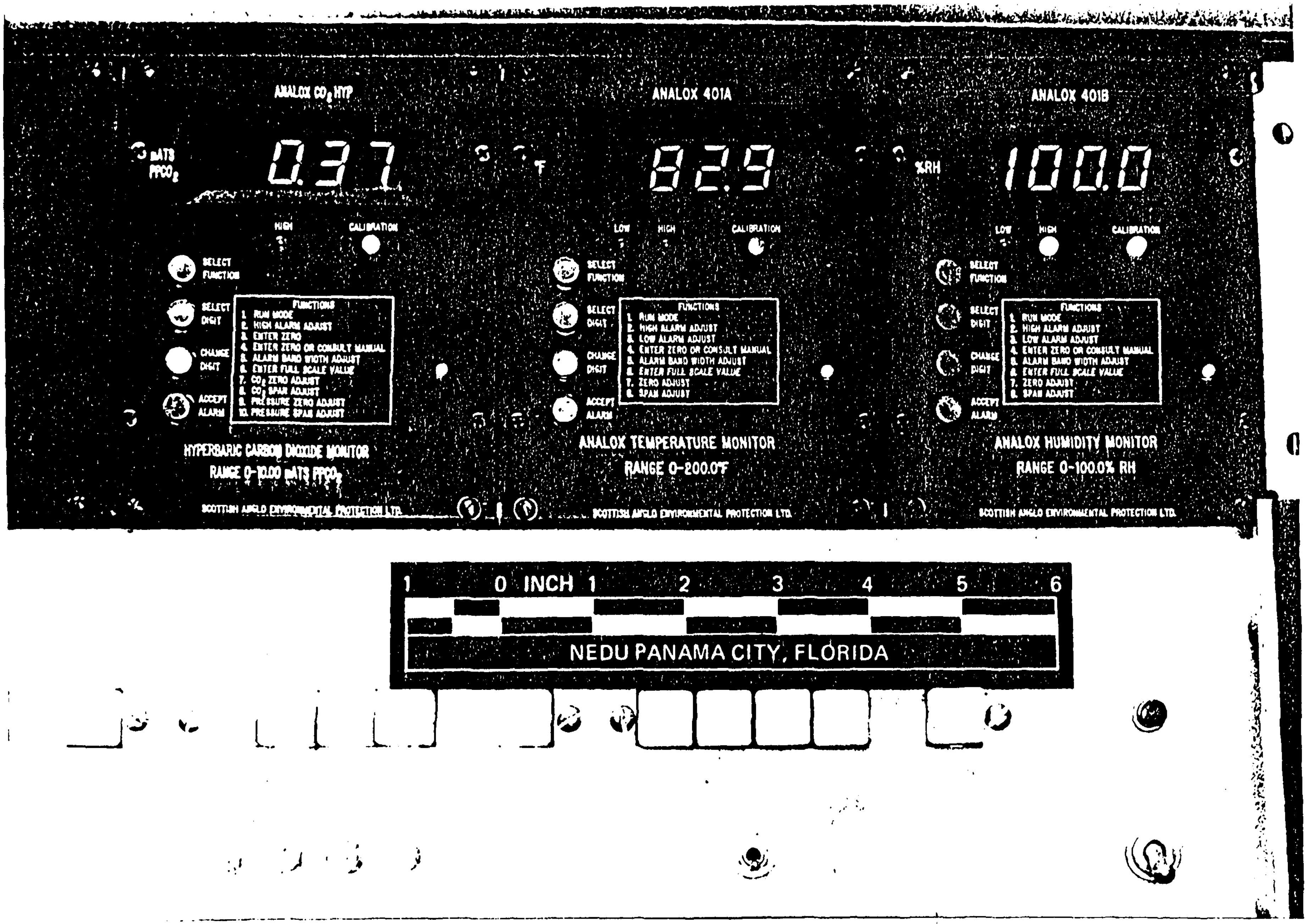

FIGURE 7. Close-up View of the Three Analox Deep Diving System Monitors as Mounted in a 19-Inch Mounting Rack at NEDU's Experimental Diving Facility.

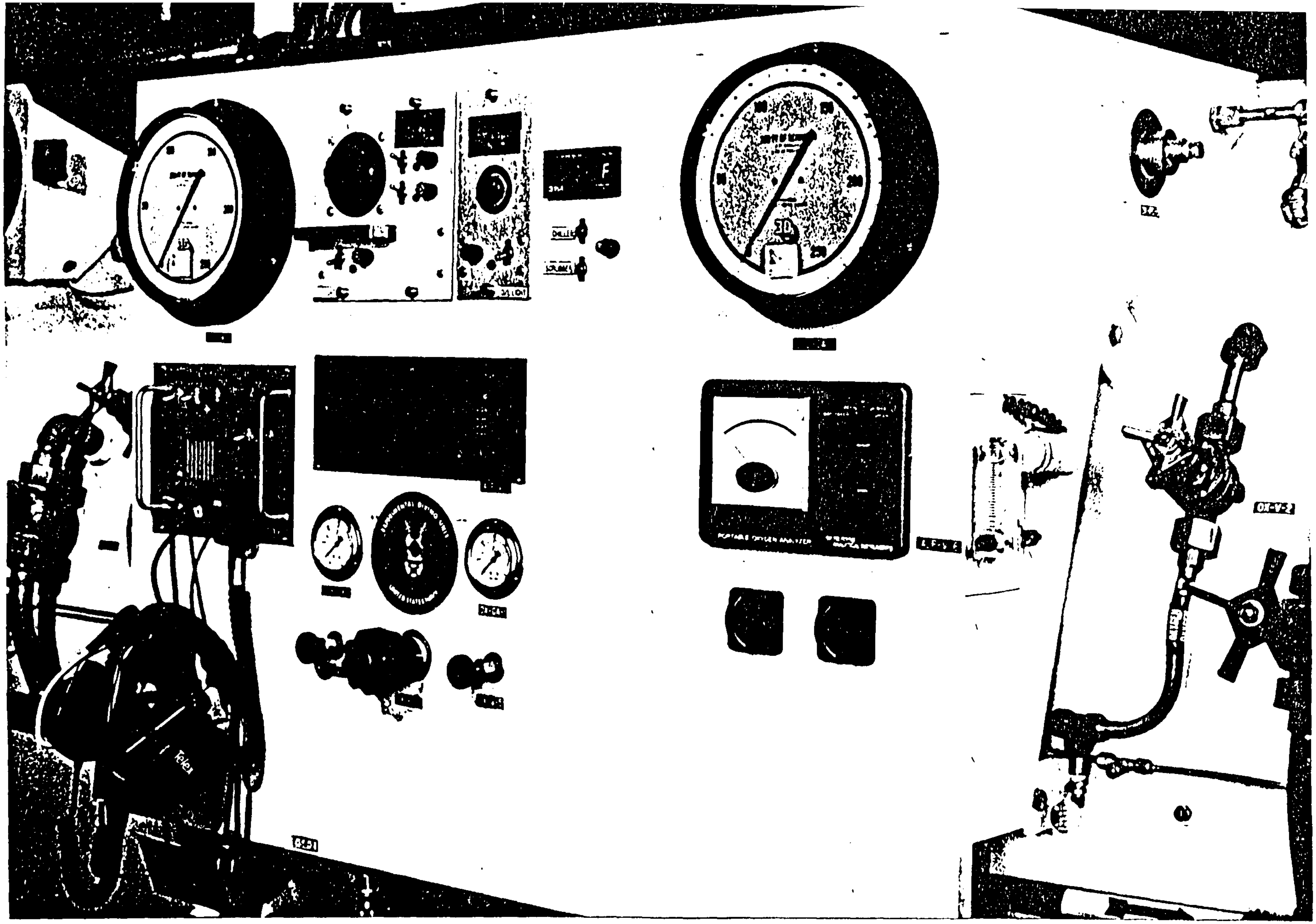

FIGURE 8. Analox 0055S Carbon Dioxide Monitor Mounted in Control Panel of Standard U.S. Navy Double-Lock Recompression Chamber.

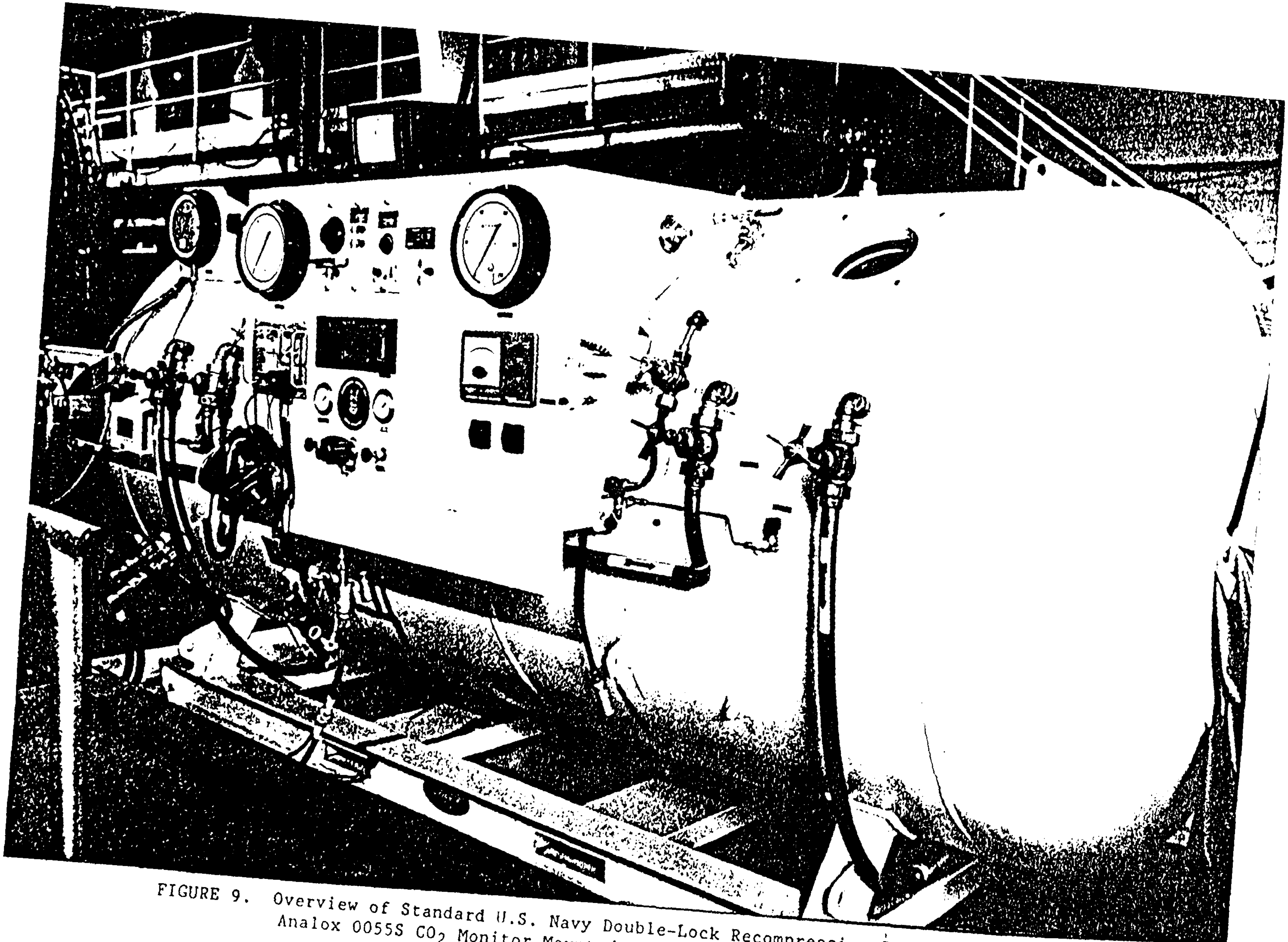

FIGURE 9. Overview of Standard U.S. Navy Double-Lock Recompression Chamber with Analox 0055S CO_2 Monitor Mounted on Chamber Control Panel.

REFERENCES

1. Military Standard: Environmental Test Methods, MIL-STD-810C, 15 June 1967.

2. Marshal Space Flight Center Document #SE-019-049-2H REV A: SRB Vibration, Acoustic and Shock Design and Test Criteria, Specification Change No. 50, November 17, 1976.

3. Blockwick, T.N.: The Evaluation of the Beckman Model "C" and the Beckman Model "D" Oxygen Analyzers for Accuracy, Simplicity of Operation, and Other Characteristics Under Various Conditions of Motion and Inclination, Navy Experimental Diving Unit Report 3-50, 26 April 1950.

4. Zwingelberg, K.M.: Test and Evaluate Analox 0055S Carbon Dioxide Monitor for use in Double-Lock Recompression Chamber, U.S. Navy Experimental Diving Unit Test Plan 87-06, March 1987.

5. Zwingelberg, K.M., et al: Unmanned Test and Evaluation of Two Double-Lock Recompression Chamber (DLRC) Carbon Dioxide Scrubbers: The Kinergetics DH-21 and Aqua Breeze II 5000S, U. S. Navy Experimental Diving Unit Report 12-87, September 1987.

6. Zwingelberg, K.M.: Test and Evaluation of the Analox CO_2 Hyperbaric Monitor System (No. 8800-01), U.S. Navy Experimental Diving Unit Test Plan 87-15, July 1987.

7. Zwingelberg, K.M.: Test and Evaluation of the Analox Temperature Monitor System (No. 401A), U.S. Navy Experimental Diving Unit Test Plan 87-18, July 1987.

8. Zwingelberg, K.M.: Test and Evaluation of the Analox Humidity Monitor System (No. 401B), U.S.Navy Experimental Diving Unit Test Plan 87-19, July 1987.

APPENDIX A

LLOYD'S REGISTER OF SHIPPING CERTIFICATES

on:

Analox 0055S - CO_2 Monitor
Serial No. 102F

Analox CO_2 Hyperbaric Monitor
Serial No. 016fch

Analox 401A and 401BC Temperature
and Relative Humidity Controller
Serial No. 1032C

COPY

Lloyd's Register of Shipping

Date 9th June, 1986 Office MIDDLESBROUGH Certificate No. MDB 600407

This is to certify that at the request of Scottish Anglo Environmental Protection Limited, the undersigned Surveyor to this Society attended at their premises at Unit 1, 1a Church Street, Guisborough, Cleveland on the 6th June, 1986 and subsequently until the 9th June, 1986 to witness final testing and calibration of the following instruments stated to be intended for Drass Spa, Italy.

Order No. 179/86-C.100-06/03/1986.

4 off - Analox 100FD - O2 Monitor
Power: 115V-60Hz A.C.
Serial Nos. 1354a, 1356a, 1357a, 1359a.

1 off - Analox 100FD - O2 Monitor
Power: 24V D.C.
Serial No. 1358a.

1 off - Analox 0055S - CO2 Monitor
Power 24V D.C.
Serial No. 102f.

3 off - Analox 0055S - CO2 Monitor
Power: 115V-60Hz A.C.
Serial Nos. 103f, 104f, 105f.

7 off - Analox 1010C - O2 Controller & Auto Injection
Power: 115V-60Hz A.C.
Serial Nos. 029c, 030c, 031c, 032c, 033c, 034c, 035c.

9 off - Analox 601-Depth Monitor
Power 115V-60Hz A.C.
Serial Nos. 023f, 024f, 025f, 026f, 027f, 028f, 029f, 030f, 031f.

1 off - Analox CO2 Hyperbaric Monitor
Power: 115V-60Hz A.C. Surface Monitor Display
24V D.C. - Sensor Bell/Chamber Display
Serial No. 016fch.

R.W. PICKUP
Surveyor to Lloyd's Register of Shipping

JR

continued .....

COPY

Lloyd's Register of Shipping

Date 22nd October, 1986 Office MIDDLESBROUGH Certificate No. MDB 600703/1

This is to certify that at the request of Scottish Anglo Environmental Protection Limited, the undersigned Surveyor to this Society attended at their premises at Unit 1, 1a Church Street, Guisborough, Cleveland on the 21st October, 1986 to witness final testing and calibration of the following instrument stated to be designed to meet the requirements of Offshore Marine Engineering Limited, Order No. 11443.

1. Off – Analox combined 401A and 401BC temperature and humidity controller, complete with triac switching. Serial No. 1032 C.

Conformity tests were witnessed in accordance with Scottish Anglo Environmental Protection Limited Specification, Factory Construction Report and Final Out Testing Procedure for Analox Microprocessor Base Equipment and was found to conform with the specification and the order requirements.

*** END ***

R.W. PICKUP

Surveyor to Lloyd's Register of Shipping

JR

COPY

MDB 600407

1 off - Analox 100F Hyp. O2 Monitor
Power: 115V-60Hz A.C.
Serial No. 1355k.

5 off - Analox 100 Hyp. O2 Portable Monitor
Power: 9V Battery
Serial No. 1296, 1297, 1298, 1299, 1300.

Pressure tests and conformity tests were witnessed in accordance with Scottish Anglo Environmental Protection Ltd., Specification - Factory Construction Report and Final Out Testing Procedure for Analox Microprocessor Based Equipment and were found to conform with the specification and the order requirements.

Robin W. Pickup

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R.W. PICKUP
SURVEYOR TO LLOYD'S REGISTER OF SHIPPING

APPENDIX B

HUMAN FACTORS EVAUATION

I. METHODOLOGY

A human factors evaluation of the Analox CO_2 Hyperbaric Monitor was conducted in August 1987. This evaluation consisted of an examination of the monitor mounted in the instrument panel of the Navy Experimental Diving Unit's (NEDU) Experimental Diving Facility (EDF). A review of the Analox CO_2 HYP operations manual dated April 1987 and photo documentation was also undertaken as shown in Figures 5 through 9. The monitor was evaluated using the guidelines set forth in Military Standard 1472-B (Human Engineering Design Criteria for Military Systems, Equipment and Facilities); Humanscale 5 (Control and Displays) Diffrient, Tilley and Harman; and Commander Operational Test and Evaluation Force Question Catalog (Human Factors).

II. GENERAL COMMENTS

The Analox CO_2 Hyperbaric Monitor was mounted in the instrument panel as shown in Figure 5 IAW instructions provided in the accompanying manual. The monitor is a simple LED display with various push buttons and rocker switches to calibrate the unit set alarms and to turn the unit on and off. The unit has a remote microprocessor sensor which is physically located in the EDF saturation chamber (simulated personnel transfer capsule, PTC). Atmosphere levels of carbon dioxide are sampled by a small pump in the sensor unit, pictured in Figure 6, which draws the sample specimen across an infrared sensor.

The frame of the unit is aluminum with an anodized front panel. It is sturdy and resistant to damage from normal handling. There are no sharp edges and the front panel fits well with the housing. The on/off switch is a rocker variety with adequate size, 0.95 x 1.9 cms, and angle of operation, 30 degrees. A green .32 cm light identifies an energized unit. There is no on/off lable. Push button switches are used for setting calibrations and alarms. The buttons are .6 cm in diameter and actuation is noted by a change in the LED display. The LED display is red on black, a seven segment matrix generation, 1.25 x 1.25 cms, and with no appreciable glare problems in this mounting configuration. The high CO_2 warning light is red and flashes at two flashes per second. It is accompanied by an audible alarm which requires acknowledgement manually. The light is small but bright. A similar non-flashing yellow light denotes the need to recheck calibration, no alarm sounds. The labels vary from .48 cm in height to .24 cm in height.

Overall the controls and displays were adequate. The majority of discrepancies related to the size of the controls which generally were smaller than optimum but still in the minimal acceptance ranges. The push button control is unacceptable for controls which need to be free from inadvertent action, however, on this monitor it would take multiple inadvertent actions to disrupt the monitor beyond quick recovery. Labels could be larger, especially the milli-atmospheres label. This label is confusing to U.S. Navy divers who are not taught to think in terms of milli-atmospheres.

The Analox CO_2 Hyperbaric Monitor is representative of all four Analox monitors evaluated for this report and pictured in Figures 5 through 9. Comments on LED displays, function select buttons, labels, and on/off switches are eually applicalbe to these Analox monitors as they were to the Analox CO_2 Hyperbaric Monitor. Displays on the 401A Temperature and 401B Humidity Monitor are labeled and calibrated in units familiar to U.S. Navy divers, degrees Fahrenheit and percent relative humidity.

III. RECOMMENDATION

A. The LED display label should be changed to CO_2 % SEV and increased to .65 cm size. This will require shifting the LED display decimal point one digit to the left.

B. The function select push button would be safer as a finger knob to prevent inadvertent actuation.

C. All display labels could be larger, though space on this monitor is already at a premium.

D. The on/off switch should be labeled.

E. The monitor shuld be mounted in a 10° angle of incidence to the visual axis to prevent glare.

APPENDIX C

OFF-GASSING ANALYSIS OF IN-CHAMBER COMPONENTS

of:

Analox CO_2 Hyperbaric Monitor
Serial #018

Analox Temperature and Humidity Sensor
HPP5

Memorandum 24 Feb 1988

From: Glen Deason: Code 3430
To: J. Schmidtt: NEDU

Subject: Offgasing Analysis of Carbon Dioxide Analyzer. Serial #018. Model HYP: Results of

1. The above sample was placed in a 25.525 cubic-centimeter outgasing chamber which had been precleaned to ensure a zero hydrocarbon background. The chamber was then charged to 10 psig. 42.890 cubic-centimeter ambient conditions. with high purity(zero) air. The hydrocarbon content of the contained sample was then allowed to equilibrate for 4 hours at 130F(54.4C) before an analysis for specific and total hydrocarbons. The analysis yielded the following results:

Component	Level	Limit
Total Hydrocarbons*	3.1 PPM	25 PPM
Carbon Monoxide	2.5 PPM	10 PPM
Total Halogens	<0.5 PPM	5 PPM
Methane	2.1 PPM	1000 PPM
Acetone	<0.1 PPM	300 PPM
Freon 113	<0.1 PPM	10 PPM
Methyl Ethyl Ketone**	<0.1 PPM	200 PPM
Benzene	<0.1 PPM	1 PPM
Toluene	<0.1 PPM	200 PPM
C4+	<0.8 PPM	
Dilution Volume	42.890 CC	
Sample Weight	2.500.0g	

*Expressed as methane equivalents
**OSHA limit

2. The above sample did not show excessive offgassing and would be safe in a man-rated. closed environment at temperatures up to 130F(54.4C).

Glen Deason
Chemist

Memorandum 24 Feb 1988

From: Glen Deason: Code 3430
To: J. Schmidtt: NEDU

Subject: Offgasing Analysis Temperature and Humidity Sensor HPFS: Results of

1. The above sample was placed in a 2000 cubic-centimeter outgasing chamber which had been precleaned to ensure a zero hydrocarbon background. The chamber was then charged to 50 psig. 6800 cubic-centimeter ambient conditions, with high purity(zero) air. The hydrocarbon content of the contained sample was then allowed to equilibrate for 4 hours at 130F(54.4C) before an analysis for specific and total hydrocarbons. The analysis yielded the following results:

Component	Level	Limit
Total Hydrocarbons*	3.3 PPM	25 PPM
Carbon Monoxide	1.0 PPM	10 PPM
Total Halogens	<0.5 PPM	5 PPM
Methane	3.3 PPM	1000 PPM
Acetone	<0.1 PPM	300 PPM
Freon 113	<0.1 PPM	10 PPM
Methyl Ethyl Ketone**	<0.1 PPM	200 PPM
Benzene	<0.1 PPM	1 PPM
Toluene	<0.1 PPM	200 PPM
C4+	<0.1 PPM	
Dilution Volume	6800 CC	
Sample Weight	622.1 g	

*Expressed as methane equivalents
**OSHA limit

2. The above sample did not show excessive offgassing and would be safe in a man-rated, closed environment at temperatures up to 130F(54.4C).

Glen Deason
Chemist