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# DEVELOPMENT AND EVALUATION OF AN OXYGEN-SENSING WARNING DEVICE



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NATICK, MASSACHUSETTS

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Evaluation of the device showed it to be a reliable and accurate monitor of oxygen concentration. Its responses to changes in other environmental factors, such as temperature and humidity, were small. Consequently, the O<sub>2</sub> sensing warning device was judged suitable for use in the DCSS. (U)

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NATICK, MASSACHUSETTS

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OXYGEN-SENSING WARNING DEVICE

by N. F. Audet and G. M. Orner

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## ABSTRACT

The Navy Clothing and Textile Research Unit (NCTRU) has evaluated an oxygen-sensing warning device, developed by Beckman Instruments, Inc., to be used as a safety feature in a Damage Control Suit System (DCSS) presently under development. The O<sub>2</sub> warning device, which employs a polarographic oxygen sensor in conjunction with control electronics and a visual output, provides a visual warning in the event oxygen concentrations in the DCSS are above or below certain preselected thresholds.

Evaluation of the device showed it to be a reliable and accurate monitor of oxygen concentration. Its responses to changes in other environmental factors, such as temperature and humidity, were small. Consequently, the O<sub>2</sub> sensing warning device was judged suitable for use in the DCSS.

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## DEVELOPMENT AND EVALUATION OF AN OXYGEN-SENSING WARNING DEVICE

### INTRODUCTION

The Navy Clothing and Textile Research Unit (NCTRU) sponsored the development of an oxygen-sensing warning device by Beckman Instruments, Inc., under Contract No. N00298-69-CK418. The device, which has been successfully tested, is to be utilized as a safety feature in a Damage Control Suit System (DCSS) presently being developed by NCTRU. The purpose of this O<sub>2</sub> detection device is to warn an individual encapsulated in the Damage Control Suit of an impending oxygen deficiency or excess so that he will have sufficient lead time to react to an abnormal environment. This report describes the operation of the warning unit and details the results of performance tests conducted on the units.

### DESCRIPTION AND OPERATION OF O<sub>2</sub> WARNING DEVICE

The O<sub>2</sub> warning device (Figure 1) consists of a Beckman nonrechargeable polarographic oxygen sensor and receptacle, a control box, a warning light package, and interconnecting cables. In normal use the oxygen sensor is located in the plenum of the DCSS life support pack, the control box is mounted on one side of the pack, and the light package is located on the headset communication device worn by an individual using the DCSS (Figures 2 and 3).

The device provides a visual warning whenever the oxygen concentration falls below or rises above preselected thresholds. The thresholds selected are 115 mm of Hg and 205 mm Hg oxygen partial pressure (pO<sub>2</sub>). People can survive in pO<sub>2</sub> concentrations as low as 80 mm Hg and in pure O<sub>2</sub> environments for greater than the DCSS two-hour mission requirements (1). When the thresholds are set at the levels indicated, inherent errors can be accounted for, thus insuring alarm actuations prior to a nonsurvivable condition. This is particularly vital for the low-oxygen concentration in which death could result. High-oxygen concentration increases the fire-hazard within the suit but does not pose an immediate personnel threat. For oxygen concentrations between the two threshold limits a green safe light remains on. Outside these limits the green light goes off, and one of two red lights goes on depending on whether the O<sub>2</sub> concentration is low or high.

Figure 4 is a schematic diagram of the device, which is designed to operate on a 12v DC battery power supply. The O<sub>2</sub> sensor input signal is amplified and directed to a meter, test terminals, relays, and alarm amplifiers. The signal and alarm amplifiers are powered by a 12 to 28v DC to DC converter. Potentiometers are provided to calibrate the signal amplifier and select the threshold signals upon which the alarm amplifiers activate the relays. Depending on the voltage delivered to the relay coils, the high, safe, or low lights are illuminated.

1. Oxygen Sensor and Receptacle. The oxygen sensor is a polarographic type and is covered under U.S. Patent No. 2,913,386, issued to Beckman Instruments, Inc. The sensor is a small electrochemical cell (2) consisting of a

gold cathode, a silver anode, potassium chloride gel electrolyte, and a thin teflon membrane. Figure 5 depicts the size of this sensor. The sensor operates as follows:

a. The teflon membrane is permeable to oxygen but keeps airborne solid or liquid contaminants away from the gel.

b. A voltage potential of 0.75 volts is applied across the anode and cathode which results in a current flow through the sensor that is directly proportional to the partial pressure of oxygen to which the sensor is exposed.

The particular type of sensor used in this system is nonrechargeable and has the following rated characteristics:

a. Operational Life - 1,000 hours

b. Shelf Life - 1 year

c. Response Time - 15 seconds for 90 percent total response to a step change in oxygen concentration.

For a device of this type which will be used by personnel unaccustomed to the handling of chemicals and the care required to properly recharge a cell, a nonrechargeable cell with a good operational life is essential.

A thermistor is located in the sensor housing to compensate for temperature changes in the range of 32 to 105°F.

2. Control Box. The control box is equipped with the DC to DC converter, sensor signal amplifier, meter, two alarm amplifiers, calibrate-adjust control, alarm set controls, relays, power switch, and connectors. All switching functions are performed in this device.

a. DC to DC Converter. The converter operates from a 10-to-15v DC power source and increases the DC level to 22 to 32v to operate the sensor and alarm amplifiers.

b. Sensor Signal Amplifier. The amplifier which increases the level of the oxygen-sensor input signal, provides a full scale range of 0 to 5 volts, corresponding to a sensor oxygen partial pressure range of 0 to 300 mm Hg. The output signal of the amplifier is directed to an integral meter, test terminals, relays, and alarm amplifier inputs.

c. Meter. A hermetically sealed 100 microamp DC meter with a scale calibrated from 0 to 300 mm Hg  $pO_2$  (0 to 5v DC) is provided as a visual indicator of  $O_2$  concentration and is needed to calibrate the system prior to use. The scale has red marks at the 115 and 205 mm Hg points to aid in setting the high and low warning levels. A green mark at the 160 mm Hg point (normal atmosphere) is provided as the calibration mark when the unit is pre-tested in a normal atmospheric environment.

d. High and Low Alarm Amplifiers. The output of the sensor amplifier is compared with the threshold signal levels set at each alarm. The difference signal is amplified. Activation of either the high, safe, or low lights depends upon the level of these difference signals.

e. Special Features. High and low O<sub>2</sub> concentration alarm lights are also mounted on the control box to permit test of the device without the light package attached. A calibrate-adjust control is provided which has sufficient range to permit exercising of both of the lights prior to use to insure that the device is functioning. Alarm set controls are provided for setting the pO<sub>2</sub> activation levels for the high and the low alarms. Normal atmospheric oxygen concentration is used to calibrate the devices prior to use.

3. Alarm Light Package. Contains the high, safe, and low alarm lights and is located on the communication headset.

4. Other Device Features

1. Size. 5.5" x 5" x 1.25"
2. Weight. 1.00 lb.
3. Electrical Power Requirement. 12v DC--.125 amp. Max--1.5 watts Max.

5. Device Configuration. The present device configuration, which has not been optimized, has three obvious deficiencies.

a. The power switch on the units is not completely recessed below the housing, making it susceptible to damage.

b. The presence of a high O<sub>2</sub> concentration suggests a possible fire hazard, but does not immediately pose a threat to the life of an individual encapsulated in the DCSS. For this reason as well as to permit better discrimination between the warning lights, a color other than red will be used for the high O<sub>2</sub> alarm light.

c. Presently, the control box and sensor are separated by an inter-connecting cable. Bulk can be reduced by packaging the sensor within the control box, thus eliminating this cable and its connectors.

#### TEST PROCEDURE

To determine the effectiveness of the O<sub>2</sub> warning device for use in the DCSS, tests were conducted with two units to measure the following:

1. Effect of temperature on O<sub>2</sub> warning device output.
2. Effect of humidity on output of device.
3. Effect of temperature on high and low pO<sub>2</sub> threshold activation levels.
4. Effect of humidity on high and low pO<sub>2</sub> threshold activation levels.
5. Accuracy of device to specific oxygen concentrations.
6. Response of device to sudden changes in oxygen concentrations.
7. Effect of low temperature storage on sensor.
8. Weight of device, electrical power requirements, and effect of input voltage on sensor output.

The test setup for determining the accuracy of the O<sub>2</sub> indications is illustrated graphically and schematically in Figures 6 and 7. A welded stainless steel plenum was provided with suitable threaded openings for attaching transducers from the O<sub>2</sub> warning system and from a Beckman Field-Lab Oxygen Analyzer. Additional openings for admitting and exhausting O<sub>2</sub> and N<sub>2</sub> gases were also provided. Power for energizing the unit was obtained from an adjustable filtered voltage DC power supply. An additional Lab-type voltmeter (Weston Model 931, 5K ohms/volt) was connected to terminals provided on the control box of the O<sub>2</sub> warning device. This Weston voltmeter permitted a more accurate output-signal readout than could be made from the small meter installed on the units. The Weston voltmeter was calibrated before any tests were made.

Prior to testing, the effect of the additional load imposed on the warning unit's circuitry by the Weston voltmeter was determined. A VTVM was connected across the output signal terminals of the O<sub>2</sub> warning device. While a signal was monitored with the VTVM, the Weston voltmeter (connected in parallel with the VTVM) was alternately connected and disconnected from the circuit. The signal change on the VTVM was noted and found to be only 1 percent of the total output. This signal change was considered to be negligible and was disregarded in all remaining tests.

Gases O<sub>2</sub> and N<sub>2</sub> were supplied to the plenum from high pressure gas cylinders through regulating valves and gas flow gauges. To insure that no significant errors in gas flow measurements were introduced by temperature differences between the two gases, gas temperatures were monitored immediately downstream from each flow gauge by means of thermocouples mounted directly in the gas streams and connected to a precision millivolt potentiometer. Temperature difference between the gases was observed to be only 3°F in an extreme case (after maximum, prolonged flow). The error introduced by this small temperature difference was considered to be negligible for the purposes of these tests and was, therefore, disregarded.

Another potential source of error in the O<sub>2</sub> partial pressure indications was thought to be variations in the voltage from the Silver-Zinc (AgZn) battery pack used for energizing the warning units during actual field applications of the Damage Control Suit System. Tests revealed, however, that for supply voltage variations in the range of 7.5 and 14.8 volts, there was no discernible effect on signal output.

A Webber environmental cabinet (Figure 8), which can produce a wide range of temperature and relative humidity conditions, was used for the tests involving the effects of temperature and humidity on the signal output from the O<sub>2</sub> warning units. Both units, each with its own sensor and warning light assembly, were placed inside the cabinet. The power supply and the voltmeter used for signal readout were mounted externally, electrical connections being made through special terminals mounted on the wall of the cabinet. A double pole, double throw switch was used to direct the output signals from either warning unit to the Weston voltmeter.

## TEST RESULTS

### Reliability

No tests were run for the specific purpose of determining the reliability

of O<sub>2</sub> warning devices. However, sufficient overall testing was performed to demonstrate that a high degree of reliability can be expected from these devices. Total test time exceeded 100 hours on each unit with no malfunctions of any kind except for a sticking pointer on the O<sub>2</sub> indicator of the No. 2 unit. This deficiency can affect the O<sub>2</sub> pressure levels at which red warning lights actuate because a false calibration is possible. (Proper quality control can eliminate this type of deficiency.)

#### Accuracy of O<sub>2</sub> Indications

In the initial test O<sub>2</sub> and N<sub>2</sub> were admitted into the plenum through separate openings, mixing of the gases taking place inside the plenum. Since no provision was made for arresting the metered gas flows simultaneously, gases were allowed to flow continuously into the plenum while readings were being taken. It became apparent, however, that incomplete mixing was taking place. Consequently, in subsequent tests both gases were fed into a single tube simultaneously, then into the plenum through a single opening, as shown in Figure 7. This arrangement resulted in much better mixing of the gases and allowed both gases to be shut off simultaneously with a simple tube clamp. After both inlet and exhaust tubes were closed, several minutes were allowed to insure complete mixing of the gases before readings were taken.

Initially, O<sub>2</sub> pressure indications from one of the warning devices were compared with indications given by a Beckman Field Lab O<sub>2</sub> Analyzer; however, the zero adjustment of this instrument could not be accurately controlled. Since the proportions of O<sub>2</sub> and N<sub>2</sub> within the plenum could be accurately controlled by the rates at which the gases were admitted (as monitored by the flow gauges), the use of the Beckman Analyzer for the remaining tests was discontinued. Instead, both O<sub>2</sub> warning devices were tested simultaneously, each with its own O<sub>2</sub> sensor mounted inside the plenum. Oxygen and nitrogen gases were allowed to flow, at predetermined rates, through the plenum for several minutes to insure thorough purging of the system with the gas mixture. The plenum openings (gas inlet and outlet) were then closed and, after several minutes delay to allow diffusion of the gases, data were taken. Prior to testing, the indicating meter on each unit was adjusted with its calibrating potentiometer to read atmospheric O<sub>2</sub> pressure in mm Hg. During testing each unit was connected in turn to each sensor at each pO<sub>2</sub> data point. When sensors were switched from one unit to the other, no recalibrations were made; thus, the differences in output between the two sensors could be evaluated. To facilitate accurate readings of the output from each unit, as in the previous tests, a voltmeter with a greatly expanded scale was connected across the terminals of each unit's meter.

The data are presented in Figure 9. Both O<sub>2</sub> warning devices produced a linear response to O<sub>2</sub> partial pressure concentration. Their sensitivities, however, were different--13.4 and 15.7 mv output per mm Hg pO<sub>2</sub>. Variations in system outputs caused by a change in sensor were small. The sensitivities observed for both units differed from the design value of 16.7 mv per mm Hg pO<sub>2</sub> (0 to 5 v output for a pO<sub>2</sub> range of 0 to 300 mm Hg). Since each unit was calibrated prior to use in normal operation, the absolute sensitivity level was not significant as long as a sufficient output was provided to drive meters, alarm amplifiers, etc. The output was adequate in this respect. A better

initial calibration of these devices would make their outputs more comparable. The important features are that the system response to  $pO_2$  concentration approaches linearity and is continuous. The device outputs are linear, continuous, and sufficient to drive other system components.

#### Response of Warning Light to $O_2$ Partial Pressure Level

Tests were conducted to determine how closely the  $O_2$  partial pressure levels at which the red warning light operated corresponded to the nominal levels at which they were set.

In these tests no external meter was used. The units were calibrated, as they would be in the field (Appendix A), by use of their own indicating meters to set the high  $O_2$  and low  $O_2$  operating levels. Finally, the  $pO_2$  indication on the meter was set at the ambient  $pO_2$ .

The test was conducted with the test setup shown in Figure 7, using the Beckman Field Lab  $O_2$  Analyzer to show the  $O_2$  partial pressure within the plenum.

The results of these tests are presented in Table 1. Note the very small errors associated with the operation of the warning lights for Unit No. 1, and the rather large errors apparent for Unit No. 2. In both systems the span of error was less than 1 percent. The apparent  $pO_2$  error measured for system No. 2 was caused by a poor calibration, which resulted from a sticking pointer.

TABLE I. ACCURACY OF PANEL METER SETTINGS  
( $pO_2$  (mmHg) at which High and Low Alarm Lights Operated)

	Unit No. 1			Unit No. 2		
	High	Low	Span	High	Low	Span
Desired	205.0	115.0	90.0	205.0	115.0	90.0
Test Result	204.4	114.7	89.7	196.8	106.4	90.4
Error (%)	-0.3	-0.3	-0.33	-4.0	-8.0	+0.44

#### Effect of Temperature and Humidity on Performance of $O_2$ Warning Units

Temperature. The warning unit sensors are temperature compensated for variations in the range of 32 to 105°F. Tests of the systems at temperatures of 40 to 110°F showed a setpoint change of less than 3 percent between 40 and 105°F (see Figure 10). The general effect of temperature is to increase output as the temperature increases with an overall change in output of less than 5 percent over the range tested.

Humidity. The effect of relative humidity at 70°F on the output from the  $O_2$  warning units is illustrated in Figure 11. As can be seen, the effect of humidity on the readout of either system was less than 2 percent.

Additional tests were run to determine the effect of humidity at other than ambient temperatures. Tests were conducted at the extreme values likely to be encountered in the Damage Control Suit System, i.e., 40°F and 110°F, 20 percent and 100 percent RH. These tests showed that at 40°F a change in RH

from 100 percent to 20 percent had no apparent effect on the O<sub>2</sub> warning system output. Test results at 110°F, however, showed that, when RH was reduced from 100 percent to 21 percent, signal outputs were increased by 8.0 percent and 6.5 percent for Devices No. 1 and 2, respectively. This change was essentially predictable. At 21 percent RH the pO<sub>2</sub> concentration would be 8.5 percent higher than at 100 percent RH since total ambient pressure was constant (Table II).

TABLE II. CHANGE IN ATMOSPHERIC pO<sub>2</sub> CONCENTRATION vs RH CHANGE

Temperature °F	RH (%)	Atmospheric Composition (mm Hg)			
		pO <sub>2</sub>	pN <sub>2</sub>	pH <sub>2</sub> O	p Total
110	100	144	550	66	760
110	21	156	590	14	760

For the water vapor concentrations to which the warning device was subjected, there was a maximum error in pO<sub>2</sub> readout of 2 percent after measurements were corrected for changes in atmospheric pO<sub>2</sub> concentrations. The output variation observed at 110°F was caused principally by these changes in pO<sub>2</sub> concentrations. The effect of pH<sub>2</sub>O on the accuracy of the signal output was therefore essentially insignificant in all tests.

The output change at 110°F and 100 percent RH does, however, reflect a source of error associated with the device if pH<sub>2</sub>O is not accounted for when the systems are calibrated prior to use, as would be the case in practice. At 110°F and 100 percent RH, pH<sub>2</sub>O is 66 mm Hg. If the systems were calibrated at this condition, which is the worst one that would be encountered, the pO<sub>2</sub> concentration would be set at 160 mm Hg, while in reality, it is only 146 mm Hg at a barometric pressure of 760 mm Hg. The effect of this error on warning threshold levels would be such that the low O<sub>2</sub> alarm would actuate at 101 mm Hg pO<sub>2</sub> instead of 115 mm Hg and the high O<sub>2</sub> alarm would actuate at 191 mm Hg pO<sub>2</sub> instead of 205 mm Hg. Yet, the warning lights would still actuate at pO<sub>2</sub> concentrations that are sufficient to maintain life (greater than 80 mm Hg) and would provide time to react even under this worst condition.

#### Effect of Temperature and Humidity on Operation of Warning Lights

Tests were conducted to determine the effect of temperature and RH on the operation of the red warning lights which indicate unsafe O<sub>2</sub> concentrations in the atmosphere within the Damage Control Suit System. Temperatures varied between 40° and 110°F, RH between 20 and 100 percent.

The results from these tests are tabulated in Table III. Note that there is no significant effect on the operating voltages of these lights from any of the temperature-humidity combinations utilized for the tests. The maximum variation is ± 1.2 percent, i.e., within the limits of experimental error.

TABLE III. EFFECT OF TEMPERATURE AND HUMIDITY ON WARNING LIGHT ACTIVATION VOLTAGES

Temp. °F	RH %	System No. 1		System No. 2	
		High Light volts*	Low Light volts*	High Light volts*	Low Light volts*
70	65	3.50	1.96	3.50	1.96
110	65	3.52	1.98	3.52	2.00
71	63	3.50	1.98	3.50	1.97
111	66	3.53	2.00	3.53	2.00
40	66	3.48	1.96	3.50	1.95
71	65	3.48	1.96	3.48	1.96
70	100	3.48	2.00	3.49	1.96
70	20	3.48	1.97	3.49	1.96

\*The high and low warning light activation voltages were arbitrarily set at 3.5 and 1.96v, respectively, for each system without regard to the meter markings on each control box.

#### Response of O<sub>2</sub> Warning System to Dynamic Changes in Gas Concentrations

For obvious safety reasons, the rapid detection of any unsafe O<sub>2</sub> concentration within the Damage Control Suit System is necessary. Thus, tests were conducted to determine the time response of the warning systems to very rapid changes in O<sub>2</sub> concentrations.

For these tests both O<sub>2</sub> sensing systems were mounted in the plenum as before (See Figure 7) and connected to their respective O<sub>2</sub> warning units. The high O<sub>2</sub> and low O<sub>2</sub> warning lights were adjusted to operate at voltage limits of 3.48 and 1.96 volts, respectively. The units were then calibrated to give an output for atmospheric air of 2.7 volts. Nitrogen was then admitted into the plenum at an estimated rate in excess of 50 liters/min. Both low O<sub>2</sub> warning lights came on within a few seconds. After 15 seconds, the output from both units had dropped to below 0.2 volts (better than 90 percent change in output). Pure O<sub>2</sub> was then admitted to the plenum at approximately the same rate as the N<sub>2</sub>. The high O<sub>2</sub> concentration warning lights responded almost immediately, after 10 seconds the output from both units exceeded 16 volts. After five minutes N<sub>2</sub> was again admitted into the plenum to displace the O<sub>2</sub>. This time there was no response for about 15 seconds, after which time voltage outputs fell sharply to less than 0.45 volts in a total time of 60 seconds.

The response of these units appears to be even faster than necessary for their intended application, a delay in response occurring only when the sensors were allowed to remain in a very high O<sub>2</sub> concentration (greater than 360 mmHg pO<sub>2</sub> which exceeds the system design range) for several minutes.

#### Effect of Freezing of O<sub>2</sub> Sensor

The O<sub>2</sub> sensors in these warning units used a liquid gel in their construction which was subject to freezing at temperatures below 32°F. During storage or shipment, the inadvertent freezing of the sensor could occur. Thus, the effect of freezing on the sensor output was investigated.

Sensor No. 2 was placed in an environmental cabinet at 10°F for approximately 20 hours and then allowed to thaw at room temperature. The effect of freezing on the sensor output was determined by connecting the sensor to the No. 2 warning device and measuring the voltage outputs from the unit with the sensor in ambient air, 100 percent N<sub>2</sub>, and 100 percent O<sub>2</sub> both before and after freezing. The No. 1 sensor, which was not frozen, was connected to its respective unit and tested in the plenum along with sensor No. 2 to provide control data.

The results of these tests are presented in Table IV. From these data it is apparent that freezing has had very little or no effect on the performance of the sensor.

TABLE IV. EFFECT OF LOW TEMPERATURE ON DEVICE OUTPUT  
(O<sub>2</sub> Warning Output, Volts)

	Before freezing No. 2		After freezing No. 2	
	No. 1	No. 2	No. 1	No. 2
Environmental Ambient Air	2.70	2.70	2.73	2.67
100 percent N <sub>2</sub>	0.00	0.00	0.04	0.07
100 percent O <sub>2</sub>	6.02	6.02	6.04	6.00

Effect of Combined Device Errors

The influence of the various device errors on the activation levels of the alarms for several initial conditions are given in Table V.

TABLE V. EFFECT OF COMBINED DEVICE ERRORS ON  
ALARM ACTIVATION LEVELS

Calibration Condition		Operating Condition		Warning Light "pO <sub>2</sub> " Desired		Activation Levels (mm Hg) Actual	
Temp. °F	RH %	Temp. °F	RH %	High	Low	High	Low
70	65	70	65	205	115	202	112
70	65	110	20	205	115	196	108
70	65	110	100	205	115	212	117
70	65	40	100	205	115	208	114
70	65	40	20	205	115	212	116
110	20	110	20	205	115	202	112
110	20	110	100	205	115	206	114
110	20	40	100	205	115	218	120
110	20	40	20	205	115	222	122
110	100	110	100	205	115	195	103
110	100	110	20	205	115	189	105
110	100	40	100	205	115	195	109
110	100	40	20	205	115	199	111
40	20	40	20	205	115	205	115
40	20	40	100	205	115	201	113
40	20	110	20	205	115	193	109
40	20	110	100	205	115	189	107
40	100	40	100	205	115	205	115
40	100	40	20	205	115	209	117
40	100	110	100	205	115	193	109
40	100	110	20	205	115	197	111

As can be seen the thresholds selected for alarm activation ("Desired" column) insure that activation levels are within safe limits regardless of variations on activation levels caused by changes in ambient conditions from the time of calibration to operation. Activation would not occur below 103 mm Hg  $pO_2$  and a  $pO_2$  of 80 mm Hg is still sufficient for survival.

#### CONCLUSIONS

Based on the results of these tests, it may be concluded that the  $O_2$  Warning Devices, which appear to be highly reliable and trouble-free, are suitable for use as a safety device for the Damage Control Suit System. The only significant shortcoming was the error in the response of the warning light in Unit No. 2 to the  $O_2$  partial pressure levels. It was noted previously, however, that a faulty pointer, resulting in a poor calibration, contributed to the apparent error.

The output from these units was shown to be linear with respect to  $O_2$  partial pressure and not seriously affected by temperatures between 40° and 110°F. Humidity effects were minimal.

Sufficient safety is provided in the levels set to account for possible differences between actual and intended actuation thresholds for the low and the high  $pO_2$  warning lights caused by initial calibration errors. Consequently, errors that could be induced by not correcting for  $pH_2O$  are not serious.

#### RECOMMENDATIONS

In the updating of this device before final inclusion in the Damage Control Suit System, the following changes are recommended:

1. High  $O_2$  light should be yellow instead of red to provide discrimination between high and low alarms.
2. Power switch should be completely recessed below control box housing to prevent damage to the switch.
3. Sensor and sensor housing should be integral with control box to eliminate some of the cabling and connectors.
4. Good quality control on meter should be insured to prevent the reoccurrence of a faulty pointer.

## APPENDIX A.

### FIELD CALIBRATION OF UNITS

#### A. Component Setup

##### 1. Components needed.

- a. Oxygen Sensing Warning System
- b. Sensor cable
- c. Sensor and sensor receptacle assembly
- d. Warning light package
- e. 12v DC power source

##### 2. Setup

- a. Check to insure Sensor and Sensor Receptacle are connected to control box with sensor cable.
- b. Check to insure Warning Light Package is connected to control box.
- c. Check to insure 12v DC Power Source is connected to control box.
- d. Make sure power-on switch is off.

#### B. Calibrate and Alarm Set. (Non-emergency procedure--perform periodically to insure system functioning properly.)

##### 1. Disconnect Sensor, turn on power switch.

- a. Meter pointer reads 0 mmHg
- b. O<sub>2</sub> low light on control box and light package comes on.

##### 2. Reconnect Sensor.

- a. Meter pointer pegs full scale.
- b. O<sub>2</sub> high light on control box and light package comes on.
- c. After approximately 20 seconds, meter pointer slowly moves down scale.
- d. Condition of lights depends on alarm set points.

##### 3. Let system stabilize for approximately 4 minutes.

4. Turn O<sub>2</sub> Hi alarm control all the way CW and turn the O<sub>2</sub> low alarm control all the way CCW. High and low lights should be off.

5. Safe light on light package should be on.

6. Turn, calibrate, adjust control CCW until meter pointer reads desired setting of 115 mm of Hg pO<sub>2</sub> for low alarm. Convert red mark on meter.

7. Turn O<sub>2</sub> low alarm control until O<sub>2</sub> low alarm light on panel and light package just comes on. Low alarm is now set. Safe light is off.

8. Turn, calibrate, adjust control CW until meter pointer reads desired setting of 205 mm of Hg pO<sub>2</sub> for high alarm--highest read mark on meter.

9. Turn O<sub>2</sub> Hi alarm control until O<sub>2</sub> Hi alarm lamp on panel and light package just comes on. High alarm is now set. Safe light is off.

10. Adjust, calibrate, adjust control so that meter pointer aligns with green mark on meter scale. Low  $O_2$  alarm set is made at high enough concentration so that error in calibration introduced in this technique by not accounting for water vapor presence in air will still provide adequate warning for low  $O_2$  concentration.

11. System is now calibrated and low alarm is set for 115 mm of Hg  $pO_2$  and high alarm is set for 205 mm of Hg  $pO_2$ .

#### C. Calibration Prior to Use of System in Emergency Situation

1. Turn on power switch.
  - a. Meter pegs full scale.
  - b.  $O_2$  high light on control box and light package comes on.
  - c. After approximately 20 seconds, meter pointer slowly moves down scale.
  - d. As meter pointer drops below 205 mm, Hg  $pO_2$  level on scale, Hi light goes out and safe light comes on.
2. Let system stabilize for approximately 4 minutes.
3. Turn calibrate adjust control CCW. When meter pointer indicates 115 mm Hg  $pO_2$ , low light should come on and safe light should go out.
4. Turn calibrate adjust control CW. When meter pointers climb above 115 mm Hg  $pO_2$ , low light goes out, safe light comes on; at 205 mm Hg  $pO_2$  setting, Hi light comes on, safe light goes out.
5. Turn calibrate adjust control CCW until meter pointer aligns with green mark on meter (160 mm of Hg  $pO_2$ ). High light goes off and safe light comes on.
6. System is now calibrated and ready for use.

APPENDIX B. ILLUSTRATIONS

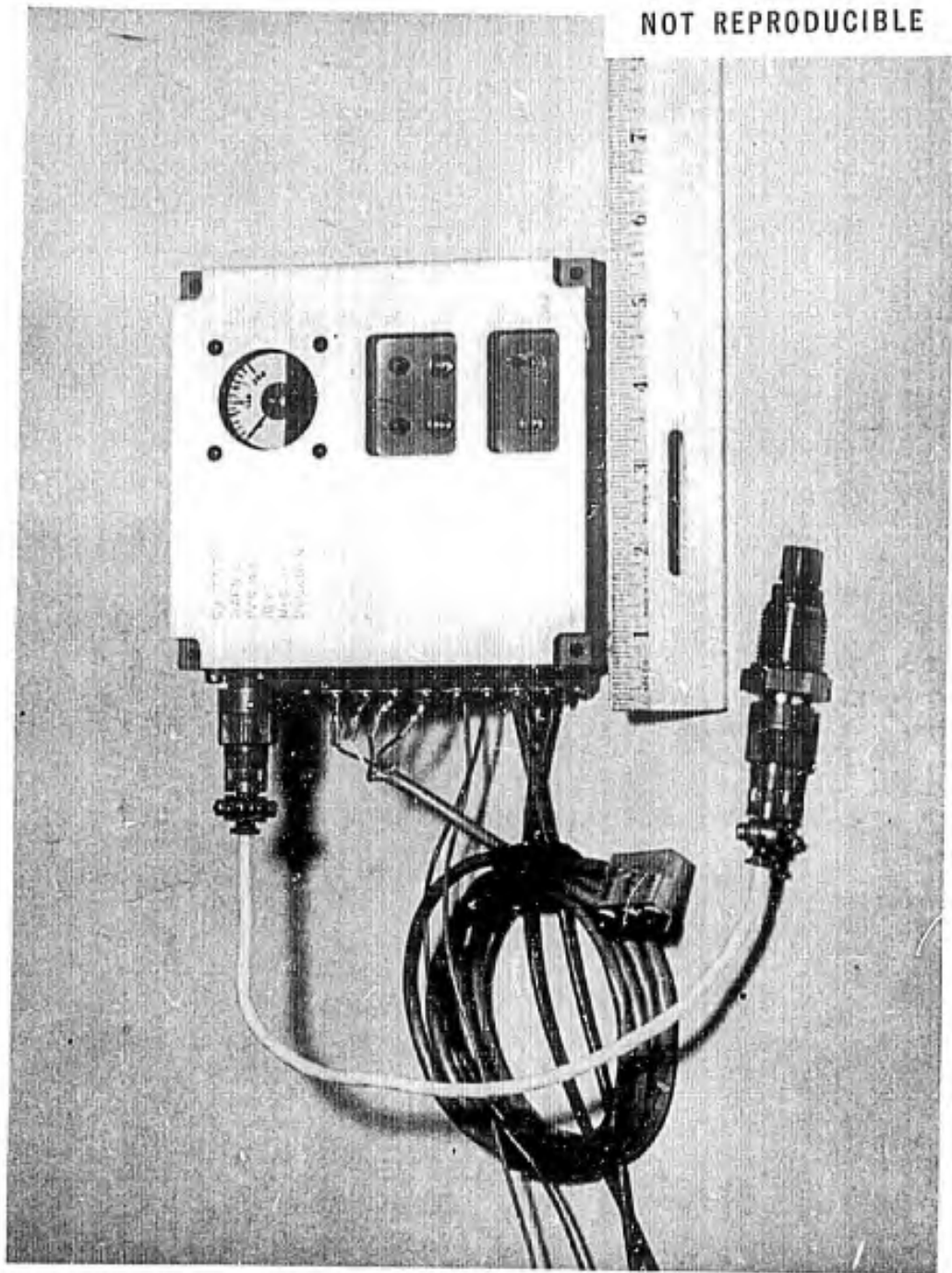


Figure 1. O<sub>2</sub> Sensing Warning Device.

NOT REPRODUCIBLE

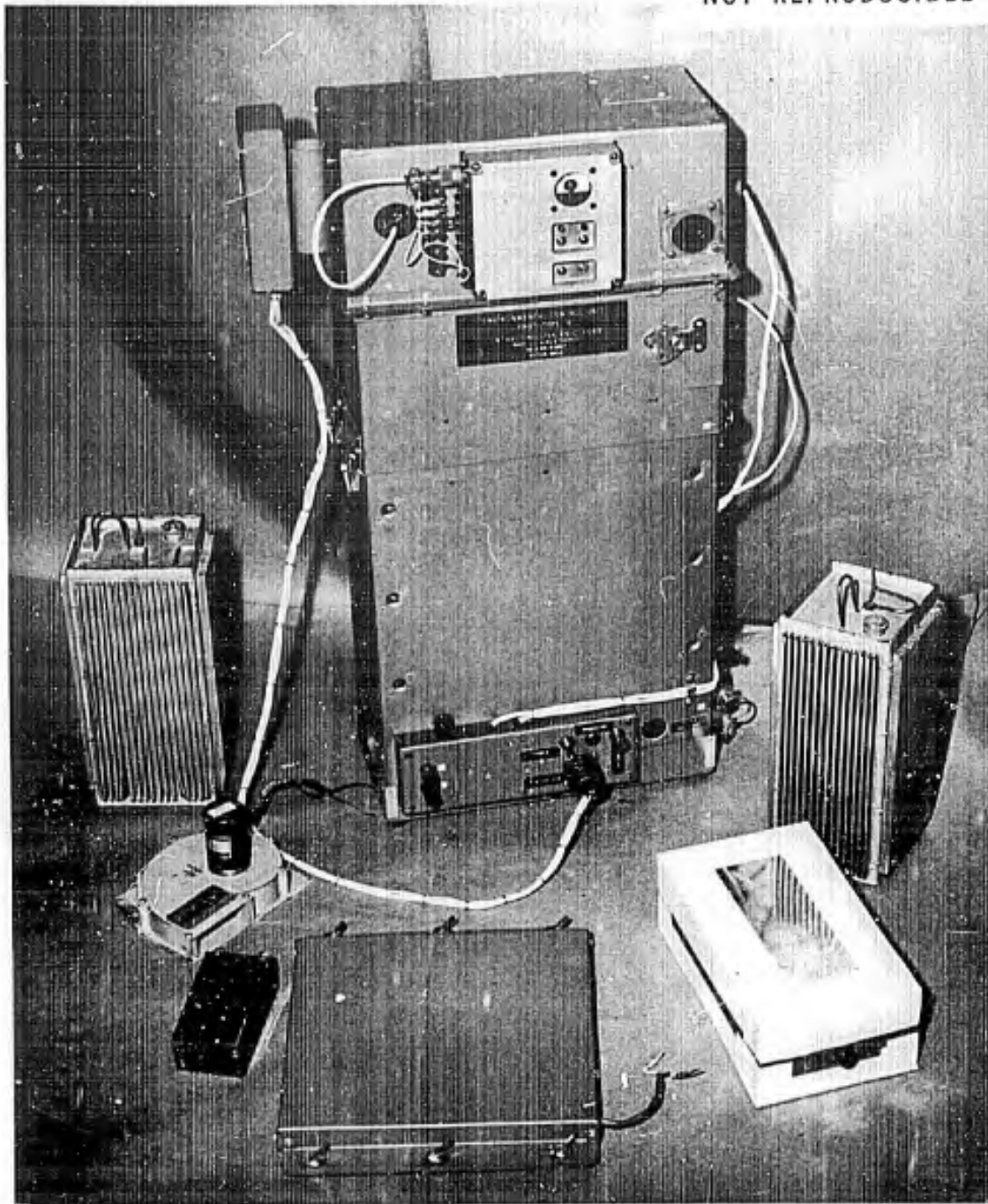


Figure 2. O<sub>2</sub> Sensing Warning Device Mounted on the Environmental Control Unit Backpack of the Damage Control Suit System.

NOT REPRODUCIBLE



Figure 3. Light Package Mounted on Communications Headset.

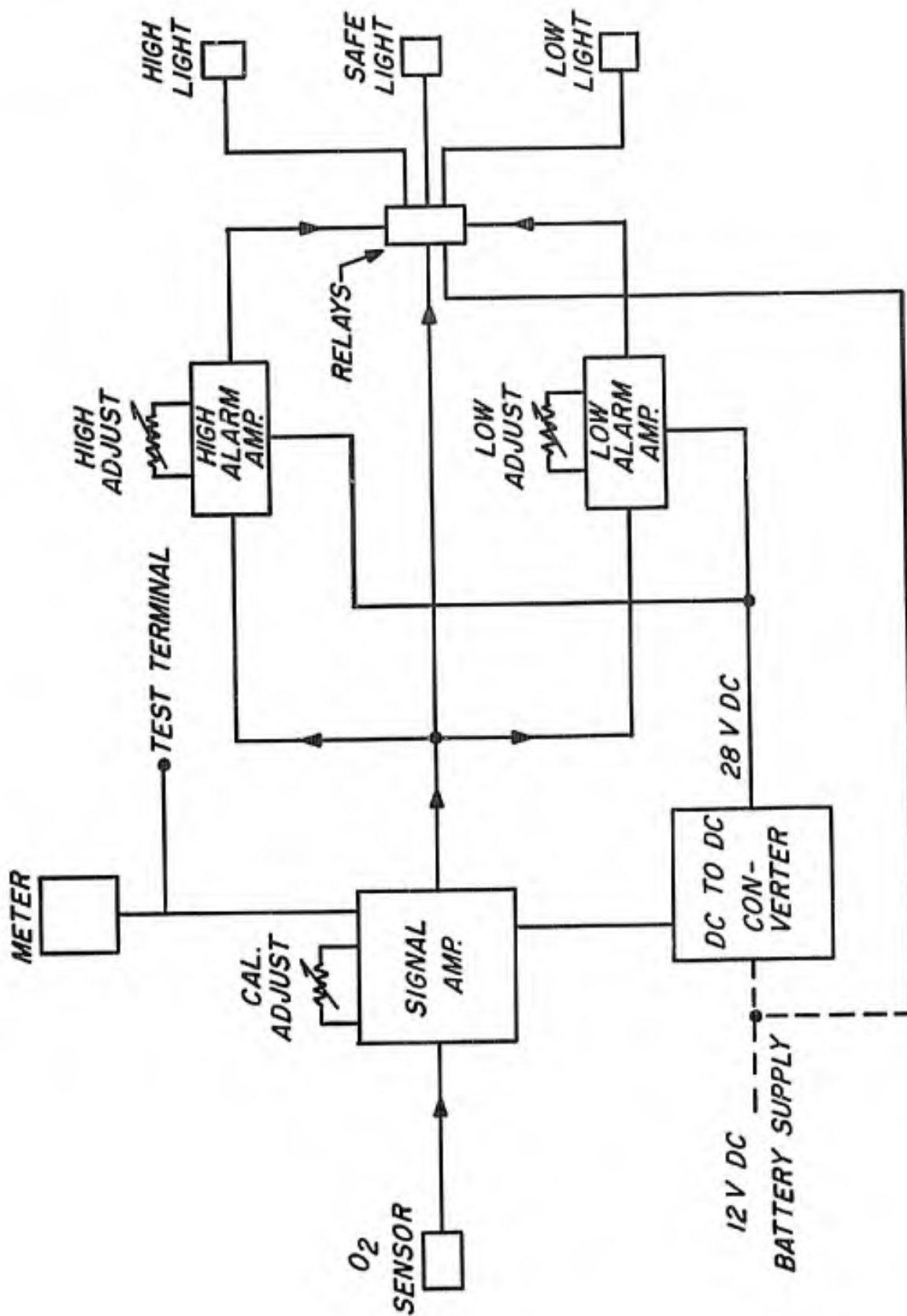
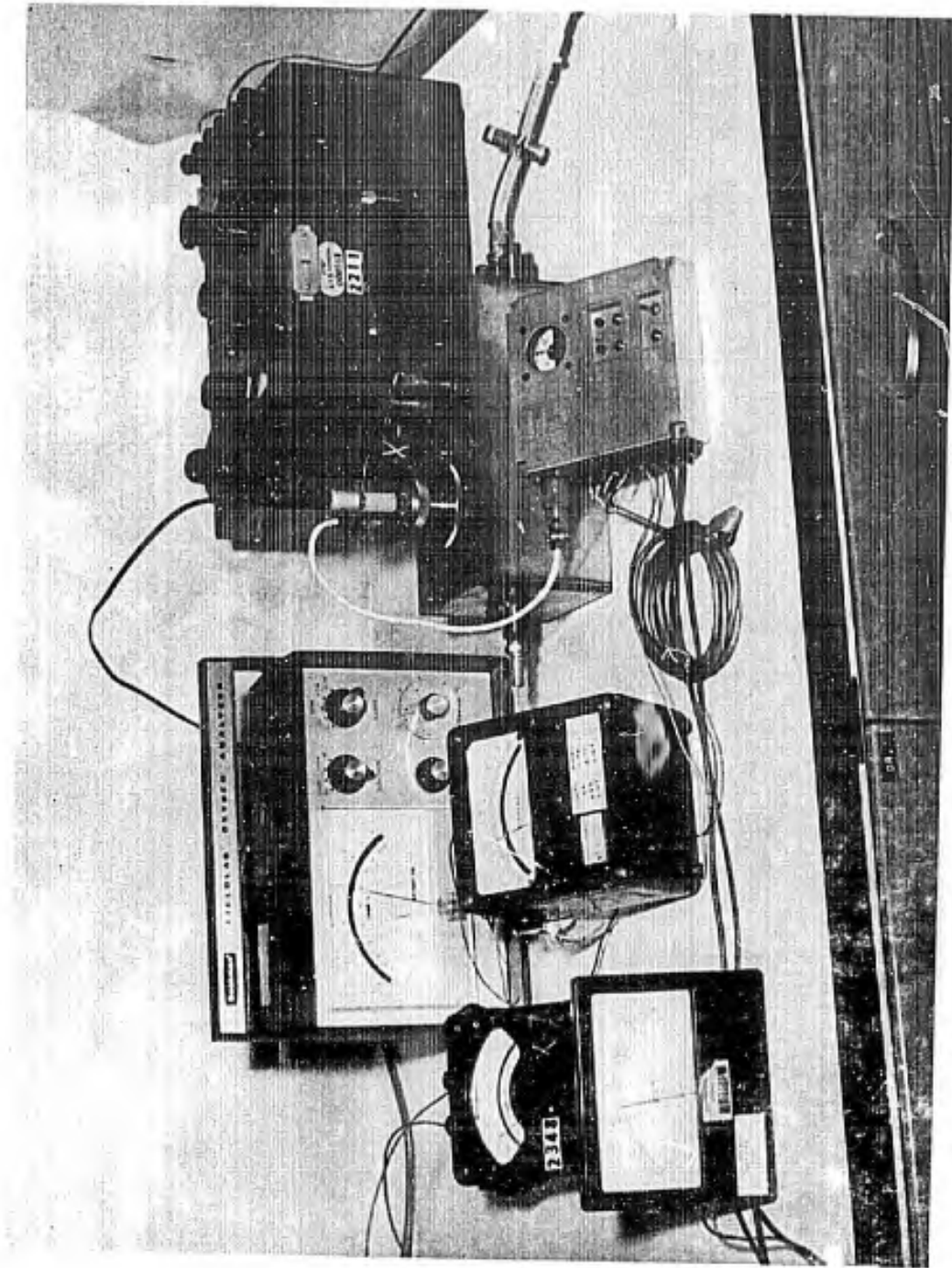


FIGURE 4. OXYGEN - SENSING WARNING DEVICE



Figure 5. Polarographic Oxygen Sensor.

NOT REPRODUCIBLE



NOT REPRODUCIBLE

Figure 6. Equipment Used to Evaluate Performance of O<sub>2</sub> Warning Devices.

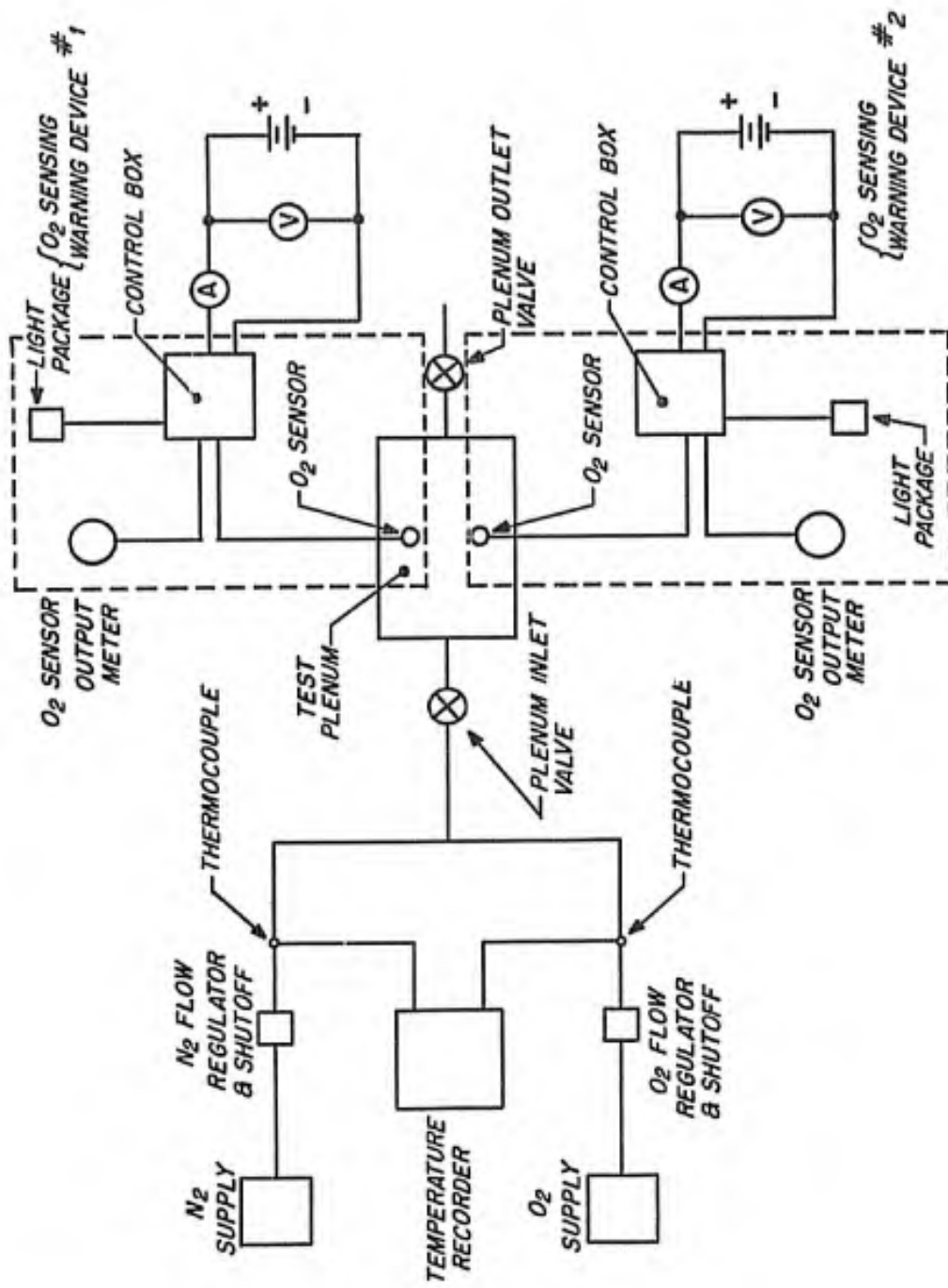


FIGURE 7. SETUP FOR RESPONSE TESTS OF O<sub>2</sub> SENSING WARNING DEVICES

NOT REPRODUCIBLE



Figure 8. View of Webber Environmental Cabinet Used for Non-Ambient Temperature and R.H. Tests.

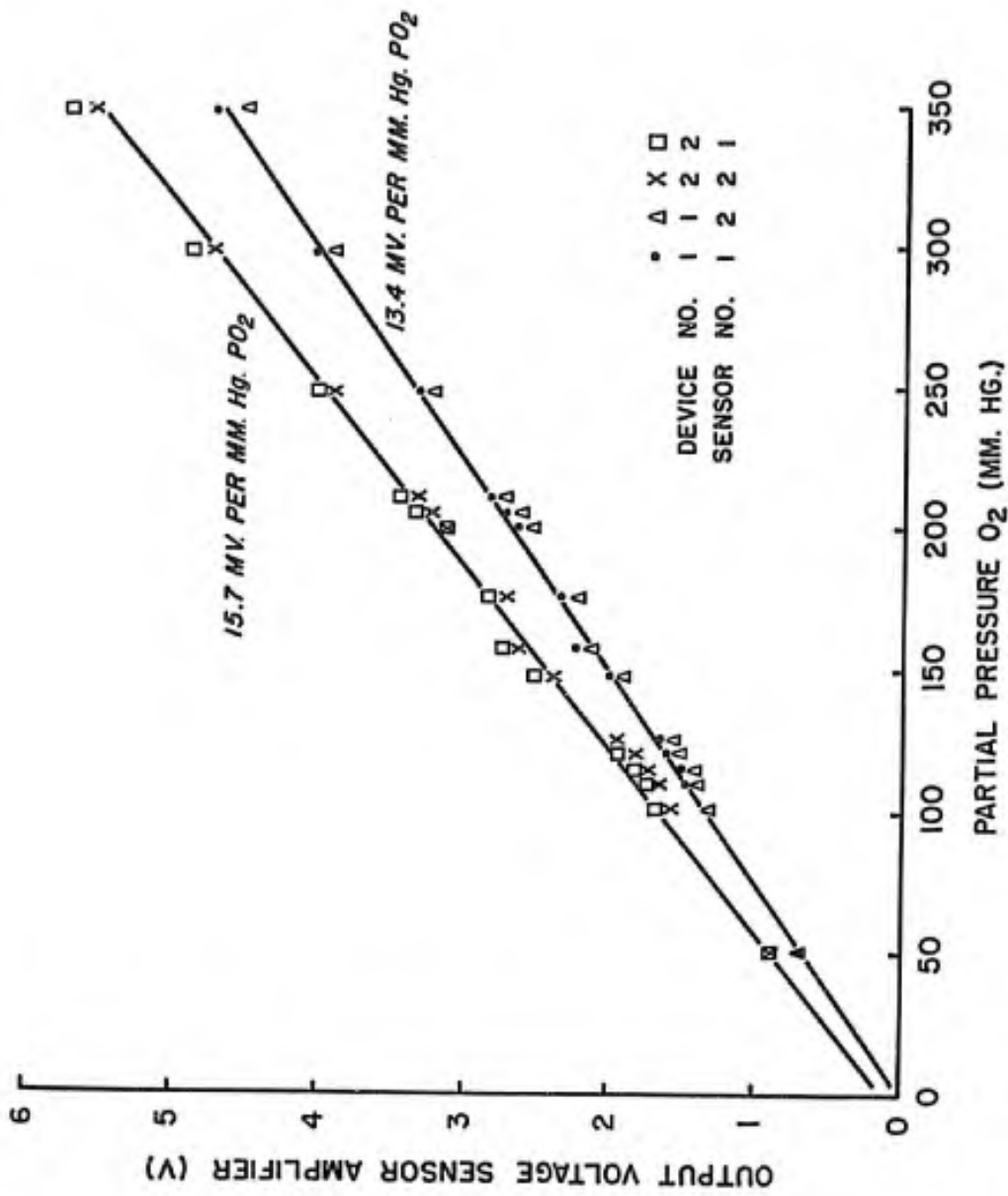


FIGURE 9. DEVICE STATIC RESPONSE TO DIFFERENT O<sub>2</sub> CONCENTRATIONS

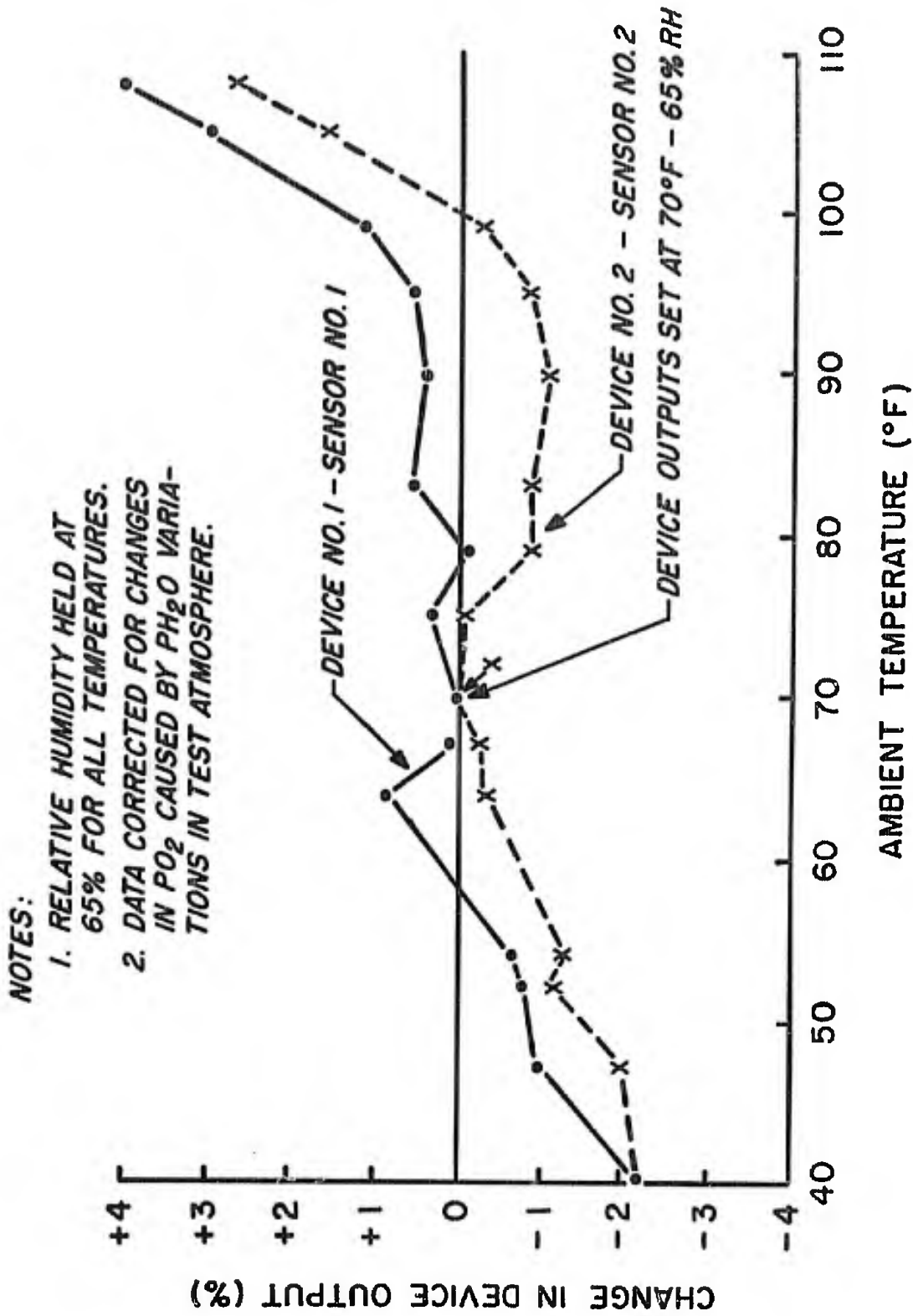
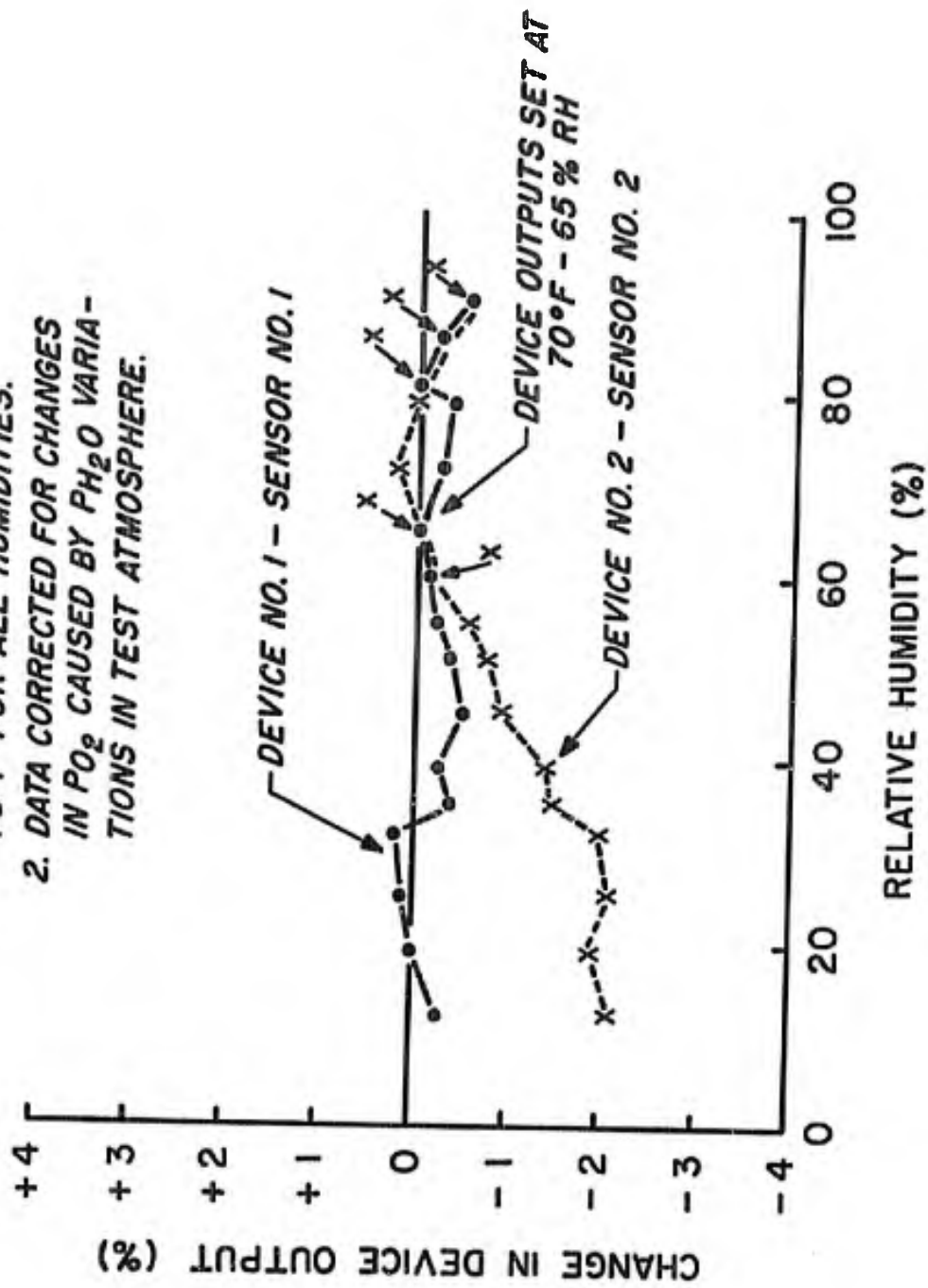


FIGURE 10. EFFECT OF TEMPERATURE ON DEVICE OUTPUTS

**NOTES:**

1. TEMPERATURE HELD AT 70°F FOR ALL HUMIDITIES.
2. DATA CORRECTED FOR CHANGES IN PO<sub>2</sub> CAUSED BY PH<sub>2</sub>O VARIATIONS IN TEST ATMOSPHERE.



**FIGURE II. EFFECT OF RELATIVE HUMIDITY ON DEVICE OUTPUTS**

APPENDIX C.

REFERENCES

1. Hilborn, Edwin H., Handbook of Engineering Psychology, Cambridge, MA 1965.
2. Operating and Service Instructions for An Oxygen Sensing and Warning System, prepared by Beckman Instruments, Inc., under Contract No. N00298-69-CD418 for U.S. Navy Clothing and Textile Research Unit.
3. Keenan, Joseph H., and Keyes, Frederick G., Thermodynamic Properties of Steam, New York, 1936.