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CRDEC-TR-062

PERFORMANCE EVALUATION OF TWO CLOSED-CIRCUIT BREATHING APPARATUS FOR USE IN CHEMICALLY TOXIC ENVIRONMENTS

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Aberdeen Proving Ground, Maryland 21010-5423

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Two closed-circuit breathing apparatus (BioPak 240, Rexnord Breathing Systems, Inc. and BG-174, National Draeger, Inc.) were evaluated to determine the most suitable system to be used with the self-contained toxicological environmental protection outfit (STEPO) currently under development. Separate tests were conducted to determine differences in the physiological encumbrance and protection levels of the two systems. The physiological evaluation protocol consisted of alternating 15-min periods of rest and exercise (4.0 kph, 0% grade) on a motor driven treadmill for 2 hr. A totally encapsulating butyl rubber suit similar to that being developed for STEPO was worn in these tests. Measurements included heart rate, minute ventilation, suit temperature, oxygen concentration, carbon dioxide concentration, water vapor pressure, and temperature. Test results indicated that neither system had substantial advantages over the other with regard to the physiological burden imposed on the user. Protection evaluations were conducted in a corn oil aerosol test chamber. (Continued on reverse)

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The BioPak 240 (a positive pressure system) provided significantly higher levels of protection than the BG-174. Based on this result, the BioPak 240 is recommended as the most suitable candidate for use in STEPO.

PREFACE

The work described in this report was authorized under Project No. 1S463747D669. This work was started in January 1988 and completed in February 1988.

The use of trade names or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

This report has been approved for release to the public.

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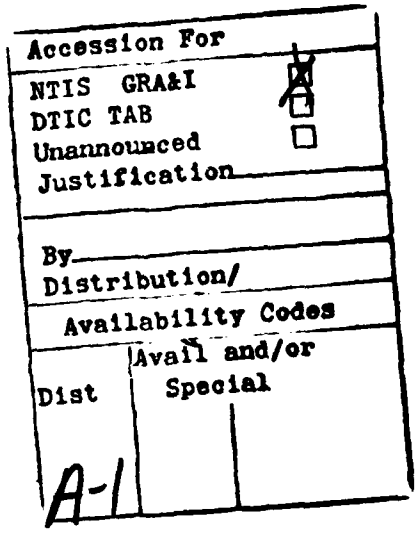

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PERFORMANCE EVALUATION OF TWO CLOSED-CIRCUIT BREATHING APPARATUS FOR USE IN CHEMICALLY TOXIC ENVIRONMENTS

1. INTRODUCTION

The U.S. Army is currently developing the Self-Contained Toxicological Environmental Protective Outfit (STEPO) to provide a higher level of protection for personnel responsible for the storage and maintenance of toxic chemicals. In one concept of STEPO, breathing gas is supplied by a 4-hr closed-circuit breathing apparatus (CCBA) worn under a totally encapsulating butyl rubber protective garment. The purpose of this study was to evaluate the performance of 4-hr CCBAs to determine the best candidate for this application. The CCBAs chosen for evaluation were required to be readily available commercially at the time of the study and certified by the National Institute for Occupational Safety and Health (NIOSH) for 4-hr use in atmospheres immediately dangerous to life or health. A market survey identified only two CCBAs that met these requirements, the BioPak 240P (Rexnord Breathing Systems, Incorporated) and the BG-174A/4 (National Draeger, Incorporated). The performances of these systems were compared in a 2-hr work/rest scenario. The protection level provided by the systems was determined in a separate test.

2. METHODS

2.1 Physiological Evaluation.

2.1.1 Subjects.

Ten male volunteers between the ages of 18 and 40 years participated in this study. The subjects were recruited from civilian and military personnel employed by the U.S. Army Chemical Research, Development and Engineering Center. All volunteers underwent a thorough physical examination before entrance into the study. Physical characteristics of the subjects are shown in Table 1.

2.1.2 Rebreathers.

Both of the CCBAs chosen provide breathing gas to the user from a compressed oxygen bottle and scrub carbon dioxide (CO_2) from the exhaled gas by chemical absorption. The primary differences between the two systems are:

- The BioPak 240 maintains a pressure above atmospheric in the facemask by means of a spring loaded diaphragm in the breathing chamber; the BG-174 allows the pressure in the facemask to fall below atmospheric during the inhalation phase of respiration.

- The BioPak 240 uses a commercial CO_2 absorbent (LimePak) consisting of CaOH (80%), NaOH/KOH (3%), and H_2O (17%). The BG-174 uses a disposable alkali cartridge (NaOH) for absorption of CO_2.

- The BioPak 240 contains a cooling canister in line with the inhalation hose to cool the inhalation gas and remove water from that gas; the BG-174 has no means of cooling the inhalation gas but does remove water by means of the alkali cartridge.

- The BioPak 240 is approximately 17.7 kg (39 lb); the BG-174 is approximately 15.0 kg (33 lb).

Table 1. Physical Characteristics of Subjects Participating in Physiological Evaluation.

Subject No.	Age (Yr)	Ht (Cm)	Wt (Kg)
1	34	180	75
2	39	185	76
3	19	178	82
4	27	170	64
5	30	178	68
6	28	170	75
7	29	170	75
8	34	183	75
9	27	175	75
10	35	180	82
$\bar{X}\pm SD$	30 ± 6	177 ± 5	74 ± 6

2.1.3 Measurements.

Heart rate was determined from the electrocardiogram (ECG) using an ECG amplifier (Gould, Incorporated, model 13-4615-65 BioTach) that provides an analog voltage signal proportional to heart rate. In addition, the ECG was continuously monitored on a digital storage oscilloscope (Iwatsu, model DS-6411). The electrodes used were standard adhesive-backed electrodes used for stress testing.

Respired O_2 and CO_2 concentrations were measured within the nosecup of the facemask, and H_2O vapor was measured in the inlet hose immediately upstream of its attachment to the mask, using a respiratory mass spectrometer (Perkin-Elmer, model MGA 1100).

A turbine flowmeter (KL Engineering, model K520) was mounted in the outlet hose to measure expired minute ventilation

($\dot{V}_E$). The values obtained were corrected to BTPS (body temperature, ambient pressure, 100% humidified) conditions.

Auditory canal temperature was used as a measure of the subject's body temperature (Tb). A small bead thermistor (Yellow Springs Instruments, model 44033) was mounted in the tip of a soft rubber ear mold (Insta-Mold Prosthetics, Incorporated) and inserted so that the thermistor was in contact with the anterior wall of the acoustic meatus.

Three thermistors (Yellow Springs Instruments, model 405) were inserted through rubber grommets mounted in the suit. These thermistors were located at the rear of the head, in the left side of the suit (approximately at the level of the diaphragm), and in the crotch of the suit. The thermistors were surrounded by a small metal cage that prevented them from touching the subject. The temperatures measured at these three sites were averaged to obtain suit temperature (Ts).

Inlet and outlet gas temperatures (Ti, To) were measured with thermistors (Yellow Springs Instruments, model 44033) placed in the inlet and outlet hoses. The inlet thermistor was located in the center of the inlet hose as close as possible to its attachment at the facemask. The outlet thermistor was located within the flowmeter. Outlet temperature was used in the correction of $\dot{V}_E$ to BTPS conditions.

All of the signals from the above measurements were sampled with an automated data acquisition system (Hewlett-Packard, model 6944 multiprogrammer, model 3852 data acquisition/control unit, model 236 microcomputer) that output the data to a line printer and also stored it on disk for later analysis. The data acquisition system read the data for 1-min periods, with 30-s intervals between the readings. In addition, heart rate (ECG) and the gas concentration signals were continuously recorded on a multichannel pen recorder (Western Graphtec, model 3500).

2.1.4 Experimental Procedure.

In addition to the self-contained rebreather, subjects wore shorts, undershirts, socks, lightweight cotton coveralls, and cooling vests (ILC Dover, Cool Vest, model 8101) that contained a battery-powered recirculating ice bath. The ice vest pump was equipped with an on/off switch that allowed the subject to regulate thermal comfort of the vest. Over this ensemble, the subject wore totally encapsulating butyl rubber overgarment, boots, and gloves. Since the STEPO overgarment was not available at the time of this study, a prototype overgarment, similar to that being developed for STEPO was used. Additional cooling was provided from an ice pouch in the overgarment that contained a copper coil connected, via plastic tubing, in series with the ice vest recirculating system.

Total weight of the ensemble, including the rebreather, was 35.7 kg for the BioPak 240 and 33.0 kg for the BG-174.

The experimental protocol consisted of alternating 15-min periods of rest and exercise (4.0 kph, 0% grade) on a motor-driven treadmill (Quinton Instruments Company, model Q65). The workload chosen has been shown to produce a metabolic rate approximately the same as that measured in chemical munitions workers performing their routine tasks.* The total protocol was 2-hr long with 4 periods of rest and 4 periods of exercise. The studies were conducted in an environmental chamber maintained at 20 °C, 40% relative humidity.

2.1.5 Data Analysis.

The data acquisition system read the data for 1-min periods with 30-s intervals between readings. The readings were then averaged over the 15-min rest or exercise period to yield a single value for each period. Readings taken during and/or within 2 min following a transition in workload were discarded. Data were analyzed using the two-factor analysis of variance. The Newman-Keuls test was used to identify significant differences ($P<.05$) between individual means. All results are reported as means ± one standard deviation. In addition, a repeated measures multivariate analysis was conducted on the exercise data to determine interaction effects of the rebreathers with time. The results of that analysis can be found in the appendix.

2.2 Protection Evaluation.

2.2.1 Subjects.

The test subjects were 1 female and 9 male volunteers between the ages of 26 and 39 who were civilian or military employees of CRDEC. Seven of these were from the same test population used in the physiological evaluation. An attempt was made to obtain as wide a range of facial sizes as possible. Facial anthropometric measurements, face length and width, were taken for each subject and are shown in Table 2.

2.2.2 Test Set-Up.

Protection Factor (PF) testing was conducted in a 10-ft by 10-ft by 32-ft test chamber. Protection Factor is defined as the ratio of the challenge concentration to the concentration within the mask. The challenge atmosphere consisted of a polydispersed corn oil aerosol having a mass mean aerodynamic diameter of 0.5-0.6 µm. A uniform challenge concentration of approximately 25 mg/m^3 was generated by the atomization of

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*Levine, L., Military Ergonomics Division, U.S. Army Research Institute of Environmental Medicine, personal communication.

liquid corn oil at room temperature using an array of six Laskin-nozzle aerosol generators. The aerosol concentration inside the chamber was controlled through dilution with room air by a 300-cfm filter/blower system.

Table 2. Facial Anthropometric Data of Subjects Participating in Protection Evaluation.

Subject	Facial Dimensions (mm) Length	Width
1	115	139
2	116	137
3	119	132
4	117	139
5	115	141
6	117	134
7	112	125
8	117	135
9	116	137
10	114	144

The leakage of aerosol inside the respirator facepiece was measured by continuously sampling at a rate of 1.0 $L \cdot min^{-1}$. Sampling was accomplished through a 5-ft length of flexible silicone tubing connecting a sample port, affixed to the nosecup of the respirator facpiece, to an automated photometer system.[1] A five-decade forward-light scattering photometer was used to quantify the amount of light scattered by the aerosol particles in the sample stream. The voltage signal from the photometer is digitized and processed by a microcomputer system. All protection factor data are calculated by the computer and recorded on flexible discs for subsequent analysis.

2.2.3 Test Procedure.

All test subjects used in this part of the study were experienced respirator wearers and received instruction on the operation and use of each CCBA prior to testing. Both CCBAs come equipped with a single size (medium) facepiece. Before entering the test chamber, subjects were instructed to self-don

[1]Brletich, R.W., Allyson, C.R., and Hughes, F.P., Development of an Automated System for Respirator Quantitative Fit Testing, CRDEC-TR-88100, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, May 1988, UNCLASSIFIED Report.

the facepiece, making it as snug as possible by properly adjusting the tension of the head harness straps. Once inside the chamber, the subject connected the facepiece sample line to the sample port located on the chamber wall and performed the following series of exercises:

- Normal breathing, keeping the head motionless
- Deep breathing, keeping the head motionless
- Slow head movement, side to side
- Slow head movement, up and down
- Talking, reciting the "Rainbow" passage
- Walking up and down step platform
- On hands and knees, looking up left and right
- Bending, reaching for floor and ceiling
- Facial expressions; yawning, smiling, frowning, and rotating chin
- Normal breathing (repeat of exercise 1)

Each of the above exercises were performed for 1 min. The exercise protocol was adopted from a standard routine developed to assess the protective performance of military mask systems, and was designed to provide a variety of field-simulated activities to stress the face seal of the respirator.

At the conclusion of a test, the computer calculated an average protection factor representing the ratio of the chamber concentration, measured at the beginning of the test, to the average aerosol concentration detected over the entire 10-min exercise period. Each of the subjects were tested five times in both the BioPak 240 and the BG-174 for a total of fifty test trials for each CCBA.

2.2.4 Data Analysis.

Protection factor data were analyzed using a test for binomial confidence intervals on proportions.

3. RESULTS

3.1 Physiological Evaluation.

The concentrations of O_2 and CO_2 measured at the mouth during inhalation are shown in Figure 1. Inlet O_2 concentration was significantly higher with the BioPak 240 during every period. Both systems reached plateau levels within 45 min of

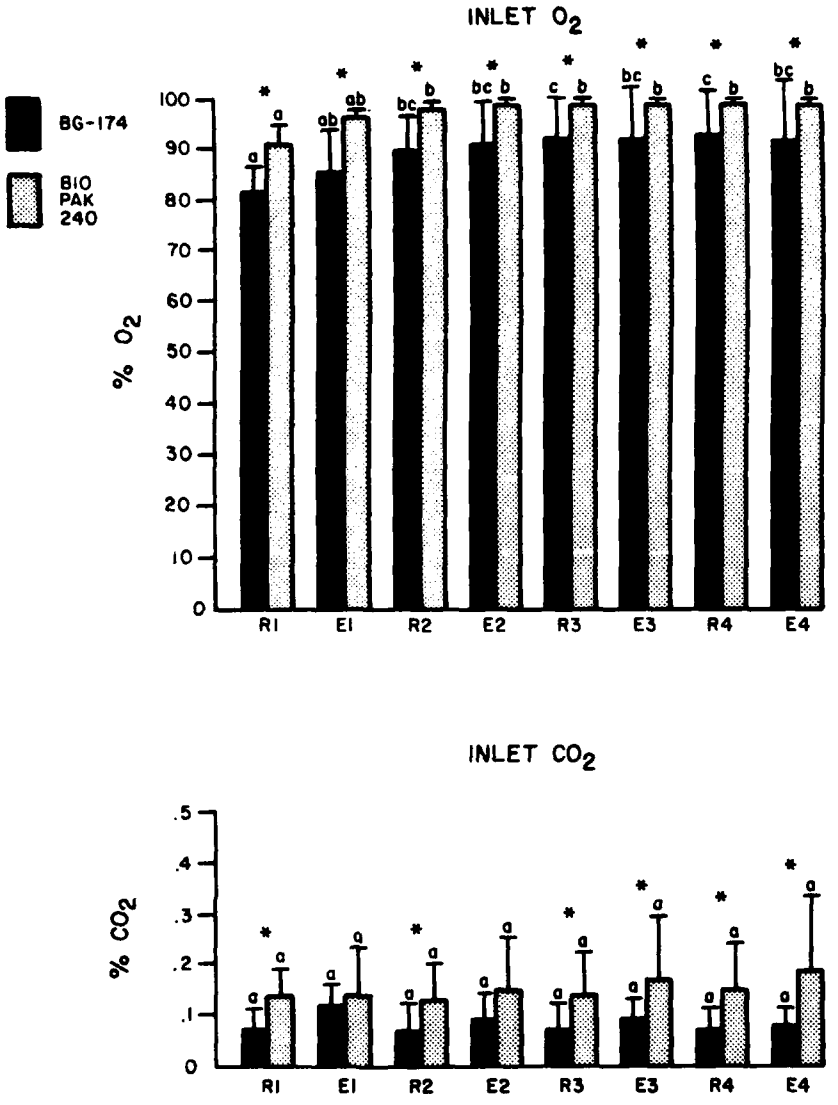


Figure 1. Inhaled Gas Concentrations. Bars represent the average O_2 or CO_2 concentration over each 15-min period ± 1 standard deviation. Periods are shown on the abscissa (Rn = Rest period, En = Exercise period). Significant differences ($P<.05$) between CCBAs within a period are denoted with an asterisk (*). Lower case letters indicate differences between periods. Within the same CCBA, periods with common letters are not significantly different ($P>.05$).

the beginning of the test. Inlet CO_2 was higher with the BioPak 240 during all but the first two exercise periods but averaged below 0.2% with botn systems throughout the test. No differences were found between periods with either system.

The temperature of the gas at the inlet to the mask ranged from 23.7 °C during the first period to 29.6 °C during the last period with the BG-174 and 17.7-23.9 °C, respectively, with the BioPak 240 (Figure 2). The differences between the two systems were significant statistically during each period. No differences were found in water vapor pressure (PiH_2O) between the two systems (Figure 2).

Despite significant differences in Ts during all periods, no differences in Tb were found between the two systems except during the final period when Tb with the BG-174 was significantly higher than that with the BioPak 240 (Figure 3). Tb rose progressively during the first half of the test with both systems but reached a plateau level by the second exercise period and remained at that level for the remainder of the 2-hr scenario.

Heart rate and minute ventilation were used as indicators of the workload the subjects were performing. No differences were found in either of these variables between the two systems (Figure 4).

3.2 Protection Evaluation.

Protection factor data for the individual test trials are presented in Table 3. These results are summarized in Table 4 where pass percentages are given for a wide range of protection factor levels. The 1667 and 6667 protection factor levels shown are standard pass/fail criteria levels established under the U.S. Joint Services Operational Requirements (JSOR) for protection factor testing of military mask systems.

Significant differences ($P<.10$) were obtained between the protection factor results of the two systems as evidenced by the lack of overlapping of the 90% confidence intervals shown in Table 4. Although not presented, significant differences can also be shown at each protection factor level for $P<.05$. The BioPak 240 was able to attain a 100% pass rate at the 6667 JSOR protection factor level, while only 56% of the BG-174 test trials were greater than this value. The superior protection factor performance of the BioPak 240 can be attributed to its positive-pressure design.

4. DISCUSSION

Both systems supplied adequate volumes and acceptable mixtures of breathing gas to the user. The BG-174 appears to be slightly more efficient at scrubbing CO_2 but both systems

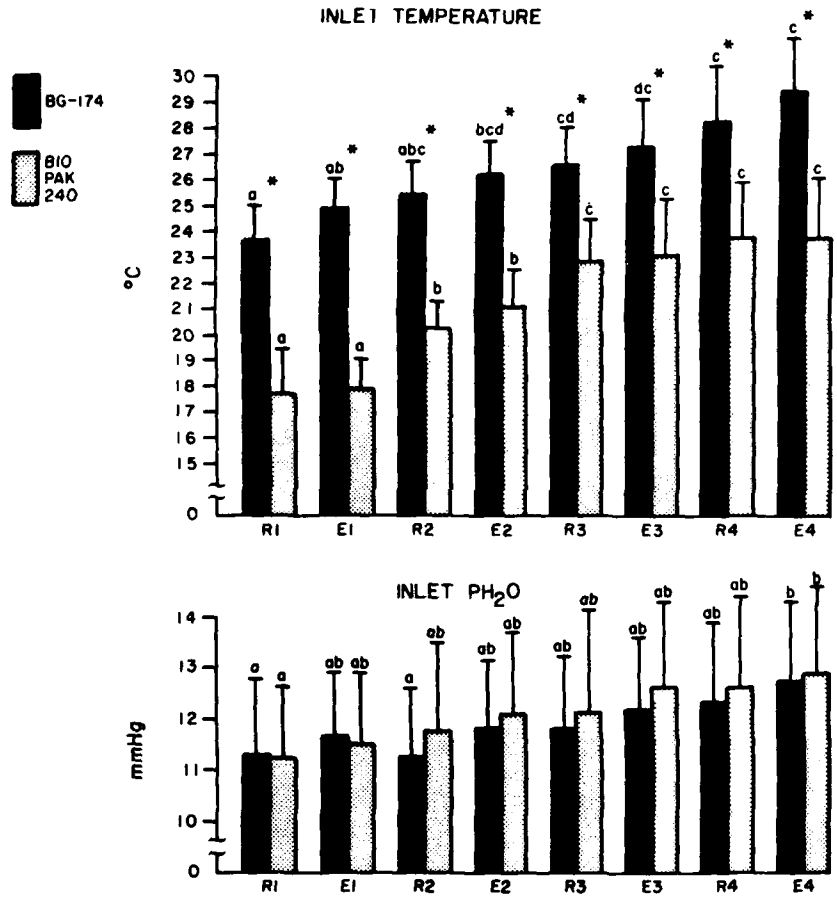
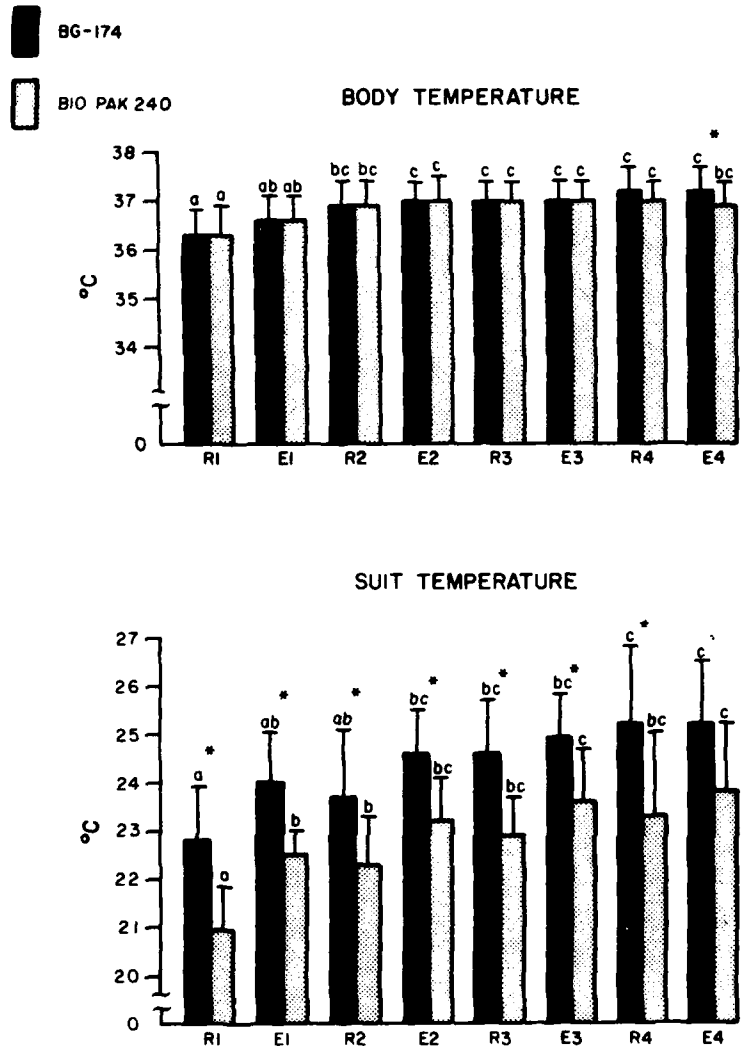
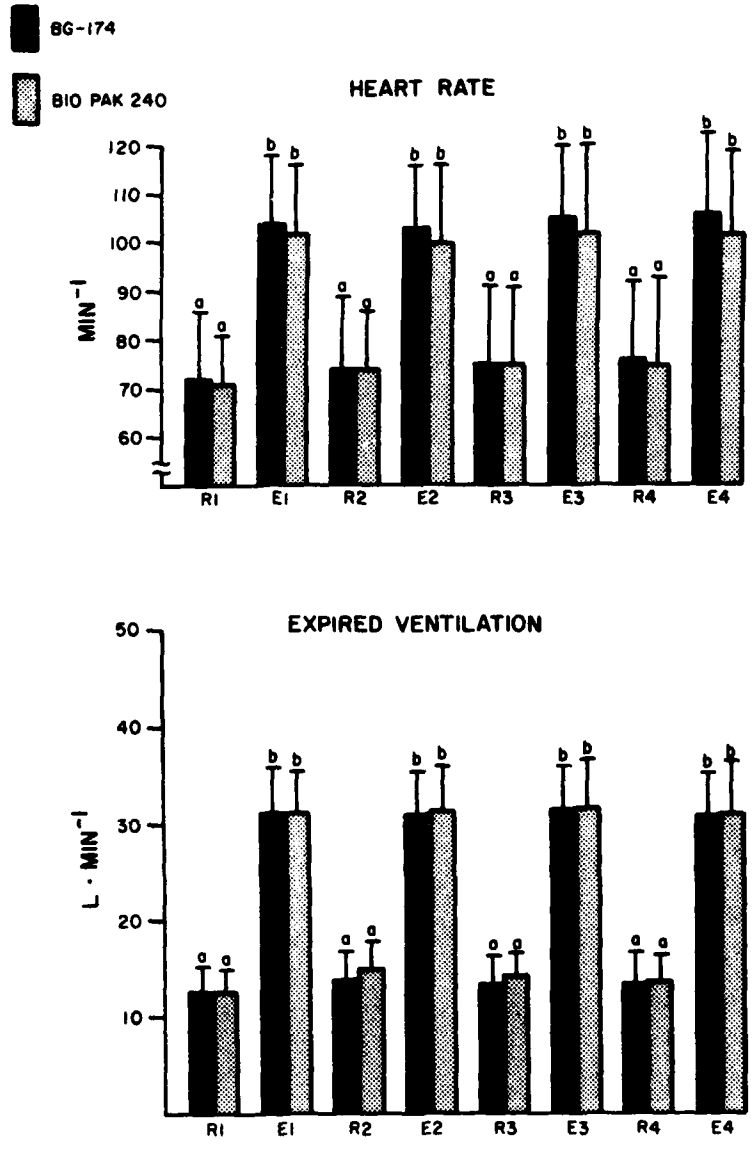


Figure 2. Inlet Gas Conditions. Average temperature and water vapor pressure of gas at the inlet to the mask over each 15-min period. See Figure 1 for definition of symbols.



See Figure 1 for definition of symbols.

Figure 3. Effect of CCBAs on Temperature. Average body temperature and suit temperature over each 15-min period.



See Figure 1 for definition of symbols.

Figure 4. Effect of CCBAs on Physical Response to Exercise. Average heart rate and minute ventilation over each 15-min period.

Table 3. Individual Protection Factors.

Subject	Trial No.	Protection Factors BioPak 240	BG-174
1	1	20000	20000
	2	20000	20000
	3	20000	20000
	4	20000	20000
	5	20000	20000
2	1	20000	6330
	2	20000	20000
	3	20000	20000
	4	20000	20000
	5	20000	20000
3	1	20000	19200
	2	20000	13700
	3	20000	18100
	4	20000	20000
	5	20000	16000
4	1	20000	73
	2	20000	248
	3	8960	64
	4	10700	45
	5	17100	252
5	1	20000	225
	2	20000	135
	3	20000	1670
	4	20000	97
	5	20000	305
6	1	20000	9510
	2	20000	8730
	3	19000	10600
	4	12600	2320
	5	18300	19700
7	1	20000	54
	2	20000	1160
	3	20000	604
	4	20000	4100
	5	20000	2080

Table 3. Individual Protection Factors (continued).

Subject	Trial No.	Protection Factors BioPak 240	BG-174
8	1	20000	19600
	2	20000	20000
	3	20000	20000
	4	17100	20000
	5	20000	20000
9	1	20000	30
	2	20000	41
	3	20000	20000
	4	20000	294
	5	20000	20000
10	1	20000	59
	2	20000	5170
	3	20000	20000
	4	20000	20000
	5	20000	20000

Table 4. Summary of Protection Factor Results.

Protection Factor	Percent Achieved (90% Confidence Limits) BioPak 240	BG-174
500	100% (95.5-100)	72% (62.3-80.3)
1667	100% (95.5-100)	68% (58.2-76.7)
3000	100% (95.5-100)	62% (52.0-71.2)
5000	100% (95.5-100)	60% (50.0-69.4)
6667	100% (95.5-100)	56% (46.0-65.6)
10000	98% (92.5-99.8)	52% (42.1-61.8)
20000	86% (77.6-92.0)	40% (30.6-50.0)

delivered breathing gas with concentration of CO_2 well below unacceptable limits.[2]

The purpose of this study was to determine the differences in physiological burden imposed on the user by these systems. Therefore, no measurements were made with unsuited subjects. However, it can be assumed that the weight of the rebreathers and the restrictions of body movement imposed by the butyl suit constituted an increase in the workload over that which would be observed in a normally clothed condition. Using heart rate and minute ventilation as indices, it does not appear that either system imposed a greater burden than the other.

The chemical reactions used by these systems to absorb exhaled CO_2 and H_2O are exothermic. It was anticipated that the continuous heat production from these reactions would impose an unacceptable thermal burden on the subjects due to entrapment of heat by the butyl rubber suit. It is likely that the ice vest was primarily responsible for the ability of the subjects to maintain body temperature within the normal range throughout the 2-hr scenario. The thermal load of the two systems, while it was well tolerated by the subjects, appeared to be greater with the BG-174 as indicated by higher Ti and Ts with that system. The cooling canister provided with the BioPak 240 likely contributed to this difference, especially with regard to Ti.

One disadvantage inherent to all self-contained positive-pressure breathing systems is the potential for decreased service life due to an improper face seal. Although absolute seal of the mask to the face is not critical from a protection standpoint, misfitting of the facepiece can cause accelerated depletion of the breathing air supply. The rate of depletion will of course depend on the degree of misfit. In the BioPak 240, an improper face seal can cause the breathing air to escape from the facepeice at a rate which will not permit the unit's breathing chamber to adequately fill. When this occurs, the bypass line is activated during inhalation flooding the chamber with pure oxygen in an attempt to satisfy the user's demand for air. This condition occurred twice during physiological testing of the BioPak 240. During these occurrences, testing had to be prematurely terminated when the unit's low-oxygen-supply alarm sounded.

Both systems come equipped with a single size (medium) facepiece; additional sizes are not available. However, both systems could benefit by offering additional facepiece sizes to better accommodate a larger proportion of the user population. This would help to alleviate the potential for reduced service

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[2]American Conference of Governmental Industrial Hygienists, "Carbon Dioxide," In Documentation of the Threshold Limit Values, Fourth Edition, pp 69-70, 1980.

time, caused by outward leakage, which was observed with the BioPak 240. In addition, the protection factor performance of the BG-174 might have been improved if other facepiece sizes were available.

During the course of the physiological evaluation, some difficulty was experienced with connecting the oxygen cylinder to the regulator assembly of the BioPak 240. On two occasions, leaks developed at the washer-seal interface of this high-pressure fitting. These leaks were audible and occurred when the unit was jarred during donning. It was found that particular attention must be given to ensure that the oxygen cylinder is securely seated in the regulator fixture before placing the cover over the unit.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the physiological evaluation, either of these systems could be used for the intended purpose if additional cooling such as the ice vest is provided. It should be emphasized that this conclusion is based on the test conditions used in this study. Differences in performance may have been noticed if the evaluation was conducted using higher workloads, longer test periods, and higher ambient temperatures.

The most important difference between the two systems is the level of protection which they provide the user. Other investigators have found that positive pressure systems, such as the BioPak 240, provide greater protection than negative-pressure systems because any leakage is outward.[3] Our results agree with this finding. Therefore, based on the superior protection demonstrated by the BioPak 240, we recommend that this unit be chosen as the most appropriate system for the interim STEPO. However, it is important to note that this selection is based solely on the data collected in this evaluation. Other important considerations, such as reliability and maintainability, were not addressed and should be evaluated in future user testing. The concerns over proper facepiece fit and connection of the oxygen cylinder to ensure maximum service life, we believe, can be satisfactorily resolved through proper training and experience with the apparatus.

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[3]Bollinger, N.J., and Schutz, R.H., NIOSH Guide to Industrial Respiratory Protection, Publication No. 87-116, U.S. Department of Health and Human Services (National Institute for Occupational Safety and Health), September 1987.

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APPENDIX

MULTIVARIATE STATISTICAL ANALYSIS

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SUMMARY OF THE SELF CONTAINED TOXIC ENVIRONMENT PROTECTIVE OUTFIT COMPARISON

1. INTRODUCTION

Ten subjects were tested in two rebreather systems. The main objective was to determine if these systems performed differently for any of these five responses:

- Minute ventilation
- Heart Rate
- Inlet CO_2
- Suit temperature
- Inlet temperature

Five subjects were randomly selected to be tested in rebreather A (BG-174) first, and the remaining five subjects were tested in rebreather B (BioPak 240) first. While in the rebreather, a subject would alternate resting and exercising every 15 min four times during a 2-hr period. During that 2-hr, measurements were made periodically on the subjects on each of the five responses. At the conclusion of the test, measurements made on a subject during each exercise interval were averaged so that there was one data point for each time/rebreather/subject combination. The time intervals are: T1 = 15-30 min, T2 = 45-60 min, T3 = 75-90 min, and T4 = 105-120 min.

2. ANALYSIS

This design was analyzed using a repeated measures multivariate analysis (sometimes called doubly multivariate) with Time and Rebreather as two fixed factors. The natural logarithmic transformation was applied to the data to stabilize the variances. The Time effect and the interaction effect of Time and Rebreather could not be analyzed multivariately since there were too few subjects. Therefore, ten smaller multivariate cases were analyzed. Each case was a different combination of three of the five response variables.

2.1 Interaction Effect.

First, the interaction effect of Rebreather and Time was examined and several combination cases were significant. To determine which variables contributed to this significance, univariate analysis was performed. To analyze the data univariately, compound symmetry must exist to use the usual F tests. Unfortunately, compound symmetry did not exist for any response variable, so the Greenhouse-Geisser approximation was

implemented. This test alters the degree of freedom for the critical F level. This test is considered to be conservative in that one may fail to reject a hypothesis that should have been rejected. However, this did not pose a problem, since those factors that are significant using the usual critical levels of F, are also significant using the Greenhouse-Geisser F test. The response variables contributing to the interaction effect are Inlet CO_2 and Inlet Temperature.

For the response variable, Inlet CO_2, as Time increases the percent of Inlet CO_2 decreases on Rebreather A. However, on Rebreather B as Time increases the percent of the Inlet CO_2 is increasing slightly. But, the slope of the regression line from the data is not significantly different from zero. This is due to the variability in the data. Table 1 below shows the 95% confidence intervals for each mean in Rebreather B. Notice they overlap, indicating they are not significantly different from each other; therefore, since Time behaves differently in each Rebreather System, an interaction effect is present.

Table 1. Percent Inlet CO_2 for Rebreather B.

Time	Mean	95% C.I.
T1	.226	(.184, .277)
T2	.235	(.189, .290)
T3	.248	(.195, .316)
T4	.260	(.202, .334)

The other response variable that had a significant Rebreather x Time interaction effect was Inlet Temperature. Although the temperature increases with Time in both systems, there is an interaction effect because the increase in temperature is linear in Rebreather A but quadratic in Rebreather B.

2.2 Main Effects.

For those response combination cases that did not have a significant multivariate interaction, the individual factor effects were tested.

2.2.1 Time.

Suit Temperature was the only response variable with a significant Time effect. Combining the Time data for both

rebreathers and performing Tukey's (HSD) Multiple Comparison Test, it was determined that the first time interval, T1, is significantly lower in temperature than T3 and T4. However, T2, T3, and T4 are not significantly different. The mean time interval value transformed back into the original units are listed in Table 2.

Table 2. Mean Time Interval Values for Suit Temperature.

Interval	Mean
T1	23.17
T2	23.86
T3	24.22
T4	24.48

2.2.2 Rebreather.

Both Suit Temperature and Inlet Temperature have a significant Rebreather Effect. Rebreather A has higher mean temperature than Rebreather B for all time periods for both responses. The mean Suit Temperature for Rebreather A transformed back into the original unit is 24.66 °C, and the mean Suit Temperature for Rebreather B is 23.23 °C. The mean Inlet Temperatures for Rebreathers A and B are 26.96 °C and 21.35 °C, respectively.

The only effect that could be tested with all five response variables simultaneously was Rebreather effect, and it is significant to even the .001 level using Pillais, Hotellings, or Wilks tests. This is consistent with the results based on the ten separate cases of analyzing three response variables at a time.

2.3 Nonsignificant Response Variables.

The response variable Minute Ventilation and Heart Rate were not affected by the Rebreather system, Time nor the interaction of the two. The overall mean Minute Ventilation is 30.81 (L/min) for Rebreather A and 30.88 (L/min) for Rebreather B. Table 3 below shows how close the mean ventilations are for each time interval under each system.

Table 3. Minute Ventilation.

Rebreather	Time	Mean	95% C.I.
A	T1	30.84	(27.74, 34.30)
	T2	30.72	(27.72, 34.06)
	T3	31.19	(28.19, 34.54)
	T4	30.51	(27.49, 33.85)
B	T1	30.84	(28.05, 33.92)
	T2	31.00	(28.02, 34.30)
	T3	31.25	(28.08, 34.78)
	T4	30.45	(26.95, 34.43)

The mean Heart Rates for Rebreather systems A and B are 103.57 and 100.41, respectively. It is not so obvious here that there is no Rebreather effect; however, Table 4 shows that the confidence intervals are overlapping, so the means are not significantly different.

Table 4. Heart Rate.

Rebreather	Time	Mean	95% C.I.
A	T1	102.82	(93.04, 113.64)
	T2	102.31	(93.69, 111.72)
	T3	103.96	(93.04, 115.12)
	T4	105.21	(93.04, 118.16)
B	T1	100.89	(92.76, 109.62)
	T2	99.09	(88.76, 110.72)
	T3	100.89	(89.12, 114.32)
	T4	100.79	(89.93, 112.96)

Another way to look at the Heart Rate data is to combine the data from each rebreather as shown below in Table 5.

Table 5. Mean Heart Rate Per Time Interval.

Interval	Mean
T1	101.85
T2	100.68
T3	102.41
T4	102.98

3. SUMMARY

In summary, Minute Ventilation and Heart Rate are not affected by Rebreather type nor Time; Inlet CO_2 and Inlet Temperature are affected by the interaction of Rebreather and Time; and Suit Temperature is affected by Time and Rebreather independently.