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The Physiological Cost Of Wearing The Propellant Handler's Ensemble At The Kennedy Space Center

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The Physiological Cost Of Wearing The Propellant Handler's Ensemble At The Kennedy Space Center

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GLOSSARY

ANOVA: Analysis of Variance, a statistical procedure for data analysis.

BRUCE TM PROTOCOL: A standard series of speed and % grade increments broken into stages. Each stage lasts for 3 min.

Stage I:	1.7 mph, 10%
II:	2.5 mph, 12%
III:	3.4 mph, 14%
IV:	4.2 mph, 16%
V:	5.0 mph, 18%
VI:	5.5 mph, 20%
VII:	6.0 mph, 22%

DELTA O_2: The difference between baseline O_2 concentration taken at minute 38 and the O_2 concentration at any other minute during the protocol; measured as the absolute change in % O_2. NOTE: Initial concentrations of O_2 vary daily as the liquid air supply was mixed weekly from cryogenic sources of N_2 and O_2.

ECU: Environmental Control Unit, worn as part of the PHE-BP. ECU weight = 17.7 kg (39 lbs.) when full with liquid air.

GRADIENT FOR HEAT EXCHANGE: The difference in rectal (Trec) and skin temperatures (Tsk) which allows heat to be taken from the body's core to the body's surface where it can be dissipated through sweating and evaporation.

HR RESERVE: This method was utilized by Karvonen et al (13) to estimate VO_2 from HR data. The HR reserve is the difference between HRmax and HR rest, i.e., HR Reserve = HRmax - HRrest. For purpose of this study, HRrest was defined as the HR at minute 38.

HYPERCAPNIA: Excessive CO_2 content, defined as $\geq$ 3.0%, the ACGIH standard.

HYPERTHERMIA: heat stress defined as a rectal temperature > 99.1°F.

HYPOXIA: Low O_2 concentration, defined as $\leq$ 18% O_2 according to American Conference of Government Industrial Hygienists (ACGIH) guidelines.

PHE: Propellant Handler's Ensemble--a whole body protective suit replacing the SCAPE.

SCAPE: Self-Contained Atmospheric Protective Ensemble--a whole body protective suit.

TM: Treadmill--a motorized walking device.

VE: minute ventilation, the total volume of air breathed per minute.

VO_2: Oxygen uptake (aka work capacity) measured as an absolute term (LO_2/min) or as a relative term (ml O_2/kg/min) which takes body weight (kg) into account. Maximum oxygen uptake, VO_2max, is a measure of an individual's aerobic fitness level. VO_{2sm} = sub-maximal VO_2, usually measured as a percentage of one's maximum capacity (i.e., 80% VO_2max).

Watts, W: A measure of physical work. Watts can be converted to VO_2 (L/min) to determine the metabolic work. Estimated from Pandolf et al (14).

Work Period 1 (WP1):	40-43 min	1.7mph, 10%	Bruce stage I
Work Period 2 (WP2):	63-66 min	1.7mph, 10%	Bruce stage I
Work Period 3 (WP3):	66-69 min	2.5mph, 12%	Bruce stage II

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INTRODUCTION

The Kennedy Space Center (KSC) is the focal point for preflight preparation and launch of numerous spacecraft. Propulsion systems on these spacecraft rely on a variety of propellants -- nitrogen tetroxide, hydrazine, monomethyl hydrazine -- all of which are toxic to the human skin and respiratory systems. The potential for exposure to such toxins during spacecraft flight preparations and propellant transfer operations dictates the use of a whole body protective suit to provide proper protection. The Self-Contained Atmospheric Protective Ensemble (SCAPE) or the Propellant Handler's Ensemble (PHE) the subject of the present report, which recently replaced the SCAPE, have been utilized at KSC since 1964.

The weight, structure, and operating conditions of the suit may have a significant impact upon the physiological responses of the worker, especially in medium to heavy work situations. The weight and encumbrance of the suit contributes an extra workload above the assigned operational tasks. Thermal loads are imposed, and restrictions to vision, mobility, and dexterity are experienced. The cumulative effects of these factors may impose limitations on the safe performance of assigned job tasks.

The connection between aerobic fitness and work capacity is direct. Highly fit individuals can work at higher work rates or for a longer duration at lesser work rates (15). The previous literature has dealt very little with the physiological demands of occupational performance while dressed in whole body protective suits. However, several studies have examined the influence of heavy weight carrying on work metabolism. The metabolic costs associated with carrying external loads while walking on a treadmill (TM) have been investigated (5,8,10-12,14) and predictive formulas have been developed based upon either the heart rate (HR) response at a given speed and grade (13) or upon the concept of a fixed energy cost per kilogram (kg) of weight at each level of speed and grade (11,14).

The Biomedical Laboratory at KSC examined two configurations of the PHE. The purpose of the present study was to examine the factors affecting the physiology of the user during extremes of temperature and workload which may be experienced during the servicing and deservicing of space vehicles. The specific objectives were: 1) evaluate the performance of the suits in different environmental conditions, 2) assess the physiologic and metabolic demands placed upon the individuals wearing them, and 3) propose appropriate fitness recommendations for individuals performing work while encumbered with the PHE.

METHODS

Subjects: Four nonsmoking male subjects participated in these tests. Their age, baseline anthropometry, maximal heart rate (HR max), and maximum oxygen uptake (VO_2 max) are listed in Table 1. All subjects underwent a complete physical examination, including a medical history review, resting electrocardiogram, blood chemistry, pulmonary function tests, and a Bruce treadmill stress test to volitional fatigue, prior to participation in this study. Subjects were fully informed about the test procedures and any risks associated with them. An informed written consent was obtained from each subject.

Suit Test Protocol: After approval of the test protocol by the Human Research Review Board at KSC, each subject participated in three different environmental test protocols lasting 89 min. in both of the configurations of the PHE; the backpack (PHE-BP) and hoseline (PHE-HL) models. The test protocol, detailed in Table 2, was conducted under three different environmental conditions: COLD (-7°C), laboratory (LAB) (23°C), and HOT (43°C). All experiments were conducted in an environmental chamber measuring 1.5 x 3.1 x 2.1 m with the relative humidity being maintained around 50% for the laboratory and HOT conditions.

Field experience showed that normal operations typically required the worker to walk several hundred meters, sometimes climbing several flights of stairs, perform light repairs or monitoring tasks, and then walk back after a two hour work period. A worst case workload may involve the rescue of a fallen co-worker during a hazardous operation. Thus, the test protocol utilized a work/rest regimen that took place in an environmental chamber. After a 20 minute standing baseline rest period (SSR - 20-40 min), each work period was followed by a 20 minute standing recovery period (43-63 min = REC1, 69-89 min = REC2) as outlined in Table 2. Because the Bruce treadmill protocol serves as the current fitness qualification test for potential PHE users (completion of Stage III qualifies an individual to perform PHE activities) and as our laboratory standard, the work intervals were selected as Stage I and Stages I & II of the Bruce protocol. The work intervals occurred at 40-43 min. (work period 1, WP1) and 63-69 min. (WP2 and WP3, respectively) during each test session.

Prior to entering the environmental chamber each subject was instrumented for a single channel electrocardiogram (ECG) using a Hewlett-Packard telemetry system. The ECG data was recorded on both strip chart and magnetic tape recorders. HR was displayed on a HR counter and was validated against the strip chart information. The data were converted into a percentage of maximal HR (%HRmax): %HRmax = HRsubmax/HRmax x 100%. The oxygen

(O_2) and carbon dioxide (CO_2) concentrations in the helmet region were analyzed with a Beckman Metabolic Measurement Cart throughout the test. Because every backpack fill yielded a slightly different liquid air O_2 concentration, a baseline concentration (minute 38) was selected and all values were recorded as the delta O_2 concentration (i.e., minute 38 O_2 concentration - O_2 concentration at a specific minute). Helmet CO_2 was recorded as the actual concentration. Also, rectal temperature (T_{rec}), four skin temperatures (forehead, upper arm, left chest, and right thigh), and interior suit temperature (helmet and chest regions) were recorded with YSI series 700 thermistors connected to a Digitec Model 2000 Datalogger. Mean skin temperature (T_{sk}) was calculated as the average of the four skin thermistor sites. Body temperature (T_b) was calculated as $T_b = (0.65 \times T_{rec}) + (0.35 \times T_{sk})$ (4) and suit temperature (T_s) was the average of the readings at the helmet and chest sites (thermistors located to avoid contact with the subject and the inner suit surface). Finally, suit pressure was recorded with a National Semiconductor integrated pressure chip connected to a buffer amplifier. The output was recorded on a strip chart and on magnetic tape.

Description of the Propellant Handler's Ensemble: The PHE is a completely enclosed whole body suit made of chlorobutyl coated Nomex material. This is one of very few materials which is relatively impervious to rocket propellants; yet, can be sewed and sealed to provide vapor tight joints that can withstand the rigors of repeated flexing during handling and transfer activities.

The PHE has two modes of environmental control. The PHE-BP contains an Environmental Control Unit (ECU) which is worn on the user's back and powered by liquid air. This ECU provides gaseous air after the expansion of liquid air through a heat exchanger wherein the user's body heat contributes to the state change. The primary air flow (42.5 l/min) is fed into a venturi and is combined with air recycled from the suit causing a total circulation of 425 liters/min (15 Standard Cubic Feet/Min (SCFM)) which is routed through a manifold allowing approximately 60% distribution to the helmet (9 SCFM) with the remainder being circulated equally to the arms and legs. Though this backpack version of the PHE allows the user complete mobility, the added weight of the 17.7 kg (39 lbs when charged) backpack mounted ECU is a drawback, bringing the total weight of the complete suit to 29.5 kg (65 lbs).

The other version, the PHE-HL, relies on a hoseline to supply air for respiratory and cooling purposes. Normal air flows are about 170 l/min (6 SCFM) with the internal distribution being identical to that of the PHE-BP, except that air is not recirculated. A vortex cooling unit was used to partially cool the inlet air in the HOT and LAB tests. The PHE-HL relieves the user from carrying an ECU. The complete suit weighs only 11.8 kg (26 lbs). However the user is encumbered with a tether (hoseline) limiting mobility.

Estimates of Exercise Metabolism: Due to the nature of the PHE, oxygen consumption (VO_2) could not be monitored directly without interruption of normal air flow patterns in the helmet. Rather, VO_2 was estimated using two different equations. Using the HR data from the rest and work periods, the equation of Karvonen et al (13) was used to estimate VO_2 in ml/kg/min. A second predictive formula, that of Pandolf et al (14), was used to estimate the workload in watts (W). The workload value, W, was then converted to VO_2 in L/min (4,6) and then converted into a percentage of each subjects' VO_2 max (%VO_2max). The predictive formulas and pertinent conversion factors are detailed in Appendix II.

Statistical Analysis: A two-way ANOVA model with repeated measures across environment and work period (WP1 = 40-43min; WP2 = 63-66min; and WP3 = 66-69min) was used to assess specific contrasts for the %HRmax variable. A paired t-test was used to examine other suit performance differences for statistical significance. The confidence level for all statistical tests was set at $P<0.05$. No statistical analyses were performed on the metabolic workload estimates, as these data were extrapolated from the raw data.

RESULTS

Heart Rate: The mean HR responses were plotted as a percentage of maximal HR (%HRmax) versus stage for the COLD, LAB, and HOT conditions in Figures 1 A, B, and C, respectively. The HR responded as expected given the imposition of load, temperature, and exercise intensity. Within any particular environment, there were no significant differences in %HRmax due to the PHE suit at any given protocol stage. In each environment, WP1 and WP2 required similar mean %HRmax values. In all cases the mean %HRmax values for WP3 were significantly greater than either WP1 or WP2 values ($P<0.001$) for either suit, independent of the environment. During the recovery periods the mean %HRmax values approached baseline SSR values for each suit only in the COLD condition and during REC1 in the LAB condition. In the HOT environment, the recovery %HRmax values remained elevated relative to SSR values.

Helmet O_2 and CO_2 Concentrations: The mean delta O_2 values are listed in Table 3. The PHE-BP suit showed a -2.11% average delta

O_2 after WP1 and a -4.51% average delta O_2 after WP3. The PHE-HL suit showed a similar negative trend although attenuated by nearly one-half with -1.24% and -2.11% average delta O_2 values after WP1 and WP3, respectively. Combining the data from both suits, the absolute helmet O_2 concentration dropped below 18.0% on one of six occasions during WP3.

The mean helmet CO_2 concentrations are plotted versus stage for each environment in Figures 2 A, B, and C. In every case the PHE-BP suit demonstrated higher CO_2 concentrations compared to the PHE-HL, and at no time was the CO_2 content less than 0.67% in the PHE-BP. After WP1 in the PHE-BP, the average helmet CO_2 was 2.13% and was 3.73% after WP3. The PHE-HL showed a better CO_2 profile with markedly lower SSR, WP1, and WP3 values. The ACGIH short-term CO_2 exposure limit (STEL) of 3.0% was exceeded only after WP3 in the PHE-BP.

Finally, a correlation analysis showed that both delta O_2 and helmet CO_2 were significantly related to %HRmax. The linear correlation coefficients were $r = -0.37$ ($p < 0.001$) for delta O_2 and %HRmax, and $r = 0.80$ ($p < 0.001$) for helmet CO_2 and %HRmax.

Temperature Profiles: The mean data and significant differences for T_{rec}, T_{sk}, T_b, and T_s appear in Tables 4-7. In the HOT environment, neither suit provided adequate cooling. A steady rise appeared throughout as T_s, T_b, and T_{sk} approached T_{rec}. However, a slight gradient for heat exchange remained. When the data were pooled across time, the PHE-BP had a significantly higher average reading for T_{rec} than PHE-HL, while PHE-HL showed significantly greater T_{sk} and T_b values.

In the LAB condition, each suit performed adequately as T_s and T_{sk} remained stable or decreased except for the exercise periods. Although the suits showed similar trends, PHE-HL did show significantly higher pooled values for T_{sk} and T_b than PHE-BP in the LAB condition.

In the COLD tests, the effects of the PHE-HL air flow system proved to be not as severe as the cryogenically supplied air of the PHE-BP. With the PHE-BP, temperatures were very cold, and the subjects were uncomfortable. There was no significant difference in T_{rec} between the suits in the COLD, but the PHE-BP had significantly cooler T_{sk}, T_s, and T_b values.

DISCUSSION

The major objective of this study was to assess the effect of two configurations of a whole body protective suit on work physiology in three different environmental conditions. According to ACGIH standards, PHE activity was classified as moderate work which required walking about with some lifting and pushing. This classification did not consider the encumbrance of the suit (2). However, our findings indicated that the weight and encumbrance of the suit, the external air supply, and the ambient temperature had a significant effect upon the cardiovascular and thermal responses to brief periods of TM walking in each PHE suit.

HR responses. Though the mean %HRmax responses between the two PHE suits were not significantly different, the mean values during WP3 were significantly greater than those during WP1 or WP2 in all cases. The mean %HRmax values for both suits at WP3, approximately 79% (COLD), 84% (LAB), and 90% (HOT), either exceeded or were at the high end of appropriate exercise prescription guidelines for aerobic conditioning (1,3). While testing a similar whole body protection suit at KSC, Doerr (8) reported equivalent %HRmax values [approximately 80%(LAB), and 92% (HOT)] during TM walking at 2.5 mph, 12% grade. Therefore, PHE operations which elicit near maximal HR responses may need to be re-classified given the intensity of cardiovascular work necessary to perform the task.

Besides TM walking, there were other major contributors to the elevated %HRmax responses in this study. These included O_2 and CO_2 concentrations; T_{rec}, T_{sk} and other temperatures affecting the thermal gradient for evaporation; and the external load (i.e., the suit and backpack itself). The delta O_2 and CO_2 profiles indicated that gas concentrations were infrequently at optimum levels for individuals working in the PHE suits. In general, this was typical for work performance in whole body suits with external air sources. Nevertheless, the ACGIH guideline for minimum O_2 concentration (18.0%) was not met during WP3 on one occasion. Poor mixing was the most likely cause of a low initial O_2 concentration. Further, the CO_2 levels exceeded the ACGIH standard (3.0%) for short-term exposure, especially in the PHE-BP suit (2). Despite these occurrences, little evidence of an adverse reaction could be noted despite an alert posture to a possible response. While minute ventilation (VE) was not monitored, the inspiration of hypoxic and/or hypercapnic air mixtures can trigger increases in VE and HR (4,6). The elevated VE and HR can increase the physical stress of the work session. When less than optimal O_2 and CO_2 concentrations occur, the work rates may decrease thereby delaying completion of the operation.

Despite the PHE-BP weighing 17.6 Kg more than the PHE-HL, the %HRmax results were nearly identical. This finding was unexpected and difficult to explain, especially when the thermal stress of the HOT exposure was taken into account. The better gradient for heat exchange in the PHE-BP may have improved the return of venous blood to the heart, thereby maintaining cardiac stroke volume and diminishing (somewhat) the expected elevation in HR. The differences in T_{rec} and mean T_{sk} lend some support to this hypothesis.

Temperature Profiles. The temperature profiles for T_s, T_b, T_{sk}, and T_{rec} were not remarkably different for either suit and were in accordance with data from others (8,9). Neither PHE suit performed well in the HOT environment as T_s, T_b, T_{sk}, approached T_{rec}, leaving little gradient for heat exchange even during the rest phases of the protocol. Although the PHE-HL HOT test was subjectively the hottest exposure, the cooler air provided by the PHE-BP ECU offered little relief for the subject as demonstrated by the significantly greater T_{rec} (PHE-BP > PHE-HL, $p < 0.05$) during the HOT test.

The greater T_{rec} in the PHE-BP may be accounted for by the increased metabolic work required to carry the heavier suit and possibly by an elevated CO_2 concentration. The result was an increased relative workload (%VO_2max), and increases in T_{rec} are known to be positively correlated with increases in %VO_2 max (6).

The temperature profiles in the LAB tests were similar, indicating that some cooling capacity was still available. In this test, the cooler air from the PHE-BP ECU had a significant effect on T_{sk}, T_b, and T_s as they showed a steady decrease throughout except for the exercise periods. In the COLD tests, the PHE-HL was the preferred suit, as the circulation of ambient air was not as severe as that from the PHE-BP ECU. In the COLD PHE-BP test, T_s dropped to 35.1 °F and several subjects were uncomfortable, though none shivered uncontrollably. The normal undergarment for this unit was a single layer of thermal underwear. However, if more clothing or insulation were added to protect the subject, then less body heat would have been available to the ECU heat exchanger, further cooling the air supplied into the venturi.

Comparison of the PHE Suits. Given the test conditions and the temperature profile data, neither suit significantly outperformed the other. The PHE-BP performed best in the LAB condition, while the potential for thermal intolerance (e.g., hyperthermia or shivering) existed in both the HOT and COLD exposures. The PHE-HL was significantly more comfortable in the COLD because of its warmer incoming air, but the suit did not provide adequate cooling in the other environments. Because neither suit could meet completely the cooling requirements in the HOT exposure, hyperthermia and its subsequent effects on HR and work rate were and may continue to be a cause for concern during PHE operations in hot ambient temperatures. The ambient heat stress, the work intensity of the operation, plus the weight and encumbrance of the PHE suit -- all act to heighten the physiologic and thermal stress placed upon the individual user. In circumstances such as these, even relatively light work performed while wearing the PHE may become arduous.

Estimated Workload Assessment. Because direct measurement of VO_2 was not possible, the metabolic work intensities were estimated using two different formulas. The Karvonen formula (13) utilized the "HR reserve" concept to estimate VO_2 during submaximal work. Davis and Convertino (7) have demonstrated the effectiveness of the Karvonen formula for estimating exercise intensity during endurance training. The second formula, a fixed energy prediction equation from Pandolf et al (14), accounted for four factors associated with load carrying: 1) a metabolic cost for standing without load; 2) a metabolic cost for load bearing while standing; 3) a metabolic cost for walking on the level, considering the total weight moved and the specific terrain; and 4) a metabolic cost for climbing a grade, considering the total weight moved and the specific terrain. This prediction formula extended an original equation developed by Givoni and Goldman (10).

Using the Karvonen formula, Table 8 illustrates a comparison of the actual percent HR max and the estimated percent VO_2 max data. The VO_2 estimates for WP1 and WP2 were similar, while those for WP3 were much greater, indicating a greater exercise intensity. As with the %HR max results, the VO_2 estimates for the PHE-BP were somewhat greater than those for the PHE-HL in nearly all cases.

Utilizing the fixed energy cost prediction method of Pandolf et al (14), the actual workload was estimated (Table 9A) and then converted into $\%VO_2$ max (Table 9B) for each of three different stages. The heavier PHE-BP suit caused an 18% increase in the estimated VO_2 for each stage when compared to the PHE-HL configuration. In comparing the VO_2 estimates in Tables 8 and 9B for WP1 and WP3, the Karvonen formula gave more diverse and variable results which showed only slight agreement with the estimates from the fixed energy cost method. The greater amount of variability with the Karvonen formula was expected because several factors unrelated to the physical workload can contribute to an elevated HR response.

The influence of an external weight load, a thermal load, and the work intensity upon cardiac performance has been documented previously (4-6, 8, 15). Since HR can be impacted by factors unrelated to work intensity, the Karvonen formula (13) may have overestimated the submaximal VO_2. A comparison of the percent HR max and estimated percent VO_2 max responses in Table 8 illustrated the difficulty in assessing exercise metabolism (VO_2) when only HR is measured. The confounding factors of external weight, suit design, and thermal adversities elevated the HR (and hence, %HRmax) in excess of that required strictly to perform the physical work. Thus, the Karvonen formula seems to have limited usefulness for PHE operations as an estimator of metabolic workload.

In contrast, the Pandolf et al (14) prediction formula generated VO_2 estimates which account for the metabolic costs associated with each of the four factors listed earlier. However, the added dimension of walking in a pressurized garment, such as the PHE, altered mechanical efficiency, a variable not factored into their equation. Although the Pandolf et al formula may underestimate the actual VO_2 because of changes in mechanical efficiency, the equation might be a better predictor of the metabolic workload required for PHE operations since all the fixed energy costs (standing, load, terrain, grade, speed) are accounted for.

A closer look at these results (Table 9B) suggests that moderate work performed in the PHE suits (WP3) required an average of 61% or 72% VO_2 max in our subjects, depending upon which PHE configuration was worn. These energy expenditure estimates were consistent with data reported elsewhere in the literature and summarized in Table 10 of this report. Specifically, Borghols et al (5) reported linear increases in VO_2, VE and HR in subjects who walked for 10 min at 5 km/hr and 0-9% grade (approximately 30-50% VO_2 max) as the external load increased from 0 to 30 kg.During self paced TM walking, Hughes and Goldman (12) observed that individuals routinely selected a walking pace that resulted in an energy expenditure of 400-450 kcal/hr (1.33-1.50 L O_2/min) regardless of the external load (0-60 kg). This self-selected energy expenditure approximated PHE operations equivalent to Bruce Stage I (our WP1) in either the PHE-HL (estimate range = 1.23-1.53 L O_2/min) or the PHE-BP (estimate range = 1.47-1.72 L O_2/min) suit. Essentially, this is the type of work intensity which can be maintained throughout the course of an 8-hr shift, approximately 50% VO_2max (4,15). However, there must be an adequate margin of safety to meet any unexpected increase in work demands.

None of the above studies examined whole body protective equipment per se; so, there may be difficulty in extending their observations to these unique garments. However, Doerr (8) conducted a pilot study (n=2) on the Trelleborg TC Super Suit, a protective garment for first responders to spills of hazardous materials [total weight of suit and breathing apparatus = 22.4 kg (49.5 lbs)]. The subjects performed TM walking in a neutral environment while wearing gym clothes alone; gym clothes and a backpack containing weight equivalent to the suit; and wearing the suit, pressurized, but not breathing on the apparatus. The measured mean VO_2 results at 2.5 mph, 12% grade (our WP3) were

1.62 L/min (baseline), 2.23 L/min (shorts + backpack), and 2.35 L/min (suit), respectively. The encumbrance of the suit led to a 45% increase in VO_2 between the baseline and suited conditions and a 5.4% increase between the weighted and suited conditions despite no change in TM speed or grade. Our estimated VO_2 results via Pandolf et al (14) were in close agreement with those reported by Doerr (8). In the LAB condition, our WP3 estimates ranged from 2.00-2.53 L/min for the PHE-HL, while those for the PHE-BP ranged from 2.38-2.81 L/min.

In summary, the imposition of a whole body protective suit, such as the PHE, resulted in significant physiologic and thermal stress for the user due solely to the protective system. In nearly every instance the HR was driven to moderately high levels, the supplied respiratory gases were less than optimum, and thermal adversities were introduced. Each PHE configuration burdened the user with a weight load that may be prohibitive for the less fit worker, or the smaller, lighter individual. Since neither PHE configuration offered clearly superior performance, our findings suggested that the operational choice of which PHE suit to use should be made after careful consideration of the task difficulty, length and type of operation, ambient conditions, and perhaps, even the fitness capabilities of the worker(s).

RECOMMENDATIONS

Because the relationship between aerobic fitness and work capacity is a direct one, questions remain concerning the cardiorespiratory fitness level (VO_2max) desired or required for individuals who are performing PHE operations at KSC. The current physical qualification standard is completion of Bruce Stage III (3.4 mph, 14%), a 9 minute test. Data from KSC workers (N=109) indicated that this test corresponded to a VO_2 of approximately 33 ml O_2/kg/min or 2.31 LO_2/min for a 70kg reference individual. As reported here, and previously by Doerr (8), this level of exertion was comparable to performing PHE operations at Bruce Stage II (moderate to difficult work). Working at light to moderate PHE tasks, comparable to Bruce Stage I, will require approximately 65% (1.5 L/min/2.31 L/min) of VO_2max (70 kg person) for an individual who barely complies with the current standard. This level of physiologic stress can be maintained for long periods in highly fit individuals; however, PHE tasks of this intensity may be more demanding than the suggested "self-selected" work pace of 30-50% VO_2max (4,12,15).

Based on these results and our experience with the PHE, we have outlined several critical areas of concern and our recommendations for minimizing their effects.

1. ISSUE:
The physical demands of working in the PHE can sometimes exceed the fitness level to which individuals are certified at present.

RECOMMENDATIONS:
a) Continue annual certification procedures.
b) Review the present physical standard.
c) Consider extending the qualification TM test into Bruce Stage IV (minute 2).

2. ISSUE:
Develop optimum work/rest ratios to minimize physical stress to the worker and maximize the quality and timely completion of PHE operations.

RECOMMENDATION:
a) Continuous monitoring of the ambient temperature to assist in the prevention of potential heat injuries.
b) Prolonged operations >90 min should be of light to moderate intensity with work periods of 10-20 min followed by an equivalent rest period.
c) Intense PHE operations should be <90 min in duration with work periods of up to 10 min followed by a minimum rest period of 10 min.
d) When a PHE worker is required to perform monitoring functions, the maximum time allowed in the suit should not exceed the safe limits of the air supply, approximately 150-180 min.

3. ISSUE:
During work in a hot, humid environment, the elevation of core temperature may be of sufficient magnitude to decrease physical performance and lead to potential medical problems.

RECOMMENDATIONS:
a) Develop guidelines to encourage all PHE users to become heat acclimated, and to consume extra fluids (non-caffeinated) prior to donning the suit. Enhanced fluid consumption should begin 18-24 h prior to the operation.
b) Explore the effects of cold air inhalation (3.6°C) on PHE work performance. Recent research evidence suggests that breathing cold air can reduce the rise in core temperature associated with heat stress (9).
c) Explore methods to improve air flow for evaporative cooling.
d) Consider monitoring pre- and post body weight, heart rate, and/or blood pressure during PHE operations. This

data will help establish guidelines to enhance physical recovery for PHE users.

4. ISSUE:
   The O_2 and the CO_2 gas concentrations were not always within ACGIH guidelines.

   RECOMMENDATIONS:
   a) Increase level of O_2 in liquid air mix from 21% to 25%.
   b) Consider methods to reduce CO_2 build up in the helmet region.

5. ISSUE:
   There is a need to validate the work intensity of PHE operations so that appropriate work categorizations can be made.

   RECOMMENDATIONS:
   Through field tests and assessments of PHE operations, determine a worst case scenario (e.g., heavy physical work with victim rescue) and evaluate its work intensity and safety (via HR and rectal temperature data).

6. ISSUE:
   Develop operational procedures to determine which PHE configuration best meets the requirements of the operation and best accommodates the user, given the task intensity, duration, and ambient conditions.

   RECOMMENDATION:
   a) Assess the need for mobility during the operation (hoseline tether vs. backpack).
   b) Evaluate the potential interaction between task intensity, ambient conditions, and task duration.
   c) Select appropriate PHE configuration after considering all aspects of the operation (using the matrix below.

AMBIENT TEMPERATURE	LIGHT WORK	HEAVY WORK
HOT	PHE-BP	PHE-BP
NEUTRAL (LAB)	PHE-HL	PHE-BP
COLD	PHE-HL	PHE-BP

In summary, these recommendations reflect a concern that low aerobic fitness, in combination with ambient heat stress, heavy physical work, a reduced cooling capacity, and less than optimal

O_2 and CO_2 concentrations, may lead to difficulty during PHE operations. By incorporating these recommendations, this risk can be minimized and the safety of the operation will be improved.

REFERENCES

1. American College of Sports Medicine. Guidelines for Exercise Testing and Prescription. Philadelphia: Lea & Febiger, 1986.

2. American Conference of Government Industrial Hygienists. Threshold limit values and biological exposure indices for 1986-1987. Cincinnati, OH:ACGIH, 1986.

3. American Heart Association Subcommittee on Rehabilitation. The Exercise Standards Book. Dallas: American Heart Association, 1979.

4. Astrand, P.O., and K. Rodahl. Textbook of Work Physiology. New York: McGraw-Hill Book Company, 1970.

5. Borghols, EAM, HMW Dresen, and AP Hollander. Influence of heavy weight carrying on the cardiorespiratory system during exercise. Eur. J. Appl. Physiol., 38: 161-169, 1978.

6. Brooks, G.A. and T.D. Fahey. Exercise Physiology. New York: J. Wiley & Sons, 1984.

7. Davis, J.A. and V.A. Convertino. A comparison of heart rate methods for predicting endurance training intensity. Med. Sci. Sports. 7:295-298, 1975.

8. Doerr, D.F. Trelleborg Trellchem Super Suit with Spiromatic 930 Self-Contained Breathing Apparatus. Report from the Kennedy Space Center, January, 1986.

9. Geladas, N. and E.W. Banister. Effect of cold air inhalation on core temperature in exercising subjects under heat stress. J. Appl. Physiol., 64(6): 2381-2387, 1988.

10. Givoni, B., and R.F. Goldman. Predicting metabolic energy cost. J. Appl. Physiol., 30: 429-433, 1971.

11. Goldman, R.F., and P.F. Iampietro. Energy cost of load carriage. J. Appl. Physiol. 17:675-676, 1962.

12. Hughes, A.L. and R.F. Goldman. Energy cost of "hard work". J. Appl. Physiol., 29(5): 570-572, 1970.

13. Karvonen, M.J., E. Kentala, and O. Mustala. The effects of training on heart rate. A longitudinal study. Ann. Med. Exper. Fenn. 35:307-315, 1957.

14. Pandolf, K.B., B. Givoni, and R.F. Goldman. Predicting energy expenditure with loads while standing or walking very slowly. J. Appl. Physiol., 43(4): 577-581, 1977.

15. Sharkey, B.J. Fitness and Work Capacity Testing. Forest Service, U.S. Department of Agriculture, July, 1977.

APPENDIX I

TABLE 1

SUBJECT CHARACTERISTICS

	SUBJ. NO.	AGE (yr)	HT (cm)	WT (Kg)	HRmax b/min	VO_2max ml/kg/min
S 1	298	38	179.1	74.6	183	47.2
2	344	26	182.9	78.9	195	54.8
3	347	38	181.0	95.2	164	38.1
4	532	49	172.1	85.4	171	37.5

TABLE 2

PHE TEST PROTOCOL

PROTOCOL TIME (min)	DURATION (min)	CONDITION
0 - 10	10	STANDING REST
10 - 20	10	SUITING
20 - 40	20	STANDING SUITED REST (SSR) IN ENVIRONMENT
40 - 43	3	WORK PERIOD #1 (WP1) -TREADMILL WALK (1.7 mph at 10% grade)
43 - 63	20	STANDING SUITED RECOVERY IN ENVIRONMENT (REC 1)
63 - 66	3	WORK PERIOD #2 (WP2) -TREADMILL WALK (1.7 mph at 10% grade)
66 - 69	3	WORK PERIOD # 3 (WP3) -TREADMILL WALK (2.5 mph at 12% grade)
69 - 89	20	STANDING SUITED RECOVERY (REC 2)

FOR -7°C (20°F) and 43°C (110°F) TESTS, SUBJECT ENTERED ENVIRONMENTAL CHAMBER AT MIN. 20 AND REMAINED IN THE CHAMBER UNTIL COMPLETION.

TABLE 3

MEAN DELTA OXYGEN (PERCENT)

	COLD	LAB	HOT	TIME
PHE - BP	26.8 ± 2.0	27.1 ± 0.9	22.4 ± 1.3	Min 38
	-2.23 ± 0.2	-2.01 ± 0.07	-2.07 ± 0.13	Min 43
	-0.18 ± 0.05	-0.15 ± 0.01	-0.34 ± 0.02	Min 63
	-2.80 ± 0.30	-2.11 ± 0.08	-2.36 ± 0.15	Min 66
	-4.90 ± 0.55	-4.03 ± 0.15	-4.60 ± 0.44	Min 69
	-1.03 ± 0.08	-0.65 ± 0.02	-0.82 ± 0.04	Min 86
PHE - HL	20.7 ± 0.40	21.0 ± 0.20	20.1 ± 0.3	Min 38
	-1.21 ± 0.02	-1.58 ± 0.03	-0.92 ± 0.01	Min 43
	-0.27 ± 0.01	-0.10 ± 0.01	+0.22 ± 0.01	Min 63
	-1.30 ± 0.02	-1.44 ± 0.02	-1.00 ± 0.01	Min 66
	-2.04 ± 0.03	-2.39 ± 0.02	-1.89 ± 0.01	Min 69
	-0.66 ± 0.01	-0.13 ± 0.01	-0.12 ± 0.00	Min 86

38 min value was used as baseline. Other values are mean ± SE, representing the change in O_2 concentration from baseline.

KEY:

Minute 38 - standing suited rest
Minute 43 - work period #1
Minute 63 - recovery #1
Minute 66 - work period #2
Minute 69 - work period #3
Minute 86 - recovery #2

Significant Result: When the values for each PHE were pooled Delta O_2 correlated with %HRmax, $r = -0.37$ ($p<0.0001$).

TABLE 4

MEAN RECTAL TEMPERATURE (°F)

	COLD	LAB	HOT	TIME
PHE - BP	99.08 ± 0.23	99.13 ± 0.13	99.15 ± 0.17	Min 38
	99.10 ± 0.23	99.05 ± 0.12	99.23 ± 0.18	Min 42
	99.05 ± 0.20	98.88 ± 0.15	99.33 ± 0.13	Min 62
	99.13 ± 0.22	98.95 ± 0.16	99.48 ± 0.18	Min 66
	99.10 ± 0.23	98.98 ± 0.14	99.63 ± 0.15	Min 68
	98.95 ± 0.55	99.18 ± 0.17	100.08 ± 0.09	Min 86
PHE - HL	99.40 ± 0.09	99.18 ± 0.39	99.08 ± 0.03	Min 38
	99.38 ± 0.10	98.98 ± 0.46	99.10 ± 0.00	Min 42
	99.43 ± 0.19	98.93 ± 0.51	99.35 ± 0.06	Min 62
	99.45 ± 0.18	98.93 ± 0.60	99.38 ± 0.05	Min 66
	99.45 ± 0.20	98.88 ± 0.64	99.43 ± 0.08	Min 68
	99.55 ± 0.29	99.20 ± 0.64	99.58 ± 0.10	Min 86

Values are mean ± SE

KEY:

Minute 38 - standing suited rest
Minute 42 - work period #1
Minute 62 - recovery #1
Minute 66 - work period #2
Minute 68 - work period #3
Minute 86 - recovery #2

Significant Results:

Condition	Suit
HOT	PHE-BP > PHE-HL $p<0.05$
LAB	No significant differences
COLD	No significant differences

TABLE 5

MEAN SKIN TEMPERATURE (°F)

	COLD	LAB	HOT	TIME
PHE - BP	76.1 ± 1.7	82.5 ± 3.0	92.5 ± 0.9	Min 38
	74.7 ± 1.4	81.6 ± 2.7	93.6 ± 0.6	Min 42
	70.8 ± 2.3	79.0 ± 2.4	93.8 ± 0.3	Min 62
	70.4 ± 2.3	79.1 ± 2.5	94.4 ± 0.3	Min 66
	70.8 ± 1.6	80.3 ± 2.4	95.9 ± 0.5	Min 68
	70.1 ± 2.3	79.2 ± 1.4	94.9 ± 0.6	Min 86
PHE - HL	79.8 ± 0.5	89.2 ± 0.6	96.1 ± 0.6	Min 38
	79.4 ± 0.9	89.9 ± 0.8	96.2 ± 0.2	Min 42
	77.4 ± 0.7	89.0 ± 1.0	95.7 ± 0.3	Min 62
	78.1 ± 1.9	89.8 ± 0.9	96.5 ± 0.3	Min 66
	77.3 ± 1.4	91.7 ± 1.0	97.2 ± 0.4	Min 68
	76.0 ± 1.0	89.0 ± 0.5	97.2 ± 0.4	Min 86

All values are mean ± SE.

KEY:

Minute 38 - standing suited rest
Minute 42 - work period #1
Minute 62 - recovery #1
Minute 66 - work period #2
Minute 68 - work period #3
Minute 86 - recovery #2

Significant Results:

Condition	Suit	
HOT	PHE-HL > PHE-BP	$p<0.05$
LAB	PHE-HL > PHE-BP	$p<0.05$
COLD	PHE-HL > PHE-BP	$p<0.05$

TABLE 6

MEAN BODY TEMPERATURE (°F)

	COLD	LAB	HOT	TIME
PHE - BP	91.0 ± 0.7	93.3 ± 0.7	96.8 ± 0.4	Min 38
	90.5 ± 0.6	93.0 ± 0.6	97.2 ± 0.3	Min 42
	89.2 ± 0.9	92.0 ± 0.7	97.4 ± 0.2	Min 62
	89.1 ± 0.9	92.0 ± 0.6	98.7 ± 0.2	Min 66
	89.2 ± 0.7	92.7 ± 0.7	98.4 ± 0.3	Min 68
	89.7 ± 0.7	92.2 ± 0.6	98.1 ± 0.2	Min 86
PHE - HL	92.6 ± 0.2	95.7 ± 1.0	98.0 ± 0.2	Min 38
	92.4 ± 0.3	95.7 ± 1.4	98.2 ± 0.2	Min 42
	91.7 ± 0.2	95.4 ± 1.4	98.1 ± 0.2	Min 62
	91.9 ± 0.6	95.4 ± 1.4	98.4 ± 0.1	Min 66
	91.7 ± 0.5	96.2 ± 1.7	98.7 ± 0.2	Min 68
	91.5 ± 0.2	95.3 ± 1.2	98.9 ± 0.2	Min 86

Values are mean ± SE.

KEY:

Minute 38 - standing suited rest
Minute 42 - work period #1
Minute 62 - recovery #1
Minute 66 - work period #2
Minute 68 - work period #3
Minute 86 - recovery #2

Significant Results:

Condition	Suit	
HOT	PHE-HL > PHE-BP	$p<0.05$
LAB	PHE-HL > PHE-BP	$p<0.05$
COLD	PHE-HL > PHE-BP	$p<0.05$

TABLE 7

MEAN SUIT TEMPERATURE (°F)

	COLD	LAB	HOT	TIME
PHE - BP	46.1 ± 2.3	58.3 ± 0.9	81.1 ± 1.4	Min 38
	44.1 ± 2.7	59.1 ± 0.7	83.4 ± 1.0	Min 42
	36.6 ± 3.2	52.0 ± 1.3	83.3 ± 1.5	Min 62
	38.7 ± 2.3	54.0 ± 1.2	85.5 ± 1.4	Min 66
	42.2 ± 2.0	58.2 ± 1.4	88.5 ± 1.4	Min 68
	35.1 ± 3.5	52.2 ± 1.2	89.5 ± 0.6	Min 86
PHE - HL	54.0 ± 1.4	76.9 ± 1.0	97.3 ± 0.5	Min 38
	54.5 ± 1.8	79.7 ± 0.8	97.1 ± 0.8	Min 42
	53.9 ± 1.0	77.3 ± 0.8	97.3 ± 0.7	Min 62
	55.6 ± 1.4	80.4 ± 0.1	97.7 ± 0.9	Min 66
	56.8 ± 2.5	82.4 ± 0.7	97.7 ± 0.8	Min 68
	51.4 ± 0.1	78.0 ± 0.5	97.8 ± 0.5	Min 86

Values are mean ±SE.

KEY:

Minute 38 - standing suited resting
Minute 42 - work period #1
Minute 62 - recovery #1
Minute 66 - work period #2
Minute 68 - work period #3
Minute 86 - recovery #2

Significant Results:

Condition	Suit	
HOT	PHE-HL > PHE-BP	$p<0.05$
LAB	PHE-HL > PHE-BP	$p<0.05$
COLD	PHE-HL > PHE-BP	$p<0.05$

TABLE 8

HR RESPONSE AND ESTIMATED VO_2 FOR TREADMILL WORK IN PHE SUITS AS A PERCENTAGE OF MAXIMUM

Actual Percent HRmax

	WP 1	WP 2	WP 3
COLD			
PHE - HL	58.9 (2.7)	58.7 (3.1)	77.1 (1.4)
PHE - BP	62.0 (3.1)	62.7 (3.4)	79.7 (1.7)
LAB			
PHE - HL	67.8 (3.1)	65.7 (3.8)	80.2 (2.9)
PHE - BP	61.3 (2.8)	63.2 (3.3)	81.5 (1.9)
HOT			
PHE - HL	62.3 (3.0)	69.4 (1.9)	87.9 (1.4)
PHE - BP	66.0 (2.6)	69.8 (2.2)	88.0 (2.1)

* Estimated Percent $VO_{2}max$

	WP 1	WP 2	WP 3
COLD			
PHE - HL	29.7 (3.0)	29.5 (4.3)	61.0 (2.8)
PHE - BP	36.6 (2.7)	37.9 (3.3)	65.8 (3.0)
LAB			
PHE - HL	42.0 (4.4)	38.2 (5.6)	64.7 (4.0)
PHE - BP	35.0 (3.3)	38.3 (4.2)	68.9 (2.9)
HOT			
PHE - HL	31.4 (4.7)	41.1 (3.4)	76.8 (2.6)
PHE - BP	38.3 (2.2)	44.9 (2.4)	77.3 (2.2)

Values are mean (SE) expressed as a percentage of maximal HR.
* Values were estimated using the formula of Karvonen et al (13) as detailed in Appendix II.

TABLE 9A

THE ESTIMATED METABOLIC WORKLOAD (WATTS) OF TREADMILL WALKING IN PHE SUITS

		COLD		LAB		HOT	
		MEAN	SE	MEAN	SE	MEAN	SE
PHE - HL							
STAGE	SSR	128.1	6.2	128.1	6.3	128.9	6.9
	WP1	469.3	22.1	469.5	22.5	472.1	24.0
	WP3	762.1	36.0	762.2	36.3	766.7	38.9
PHE - BP							
STAGE	SSR	149.9	4.1	150.5	4.0	149.9	4.4
	WP1	543.6	18.2	545.3	17.8	543.4	19.2
	WP3	881.6	30.7	884.5	29.6	880.0	45.1

Values are mean and standard error in WATTS. SSR = Standing Suited Rest (min 38). WP1 = Work Period 1 (min 43). WP3 = Work Period 3 (min 69). Watt values were estimated using the formula of Pandolf et al (14) detailed in Appendix II.

TABLE 9B

THE ESTIMATED METABOLIC LOAD OF TREADMILL WORK IN PHE SUITS AS A PERCENT OF MAXIMAL OXYGEN UPTAKE, VO_2MAX

CONDITIONS:		COLD		LAB		HOT	
		MEAN	SE	MEAN	SE	MEAN	SE
PHE-HL							
STAGE	SSR	10.3	0.6	10.3	0.9	10.3	0.9
	WP1	37.7	2.0	37.7	3.2	37.7	3.2
	WP3	61.3	3.3	61.3	5.1	61.2	5.1
PHE-BP							
STAGE	SSR	12.3	0.9	12.2	0.9	12.3	0.9
	WP1	44.4	3.5	44.4	3.5	44.5	3.4
	WP3	72.1	5.7	72.0	5.8	72.1	6.1

Values are mean and SE in percent (%). Abreviations are as defined in Table 9A. The percent VO_2max values were estimated by using the conversion factors (watts to L/min) detailed in Appendix II.

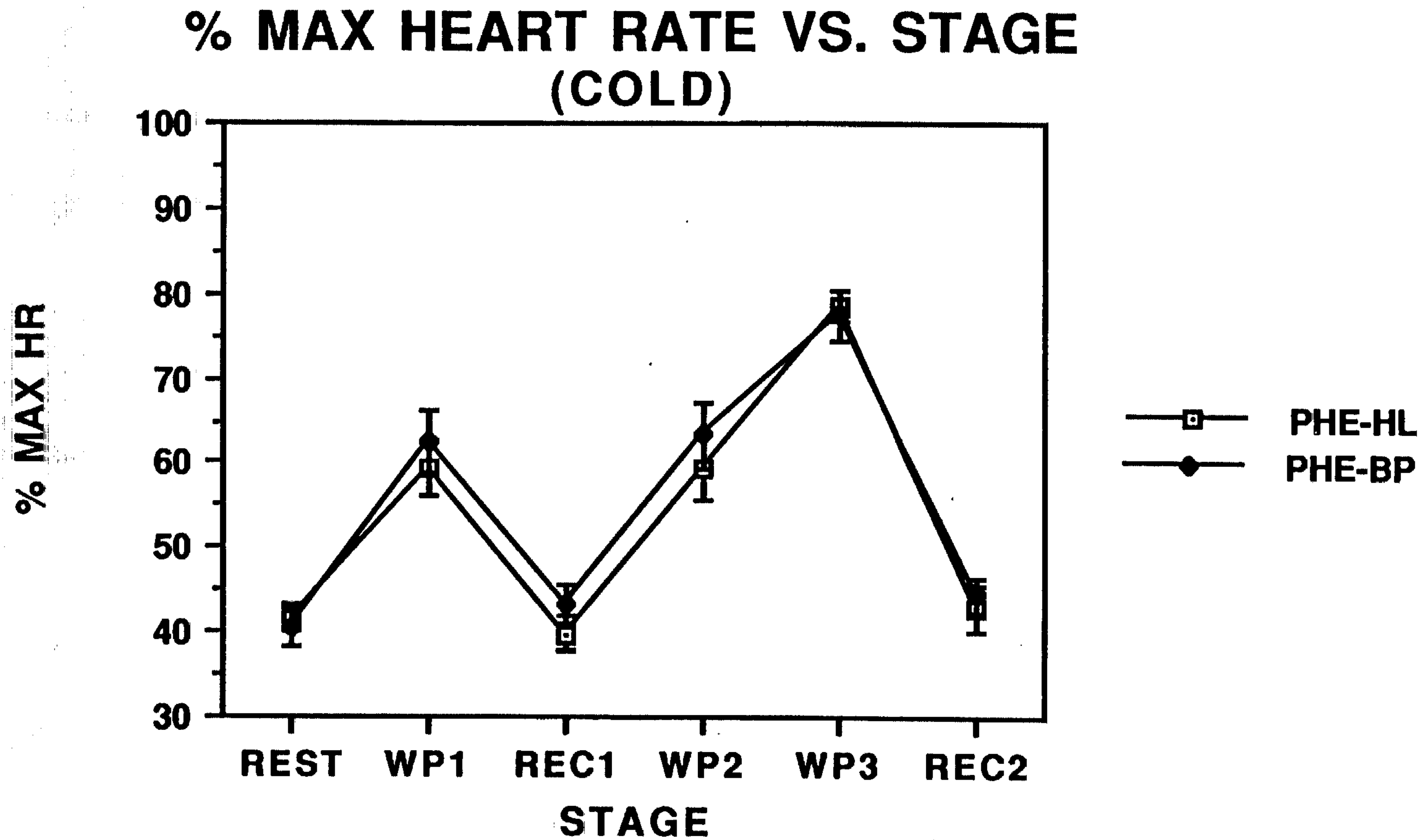
TABLE 10

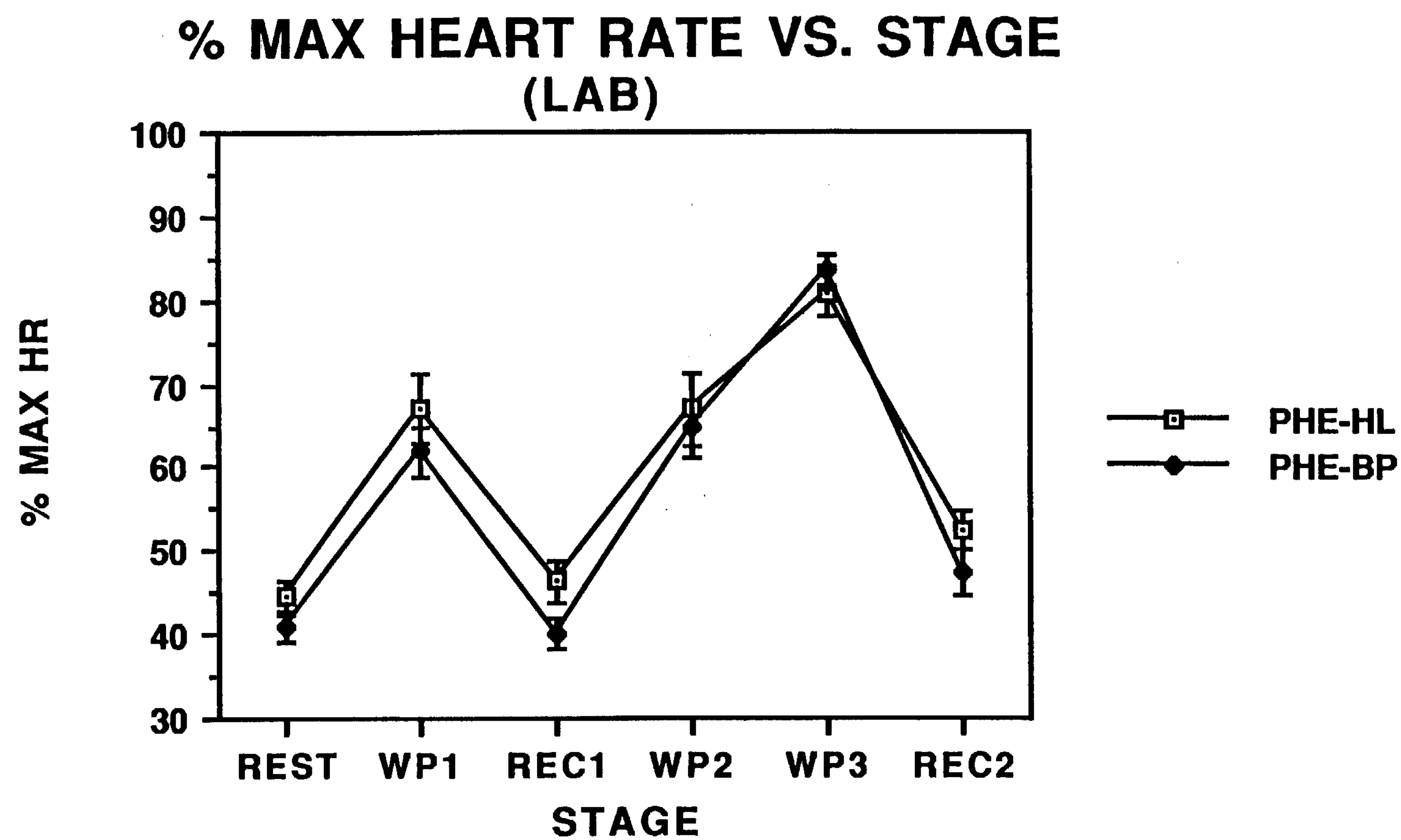
REVIEW OF OXYGEN UPTAKE (VO_2) VALUES FOR WEIGHTED TREADMILL WALKING

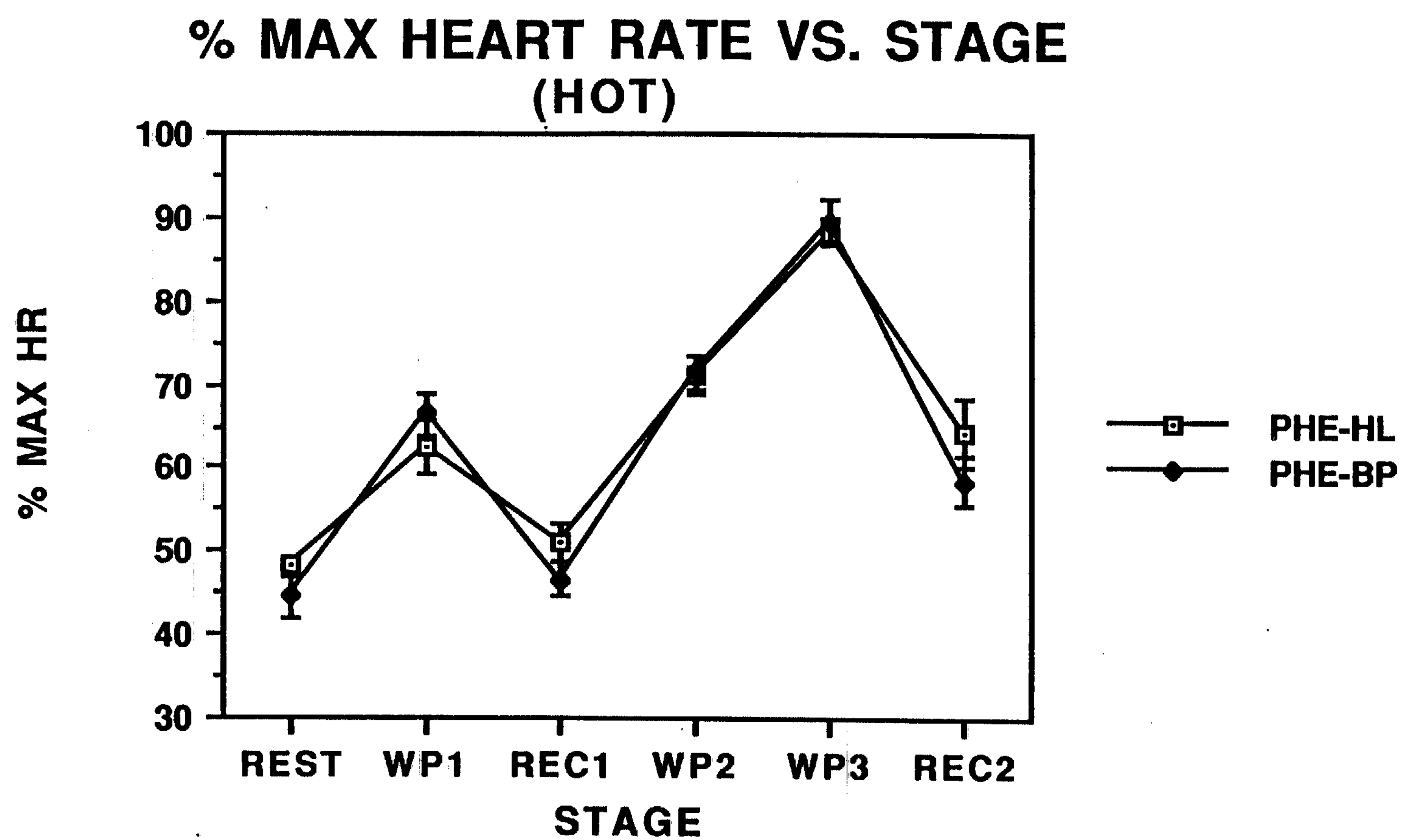
Reference	TM Speed, Grade	Suit Type (kg)	Mean VO_2	Range
Hughes & Goldman (12)[1] N=12	Self-selected, at least 3.0mph, 0%	Weighted Vest (20)	1.56 L/min	-----
		Weighted Vest (30)	1.52 L/min	-----
Borghols, et al (5) N=9	3.1 mph, 0%	Weighted Pack (10)	1.74 L/min	-----
	3.1 mph, 0%	Weighted Pack (30)	2.47 L/min	-----
Doerr (8) N=2	2.5 mph, 12%	Trelleborg TC Super Suit (22.4)	2.35 L/min	----
KSC Database N=109	3.4 mph, 14%	None	32.3 mlO_2/kg/min	27.4-37.2
Present Study[2] N=4	0 mph, 0%	PHE-HL (11.8)	0.37 L/min	0.34-0.43
	1.7 mph, 10%	PHE-HL	1.37	1.23-1.56
	2.5 mph, 12%	PHE-HL	2.22	2.00-2.53
	0 mph, 0%	PHE-BP (29.5)	0.44 L/min	0.41-0.47
	1.7 mph, 10%	PHE-BP	1.58	1.47-1.73
	2.5 mph, 12%	PHE-BP	2.57	2.38-2.81

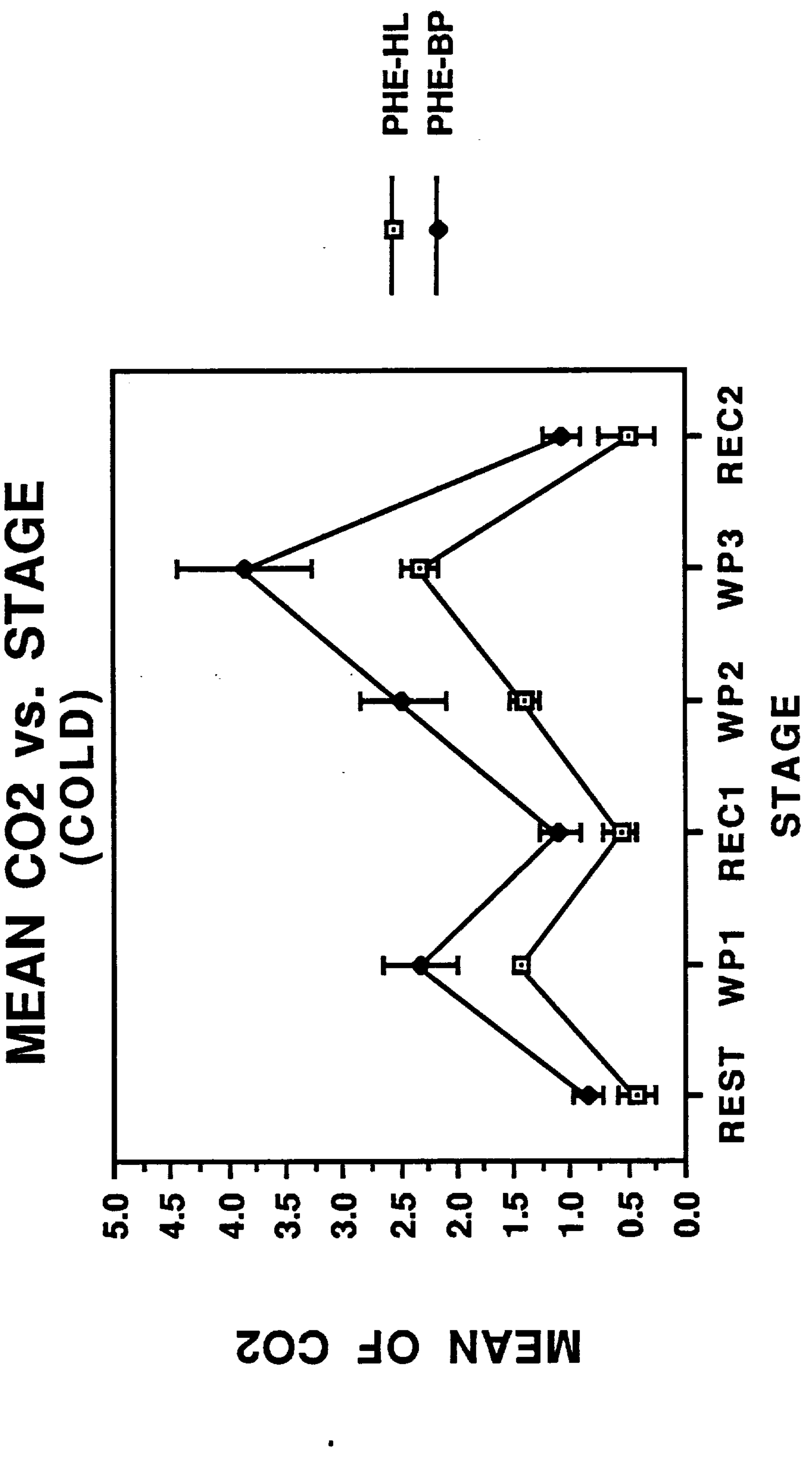
1. VO_2 Values converted from Kcal/hr to L/min.
2. VO_2 Values estimated using the method of Pandolf et al (14). Data pooled for all conditions.

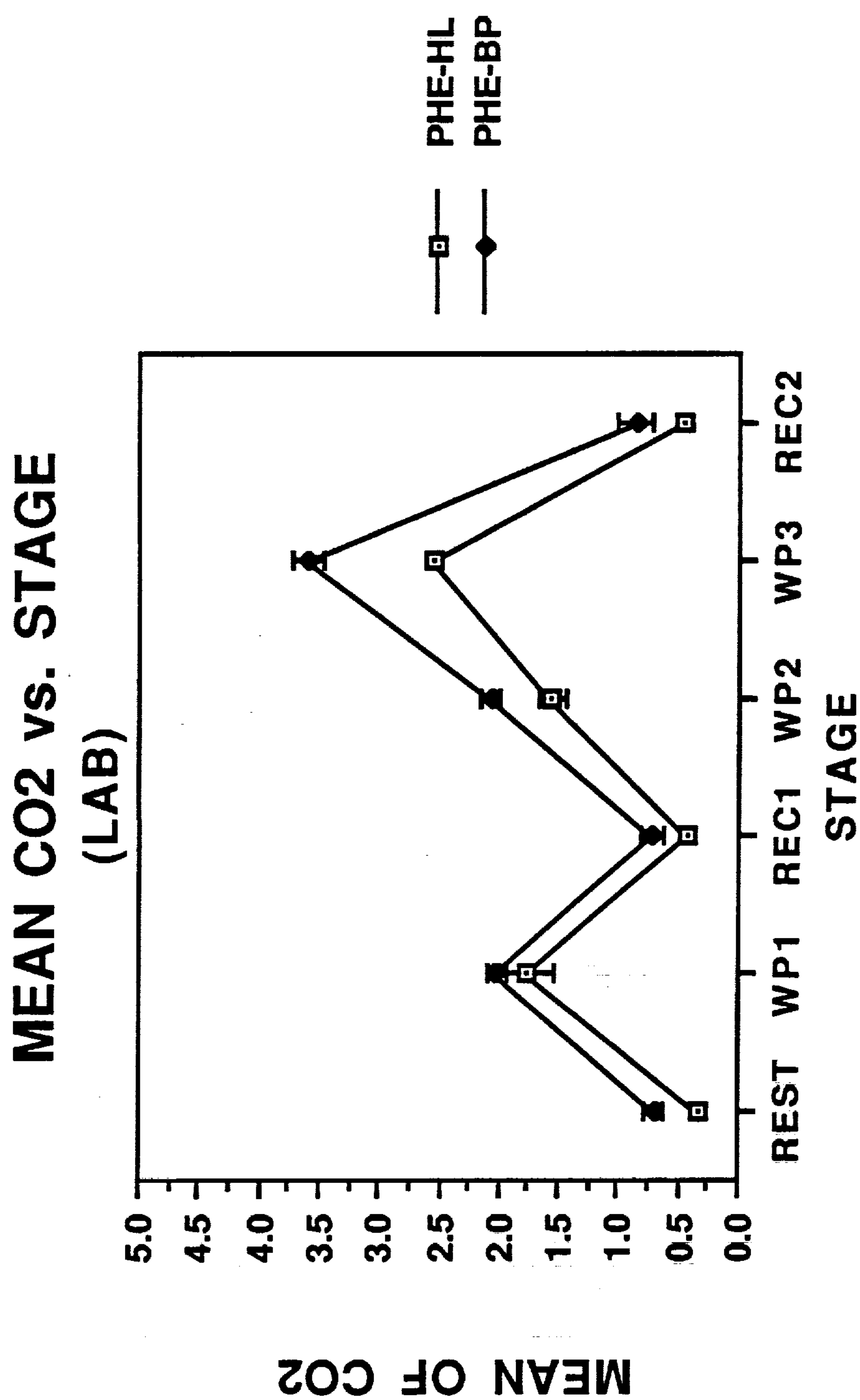
(kg) represents the weight of the suit/vest.

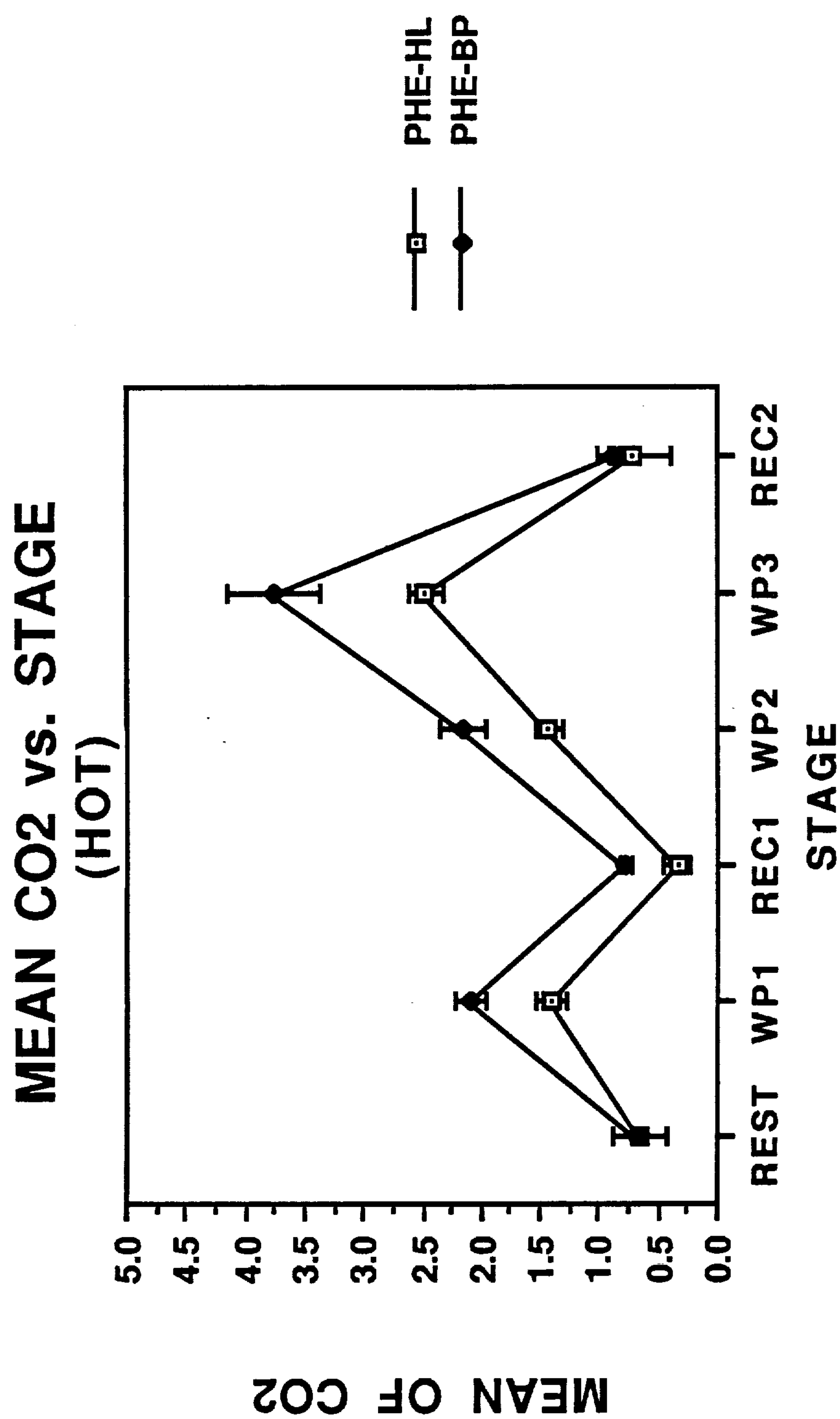

% MAX HEART RATE VS. STAGE
(COLD)
% MAX HR
100
90
80
70
60
50
40
30
REST
WP1
REC1
WP2
WP3
REC2
STAGE
PHE-HL
PHE-BP


% MAX HEART RATE VS. STAGE
(LAB)
% MAX HR
100
90
80
70
60
50
40
30
REST
WP1
REC1
WP2
WP3
REC2
STAGE
PHE-HL
PHE-BP


% MAX HEART RATE VS. STAGE
(HOT)
% MAX HR
100
90
80
70
60
50
40
30
REST
WP1
REC1
WP2
WP3
REC2
STAGE
PHE-HL
PHE-BP


MEAN CO2 vs. STAGE
(COLD)
MEAN OF CO2
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
REST
WP1
REC1
WP2
WP3
REC2
STAGE
PHE-HL
PHE-BP


MEAN CO2 vs. STAGE
(LAB)
MEAN OF CO2
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
REST
WP1
REC1
WP2
WP3
REC2
STAGE
PHE-HL
PHE-BP


MEAN CO2 vs. STAGE
(HOT)
MEAN OF CO2
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
REST
WP1
REC1
WP2
WP3
REC2
STAGE
PHE-HL
PHE-BP

APPENDIX II

APPENDIX II

ESTIMATES OF WORK METABOLISM, VO_2

I. Formula of Karvonen et al (13):

$$\frac{HR_{sm} - HR_{rest}}{HR_{max} - HR_{rest}} \times VO_{2max} = VO_{2sm} \text{ ml/kg/min}$$

Where: HR_{sm} = Submaximal HR recorded during WP1, WP2, WP3.
HR_{max} = Maximal HR from Bruce TM test.
HR_{rest} = HR at min 38 of protocol.
VO_{2max} = Maximal VO_2 from Bruce TM test in ml/kg/min.
VO_{2sm} = Calculated submaximal VO_2 in ml/kg/min.

Sample Calculation:

Subject no. 298
HR_{max} = 183 bpm
VO_2 max = 47.5 ml/kg/min

38 min HR = 71 bpm
Exposure: LAB
Time: WP2

HR_{sm} = 106 bpm

$$\frac{106-71}{183-71} \times 47.5 = 0.313 \times 47.5 = 14.8 \text{ ml/kg/min} = 31.3 \ \%VO_2 \text{ max}$$

II. Formula of Pandolf et al (14):

$$M = 1.5\ W + 2.0\ (W+L)\ (L/W)^2 + N\ (W+L)\ [1.5\ V^2 + 0.35\ VG]$$

Where:

M = Metabolic rate, watts(W)
W = Subject weight, kg
L = External load, kg   PHE-BP = 29.5 kg   PHE-HL = 11.80kg
V = Speed of walking, m/sec
G = Grade (slope), %
N = Terrain coefficient (N = 1.0 for TM)

Conversion Factors (4,6):

1 mph = 26.8 m/min = 0.447 m/sec = 0.45 m/sec
1 watt = 6.12 Kgm/min = 0.014321 Kcal/min
1 LO_2/min = 5 Kcal/min

$$1 \text{ watt} = \frac{0.014321 \text{ Kcal/min}}{5 \frac{\text{Kcal/min}}{LO_2/\text{min}}} = 0.002864 \; LO_2/\text{min}$$

Sample Calculation:

70 kg subject carrying 11.8 kg external load (i.e., PHE-HL) while walking on the TM at 2.5 mph, 12% grade.

Conversions:

2.5 mph = 2.5 X 0.447 m/sec = 1.13 m/sec
thus, V = 1.13 m/sec

$$M = 1.5(70) + 2.0(70+11.8)(11.8/70)^2 + 1.0(70+11.8)[1.5(1.13)^2 + 0.35(1.13)(12)]$$

$$= 105 + 2.0(81.8)(0.169)^2 + 1.0(81.8)[1.5(1.28) + 4.75]$$

$$= 105 + 4.67 + 545.2$$

$$= 654.87 = 654.9 \text{ Watts}$$

$$654.9 \text{ Watts X } 0.002864 \frac{LO_2/\text{min}}{\text{Watt}}$$

$$= 1.875 \; LO_2/\text{min}$$

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16. Abstract
INTRODUCTION: Kennedy Space Center (KSC) is the focal point for preflight preparation and launch of numerous spacecraft. The potential for exposure to toxins used in the propulsion systems of these spacecraft dictates the use of a whole body protective suit, the Propellant Handler's Ensemble (PHE). The weight, structure, and operating parameters of the PHE may be expected to have a significant impact upon the metabolic, cardiovascular, and thermal responses of the user, especially during ambient temperature extremes and high workload situations. METHODS: Four male subjects participated in tests in -7, 23 and 43°C (20, 74 and 110°F) environments in two versions of the PHE, the autonomous backpack (BP) and the hoseline (HL) supplied configuration. Measurements included heart rate (HR), rectal temperature, four skin temperatures, oxygen (O_2) and carbon dioxide (CO_2) in the helmet area, interior suit temperature, and suit pressure. Exercise metabolism was estimated from HR, PHE weight, and treadmill speed and grade. RESULTS: The HR responses between each

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PHE configuration were not statistically different. As a percentage of HR maximum, the mean values were 79% (COLD), 84% (LAB), and 90% (HOT). Helmet O_2 and CO_2 levels were correlated with % HR max ($P \leq 0.001$). Rectal temperatures were similar for each PHE configuration, except in the HOT exposure where the BP version exceeded the HL configuration ($P \leq 0.05$). CONCLUSIONS: In nearly every instance the HR was driven to moderately high levels, the supplied respiratory gases were not optimum, and thermal adversity was a primary stressor. Our findings suggest that medical and physical fitness standards, along with operational restrictions, should be imposed upon PHE users to avoid situations that could adversely affect the worker.