AD ________

REPORT NO ________

Thermal and Moisture Properties of Mission Oriented Protective Posture (MOPP) Clothing at High Altitude

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

August 1995

UNITED STATES ARMY MEDICAL RESEARCH AND MATERIEL COMMAND

DISCLAIMER

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

Human subjects participated in these studies after giving their free and informed voluntary consent. All Investigator adhered to U.S. Army Medical Research and Materiel Command (USAMRMC) Regulation 70-25 on Use of Volunteers in Research

Citations of commercial organization and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

DTIC AVAILABILITY NOTICE

Qualified requestors may obtain copies of this report from Commander, Defense Technical Information Center (DTIC) (formally DDC), Cameron Station, Alexandria, Virginia 22314.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

August 1995

Technical Report

Thermal and Moisture Properties of Mission Oriented Protective Posture (MOPP) Clothing at High Altitude

S.KW. Chang, W.R. Santee, L.A. Blanchard, R.R. Gonzalez

US Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

Same as 7.

The effects of hypobaria on the thermal insulative properties and heat transfer characteristics of the BDU and BDO in all four MOPP configurations were examined. Barometric pressure of 429 Torr (mmHg) was created in the USARIEM hypobaric chamber. The sea level environment was used as a baseline condition. Skin, clothing, and dew point temperatures were measured on subjects standing and walking on a treadmill. We found that hypobaria had minimal effect on the intrinsic clothing insulation values. For the less insulative BDU, hypobaria did not appreciably affect clothing insulation values. For the more insulative BDO, an average difference of 0.2 clo was found between the sea level and the altitude environments. The BDO MOPP level increase, from MOPP0 (BDU) to MOPP4, was also accompanied by a gradual increase in the average skin temperature difference between sea level and altitude environments. An interesting outcome of clothing insulation was that it segregated, thermally, the skin surface from the clothing surface. At one site, the heat transfer processes operated almost independently from the other site. As a result, in hypobaric environment, the skin temperature was found to be lower, but the clothing temperature higher, than at sea level.

chemical protective clothing, hypobaric environment, altitude, skin temperature, clothing temperature

46

Unclassified Unclassified Unclassified UL

Thermal and Moisture Properties of Mission Oriented Protective Posture (MOPP) Clothing at High Altitude

by

S. KW. Chang, W. R. Santee, L. A. Blanchard, and R. R. Gonzalez

AUGUST 1995

U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
Natick, Massachusetts 01760-5007

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Clothing insulation is the result of complex interactions between heat transfer mechanisms and clothing material thermal resistances. The effects of hypobaria on the thermal insulative properties and heat transfer characteristics of the U.S. Army battledress uniform (BDU) and U.S. Army chemical protective overgarment (BDO) in all four Mission Oriented Protective Posture (MOPP) configurations were examined. Barometric pressure of 429 Torr (mmHg), comparable to the condition at terrestrial elevation of 4,570 m (15,000 ft) above sea level was created in the U.S. Army Research Institute of Environmental Medicine (USARIEM) hypobaric chamber. The sea level environment was used as a baseline condition. Skin, clothing, and dew point temperatures were measured on subjects standing and walking on a treadmill.

We found that hypobaria had minimal effect on the intrinsic clothing insulation values. For the less insulative BDU, hypobaria did not appreciably affect clothing insulation values. For the more insulative BDO, an average difference of 0.2 clo (clo=0.155 $m^2 \bullet K \bullet W^{-1}$) was found between the sea level and the altitude environments. The MOPP level increase, from MOPP0 (BDU) to BDO MOPP4, was also accompanied by a gradual increase in the average skin temperature difference between sea level and altitude environments.

An interesting outcome of clothing insulation was that it very effectively isolated, thermally, the skin surface from the clothing surface. At one site, the heat transfer processes operated almost independently from the other site. At the skin surface, evaporation was the dominant process, while at the outer clothing surface, convection dominated. At higher altitude, enhanced evaporative transfer resulted in a lower skin temperature, while reduced convection impeded heat dissipation from clothing surface to the ambient environment, hence elevating the clothing temperature. Therefore, in hypobaric environment, the skin temperature was found to be lower, but the clothing temperature higher, than at sea level.

INTRODUCTION

This study examined the effect of hypobaria on the thermal insulative properties, and heat transfer and moisture permeability characteristics of U.S. Army Battledress Uniform (BDU) and U.S. Army chemical protective Battledress Overgarment (BDO) in all four Mission Oriented Protective Posture (MOPP) configurations. It is known that adding the layers of BDO over the BDU increases the risk of heat stress. MOPP increases the possibility of heat casualties and degrades the soldiers' performance [Field Manual 3-4]. MOPP restricts the body's natural cooling mechanisms of convective and evaporative heat loss because of its high thermal insulation and low water vapor permeability. Moreover, when a soldier is required to perform physical activity, it adds to the body's heat production, and further aggravates the strain imposed by the MOPP suits.

Higher terrestrial elevations adds another variable to the thermal insulative property evaluation of BDU and BDO. The reduction in barometric pressure (P_b) at higher elevations alters the heat transfer mechanisms that affect clothing insulation. P_b has pronounced effects on air density and mass diffusivity, which in turn change the convective and evaporative heat transfer processes. It is known that as P_b decreases, convective heat transfer diminishes [Chang et al. 1990]. Also, the evaporative transfer mechanism appears to be enhanced [Gonzalez et al. 1985]. While the evaporative heat transfer does not alter clothing insulation directly, evaporative heat loss does affect skin and clothing temperatures, thus indirectly influencing clothing insulation. The efficacy of evaporative heat transfer increases with elevations in altitude. Furthermore, insulation of air, trapped between clothing layers and at the clothing-skin boundary layer, increases with decreasing P_b [Gonzalez, 1987]. However, the combined or net effects on clothing insulation by these P_b-mediated changes are not presently known and have not been studied thoroughly. This study examines, quantitatively, the hypobaric effect on the insulative properties of BDU and BDO, and its potential impact on the soldier's performance and well-being.

METHODS

CHAMBER

The U.S. Army Research Institute of Environmental Medicine (USARIEM) hypobaric chamber was used to simulate a terrestrial altitude of 4,570 m (15,000 ft) above sea level. The chamber simulated this high altitude environment by decreasing the ambient atmospheric pressure to 429 ± 1 Torr (mmHg). The control baseline studies were conducted at sea level, 760 ± 10 Torr atmospheric pressure (sea level barometric pressure at USARIEM on the test days) in the same chamber. The ambient temperature within the chamber was maintained at 22.0 °C, with relative humidity at 50%. The wind speed was maintained at 1.0 m/s with the aid of a circulating fan. The air velocity within the chamber was measured with a cup anemometer. The chamber temperature was measured at two points (on opposite sides of the treadmill) with copper-constantan thermocouples.

SUBJECTS

Eight males, between the ages of 18 to 23, served as volunteer subjects. The volunteers received a verbal briefing on the purpose, procedures and risks of the study, and each signed an informed consent agreement. Each volunteer received a medical clearance from a medical officer. All testing procedures conformed to the U.S. Army Regulation AR 70-25, Use of Volunteers for Research.

The physical characteristics of average height, weight, body (Dubois) surface area, and maximum $\dot{V}O_2$ of the subjects are shown below ($\dot{V}O_2$ data extracted from the subjects' recent historical database).

Height (m)	Weight (kg)	Body Surface Area (m^2)	Maximum $\dot{V}O_2$ (l/min)
1.77 ± 0.11	77.6 ± 9.6	1.95 ± 0.18	4.28 ± 0.53

CLOTHING ENSEMBLES

The U.S. Army temperate zone BDU consists of a coat and trousers. The uniform is loose fitting to allow body ventilation. The material is a 50/50 nylon/cotton twill, weighing 234 g/m^2 (7 oz/yd^2). The exterior print pattern is four-color woodland camouflage. The BDU was worn with the Army regular issue leather combat boots. The BDO is a two-layer garment of coat and trousers. The outer fabric shell is a 50/50 nylon/cotton twill, with a durable water-repellent to repel liquid agents. This outer shell is laminated to an inner layer of polyurethane foam liner impregnated with activated carbon. The outer layer pattern is either olive green or four-color woodland camouflage.

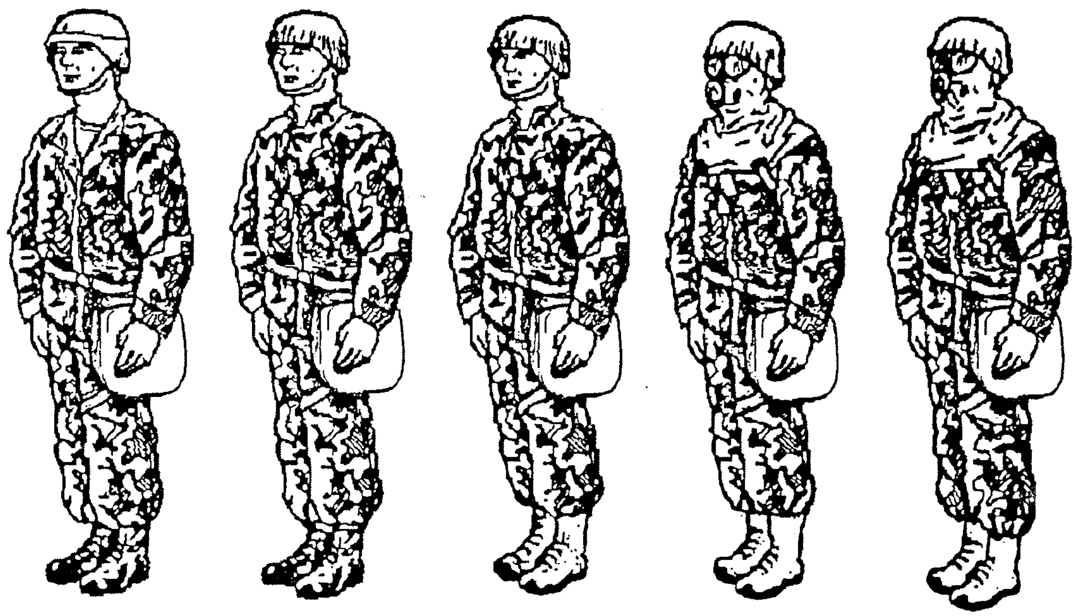
There are a total of five MOPP configurations, described in Table 1 [Field Manual 3-4]. MOPP0 is equivalent to donning only the BDU. MOPP1 to MOPP4 apply to the BDO. All five MOPP configurations were tested. In this study, the BDU was worn over cotton underwear, and the BDO was worn over the BDU. As a baseline condition, a nude (or unclothed) configuration, with the subjects wearing only gym shorts and gym shoes, was also studied.

STUDY DESIGN

The study scenario is described by the following steps.

1. Hydration - 400 ml. water (as a measure to prevent dehydration).
2. Dress and instrumentation.
3. Enter chamber.
4. Decompression of chamber to 4,570 m. condition (approximately 7.5 minutes), for hypobaric sessions.
5. 10 minute resting period while standing on the treadmill.
6. Walking at constant speed of 1.34 m/s (3 mph) on the treadmill for 45 minutes.
7. 10 minute cool-down period while standing on the treadmill.
8. Chamber recompression back to sea level condition (approximately 7.5 minutes), for hypobaric sessions.
9. Exit chamber.
10. Undress.

Table 1 MOPP Configurations (adapted from Field Manual 3-4)



EQUIPMENT	MOPP CONFIGURATIONS				
	MOPP 0	MOPP 1	MOPP 2	MOPP 3	MOPP 4
B D U	Worn	Worn	Worn	Worn	Worn
OVERGARMENT		Worn	Worn	Worn	Worn
OVERBOOTS			Worn	Worn	Worn
MASK/HOOD				Worn	Worn
GLOVES					Worn

INSTRUMENTATION

The instrumentation phase consisted of attaching probes for measuring skin, clothing, dew point, and rectal temperatures, plus a finger-tip heart rate and blood oxygen monitor.

Temperature Measurements

On the subjects, corresponding temperatures were measured from both inside and outside of the clothing ensemble, at approximately the same location, to determine the parameters across the clothing. Regional skin temperatures (T_{sk}) on the forehead, chest, back, upper arm, lower arm, thigh and lower leg were monitored. At these same sites, regional clothing temperature, T_{cl}, were measured on the outer surface of the clothing ensemble. T_{sk} and T_{cl} were measured using copper-constantan thermocouples. At the chest site, the skin and clothing dew point temperatures were measured with dew point temperature sensors [Graichen et al. 1982] similarly placed on the inside (skin surface) and outside (clothing surface) of the uniform ensemble. For the nude configuration, only a skin dew point sensor was used. The body core (rectal) temperature (T_{re}) was monitored with a 10 cm rectal temperature probe. All temperature data were collected at three-second intervals, using a personal computer system.

Other Measurements

Each subject wore a light-weight oxygen (O_2) mask at all testing sessions. The O_2 flow rate was adjusted such that the subject's blood O_2 content was approximately equivalent to that at a sea level condition. The blood oxygen level was monitored with a stand-alone finger tip blood saturation monitoring system. The monitor also measures the heart rate simultaneously. The heart rate and blood oxygen level were displayed continuously and recorded at 10-minute intervals.

It is expected that in a hypobaric environment, the expiratory heat loss will increase. The O_2 mask reduced excessive expiratory heat loss induced by hypobaria, ensuring a uniform baseline for all subjects in both environments. For the BDO, the M17A1 chemical mask was modified to allow the light-weight oxygen mask to be worn inside the chemical mask.

TREADMILL

The subjects walked on a treadmill with 0° incline. The treadmill was operated at a constant speed of 1.34 m/s (3 mph). The walking exercise was stopped at 45 minutes, or if the human use research criteria limits were reached, or when the subject voluntarily terminated. These last two conditions did not occur during the study.

ANALYSIS

Heat Loss

The dry heat exchange, H_{dry}, for a unit area of clothed skin surface, by the processes of radiation and convection, is [Nishi et al. 1975]

$$H_{dry} = h\left(\bar{T}_{cl} - T_a\right) = h \cdot F_{cl}\left(\bar{T}_{sk} - T_a\right) \qquad \text{W/m}^2 \qquad \{1\}$$

where, h is the combined convective and radiant transfer coefficient, $h = h_c + h_r$. Burton's thermal efficiency factor, F_{cl}, is a measure of the resistance of clothing to heat flow [Gonzalez and Cena, 1985]. $\bar{T}_{sk}$, $\bar{T}_{cl}$, and T_a are skin, clothing surface, and ambient temperature, respectively.

The convective transfer coefficient, h_c, is a function of air velocity and has been shown to be proportional to the barometric pressure, P_b [Gagge and Nishi, 1977].

$$h_c \propto \left(P_b/760\right)^{0.55} \qquad \text{W/(m}^2\cdot\text{K)} \qquad \{2\}$$

The evaporative transfer coefficient, h_e, in units of W/(m^2·Torr), is defined as

$$h_e = LR \cdot h_c = LR\left(\frac{760}{P_b}\right) \cdot h_c\left(\frac{P_b}{760}\right)^{0.55} = 2.2\, h_c\left(\frac{760}{P_b}\right)^{0.45} \qquad \{3\}$$

where, LR = Lewis relationship = 2.2 K/Torr at sea level [Gagge and Nishi, 1977].

Clothing Insulation

Surface Air Insulation. Surface air insulation is attributable to air held at the clothing surface boundary layer

$$I_a = \frac{(\bar{T}_{cl} - T_a) \cdot f_{cl}}{0.155 \cdot H_{dry}} \quad \text{clo} \qquad \{4\}$$

The clothing area factor, f_{cl}, typically increases by 20% ± 5% for each clo unit (1 clo = 0.155 $m^2 \cdot K \cdot W^{-1}$). For this study, f_{cl} was taken to be 1.2 for BDU and 1.4 for BDO [Breckenridge and Goldman, 1972].

Intrinsic Clothing Insulation. The intrinsic or basic clothing insulation is the insulation from skin to the clothing surface.

$$I_{cl} = \frac{\bar{T}_{sk} - \bar{T}_{cl}}{0.155 \cdot H_{dry}} \quad \text{clo} \qquad \{5\}$$

Total clothing insulation. Total clothing insulation is measured from the skin surface to the ambient environment.

$$I_{tot} = \frac{\bar{T}_{sk} - T_a}{0.155 \cdot H_{dry}} \quad \text{clo} \qquad \{6\}$$

Evaporative Exchange

Skin Wettedness. Skin wettedness, **w**, describes the percentage of body skin wetted by sweat [Gonzalez and Cena, 1985].

$$w = (P_{dp} - P_a) / (P_{sk} - P_a) \quad \text{dimensionless} \qquad \{7\}$$

where, P_{dp}, P_{sk}, and P_a are water vapor pressure at dew point temperature, T_{sk}, and T_a, respectively.

Evaporative Heat Loss. The evaporative (insensible) heat exchange from skin surface is driven by vapor pressure gradient between skin surface and the ambient air. One model of quantifying the evaporative heat transfer, E_{sk}, was proposed by Woodcock [1962].

$$E_{sk} = \frac{(LR \cdot i_m)}{I_{tot}} \left(P_{sk} - P_a\right) \qquad W/m^2 \qquad \{8\}$$

The moisture permeability index, i_m, is a measure of the resistance of clothing to water vapor passage.

STATISTICAL ANALYSIS

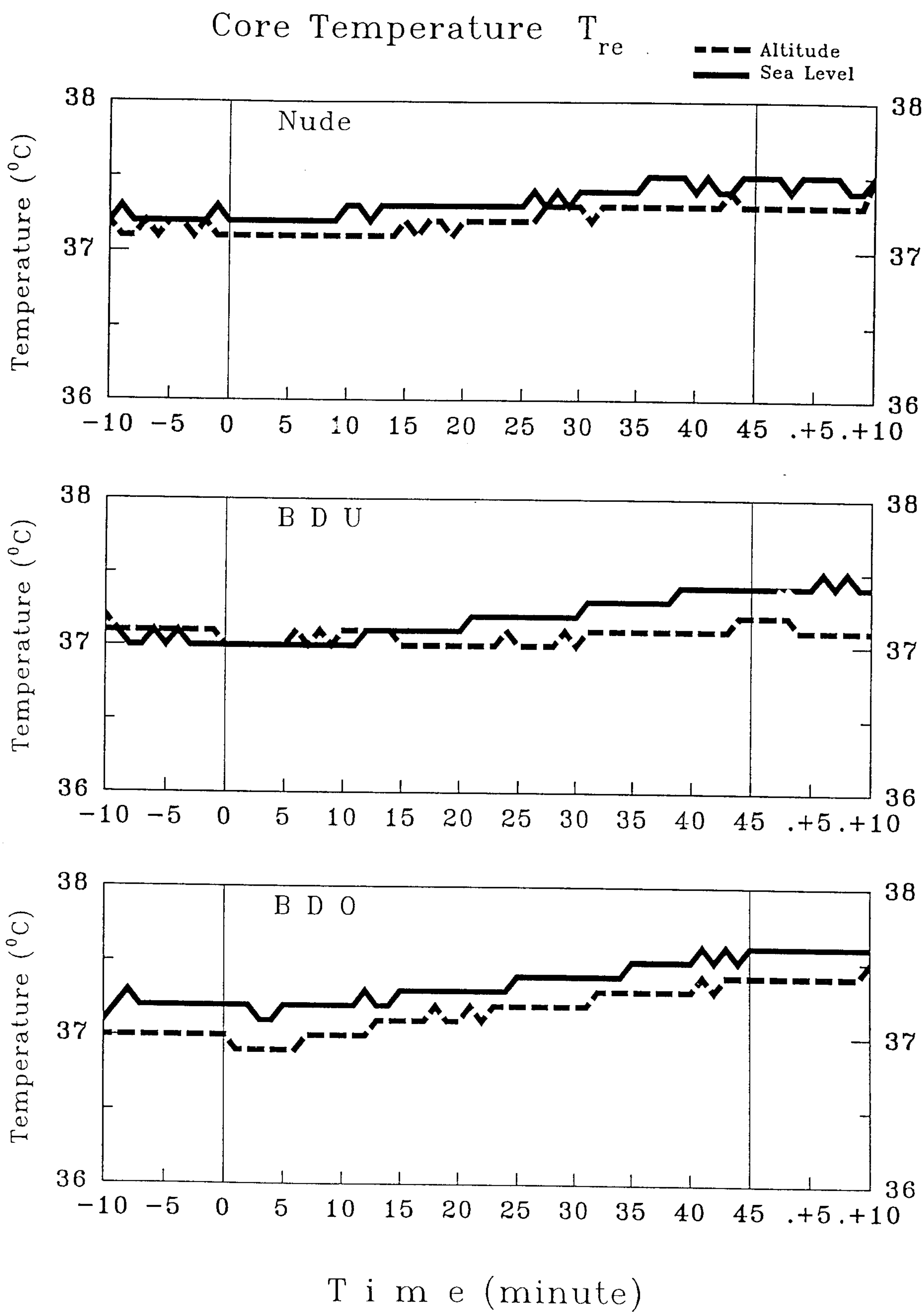
Statistical analysis consisted of repeated measures multiple analysis of variance (MANOVA). Tukey's test (significance level at $\alpha=0.05$) was used as the *post hoc* test for the existence of significant difference between sea level and altitude data, and between clothing configurations. Unless noted otherwise, the differences pointed out in the discussion are statistically significant ($p<0.05$).

RESULTS

The data presented in Figures 1 - 8 are one minute average data points combined from all eight subjects. On the time axis (horizontal axis), negative times (e.g., -10, -5) represent the period prior to the start of treadmill walk. Explicit positive times at the end of walk (e.g., +5, +10) represent rest period after the treadmill exercise. The times at which treadmill walk began and ended are also marked by two vertical time lines.

Figure 1 compares the body core temperatures at sea level and altitude, for clothing configurations Nude, BDU and BDO MOPP 4. The T_{re} shown are the average of the eight subjects. In general, only in BDO MOPP 4 did treadmill walk produce higher

Figure 1


Core Temperature T_{re}
Altitude
Sea Level
Nude
B D U
B D O
Temperature (°C)
38
37
36
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
T i m e (minute)

T_{re} (approximately 0.4°C) at the end, when compared to the beginning of exercise. The differences between sea level and altitude were not statistically significant. The T_{re} data indicate that the rate of body core heat storage was not appreciably different between the two environments.

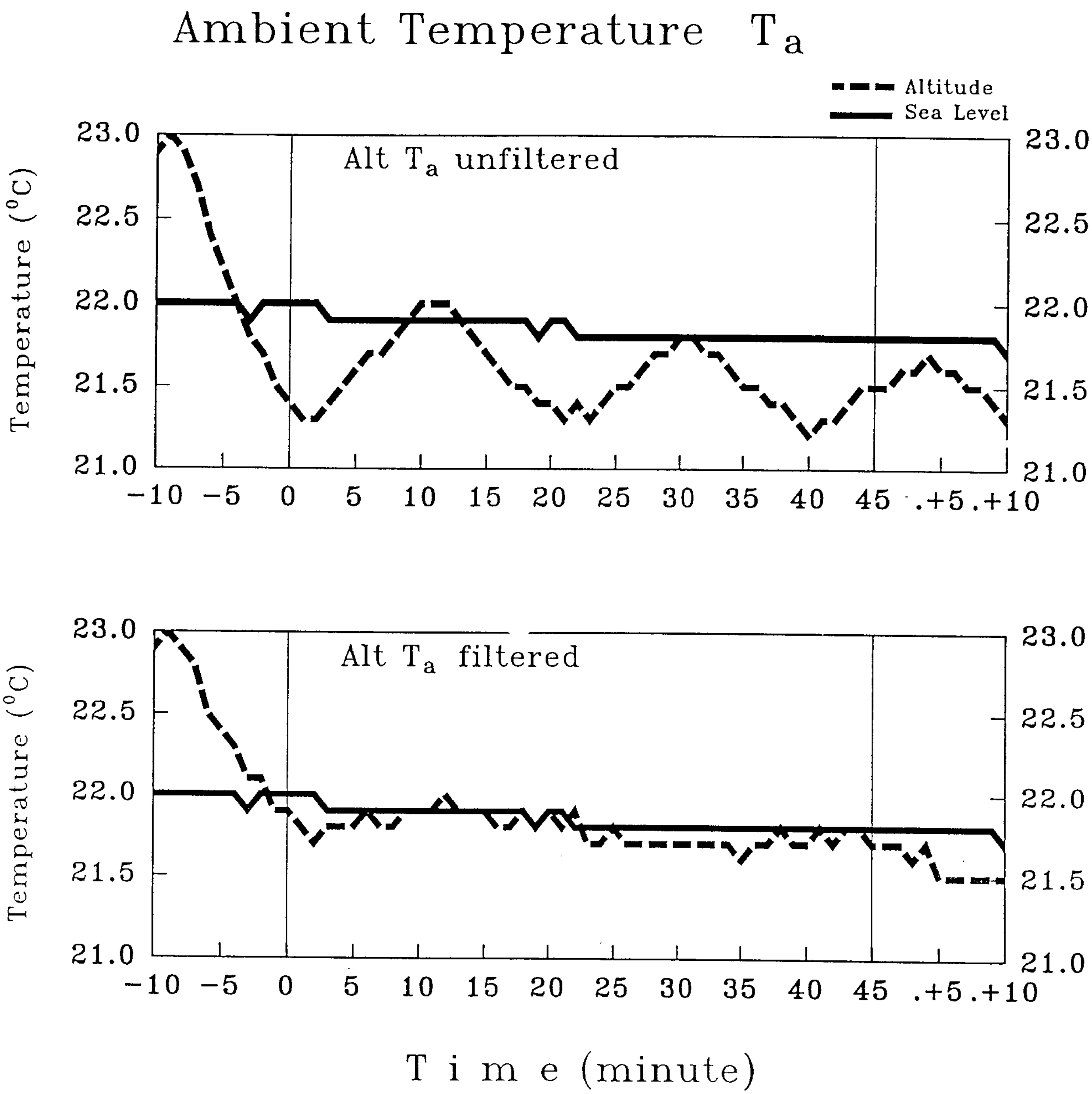
The altitude chamber's environmental temperature was maintained at 21.9 ± 0.1 °C, at sea level condition, as shown in Figure 2. Figure 2 (top graph) also shows that at the 4,570 m (15,000 ft) environment, the chamber temperature displayed a 20-minute sinusoidal cycle. This 20-minute cycle resulted from the chamber temperature control hunting around the temperature set point, representing an inherent operational limitation of the chamber. The 20-minute cycle artifact has been filtered out with a notch filter and the filtered data are also included in Figure 2 (bottom graph). The sea level temperature is included in both sets of graph of Figure 2 for reference.

In Figure 2, the initial large decrease in altitude T_a was not an artifact, but the unavoidable result of chamber dynamics. As the chamber barometric pressure decreased when ascending to the altitude environment, air was removed, the remaining air expanded thus releasing heat. The chamber temperature control then slowly cooled the chamber to give the initial decrease in T_a. The chamber temperature control could not be expected to bring down the temperature instantaneously.

The regional skin temperatures were combined to compute a weighed average skin temperature, $\bar{T}_{sk}$. The weights used were based on the approximate percentage of total body skin surface area of each body segment [Nishi et al. 1975]: head 8%, chest 18%, back 18%, upper arm 8%, lower arm 8%, thigh 20% and lower leg 20%. The same weights were used to compute an average clothing temperature, $\bar{T}_{cl}$. The 20-minute period notch filter used for the T_a was also applied to $\bar{T}_{cl}$, which also showed a 20-minute cycle artifact. The $\bar{T}_{sk}$ was not affected by the chamber temperature swings.

The insulation values of I_{cl} and I_{tot} were computed using Equations {5} and {6}. The intrinsic insulation of BDU averaged 0.6 clo, while I_{cl} of the BDO ensembles varied between 0.8 and 1.50 clo. Since the BDO was worn over the BDU, as expected, the I_{cl} of BDO was two to three times higher than the I_{cl} of BDU. The BDO overgarment accounted for most of the insulation. Further donning of the mask, gloves and overboots did not substantially change I_{cl}.

Figure 2


Ambient Temperature T_a
Altitude
Sea Level
Alt T_a unfiltered
Temperature (°C)
23.0
22.5
22.0
21.5
21.0
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
Alt T_a filtered
Temperature (°C)
23.0
22.5
22.0
21.5
21.0
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
T i m e (minute)

Figures 3, 4, 6, 7, 8 and 9 give the $\bar{T}_{sk}$, $\bar{T}_{cl}$, and I_{cl} data for the six clothing configurations: Nude, BDU, MOPP1, MOPP2, MOPP3, and MOPP4, respectively. For the Nude configuration, there were no clothing temperature data, and I_{tot} (equivalent to I_a) was presented. The data used to plot Figures 3, 4, 6, 7, 8 and 9 are also included in the Appendix, as Tables A1 to A6, to allowed for more detailed examination.

The evaporative heat transfer, E_{sk} in Figure 5, was obtained using Equation {8}. The magnitude of the E_{sk} was most probably an overestimation. Because only one dew point sensor was employed in the study, the dew point temperature for the chest region was used to compute **w** and E_{sk}. Although the chest is the site of high density of sweat glands, the degree of skin wettedness in the chest area may not wholly represent the skin wettedness of other body regions. Also, from the body surface area weights described above, the chest area comprises only 18% of the total body surface area. As Gonzalez & Cena [1985] reported when the local **w** for the chest region approached saturation (i.e. 100%), the overall body **w** could be only in the 30% – 60% range. Since **w** relates directly to E_{sk}, as evident in Equation {9}, the true magnitude of E_{sk} could be only one third as large. The purpose of the E_{sk} data is not for extraction of the exact magnitude of evaporative heat loss, but rather for graphical comparison of the altitude and sea level E_{sk} in continuous time series.

DISCUSSION

Clothing insulation is a function of the dry (nonevaporative) heat loss, H_{dry}, as dictated by Equation {1}. H_{dry} is, in turn, determined by the convective and, to a lesser degree, the radiant heat exchange. In hypobaric environment, the less dense air contains less air molecules to carry heat away from the body. Therefore, at altitude, convection is less efficient in dissipating heat. This can be seen in Equation {2}. The convective coefficient h_c is a function of $(P_b/760)^{0.55}$, hence, h_c decreases with decreasing P_b. Stated in terms of terrestrial elevation, h_c decreases and convective exchange is diminished with increasing elevation. The radiant heat exchange coefficient, h_r, governed by the Stefan-Boltzmann relationship, is not affected by P_b. The h_r averages 5.0 $W{\cdot}m^{-2}{\cdot}K^{-1}$ [Danielsson, 1990]. On the other hand, the evaporative exchange should increase in the hypobaric environment. The evaporative coefficient is inversely proportional to P_b, varying as a function of $(760/P_b)^{0.45}$, shown in Equation {3}. Hence as P_b decreases, h_e increases, and the evaporative heat loss is enhanced. While the evaporative transfer does not alter clothing insulation directly, evaporative heat loss does affect skin and clothing temperatures, thus indirectly influences clothing insulation. These heat transfer effects are then modified by clothing itself. Clothing material creates resistance to heat flux. Moreover, clothing configuration, whether loosely worn or tightly wrapped, also affects heat exchange. The complex interactions of these properties affect the final resultant clothing insulation.

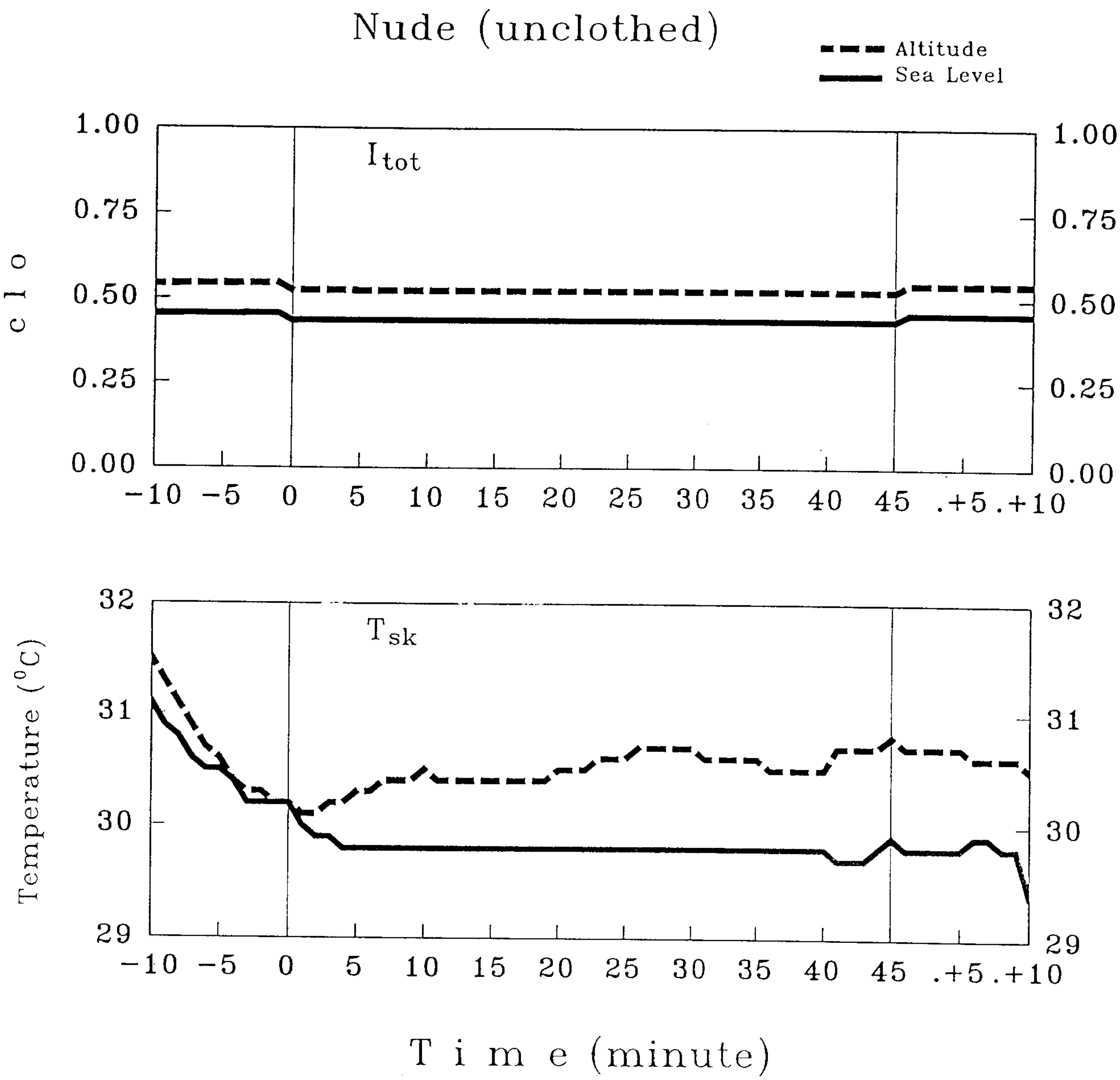
In the following discussion, Δ will be used to denote the difference between the sea level and the altitude environment data.

Nude

The nude configuration served as a baseline condition. In this state, there was zero clothing insulation. The heat exchange between the body and the environment was unhindered by clothing (or minimally hindered by the gym shorts worn). In Figure 3, since there was no clothing, total insulation, I_{tot}, equals exactly the insulation of air layer around the skin surface, I_a. The difference between altitude and sea level I_{tot} ΔI_{tot} (or equivalently, ΔI_a), was slightly less than 0.1 clo. Insulation was higher at altitude because the less dense air was less effective in dissipating heat. Evaporation had minimal contribution because there was very little sweating in this nude configuration.

The effect of convective heat loss can be seen more readily in the $\bar{T}_{sk}$. In Figure 3, during the 10-minute pre-walk resting period, convective heat loss lowered $\bar{T}_{sk}$ for both sea level and altitude. After the start of the treadmill walk, sea level $\bar{T}_{sk}$ continued to decline and then leveled off, while the altitude $\bar{T}_{sk}$ increased gradually. At higher altitude, $\bar{T}_{sk}$ increased possibly because of the diminished convective heat loss. These different progressions resulted in an altitude $\bar{T}_{sk}$ that was 1.0°C higher than sea level $\bar{T}_{sk}$, at the end of the walk. The $\Delta\bar{T}_{sk}$ stayed at approximately 1.0°C during the post-walk rest.

Figure 3


Nude (unclothed)
Altitude
Sea Level
1.00
0.75
0.50
0.25
0.00
c l o
I_{tot}
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
32
31
30
29
Temperature (°C)
T_{sk}
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
T i m e (minute)

BDU

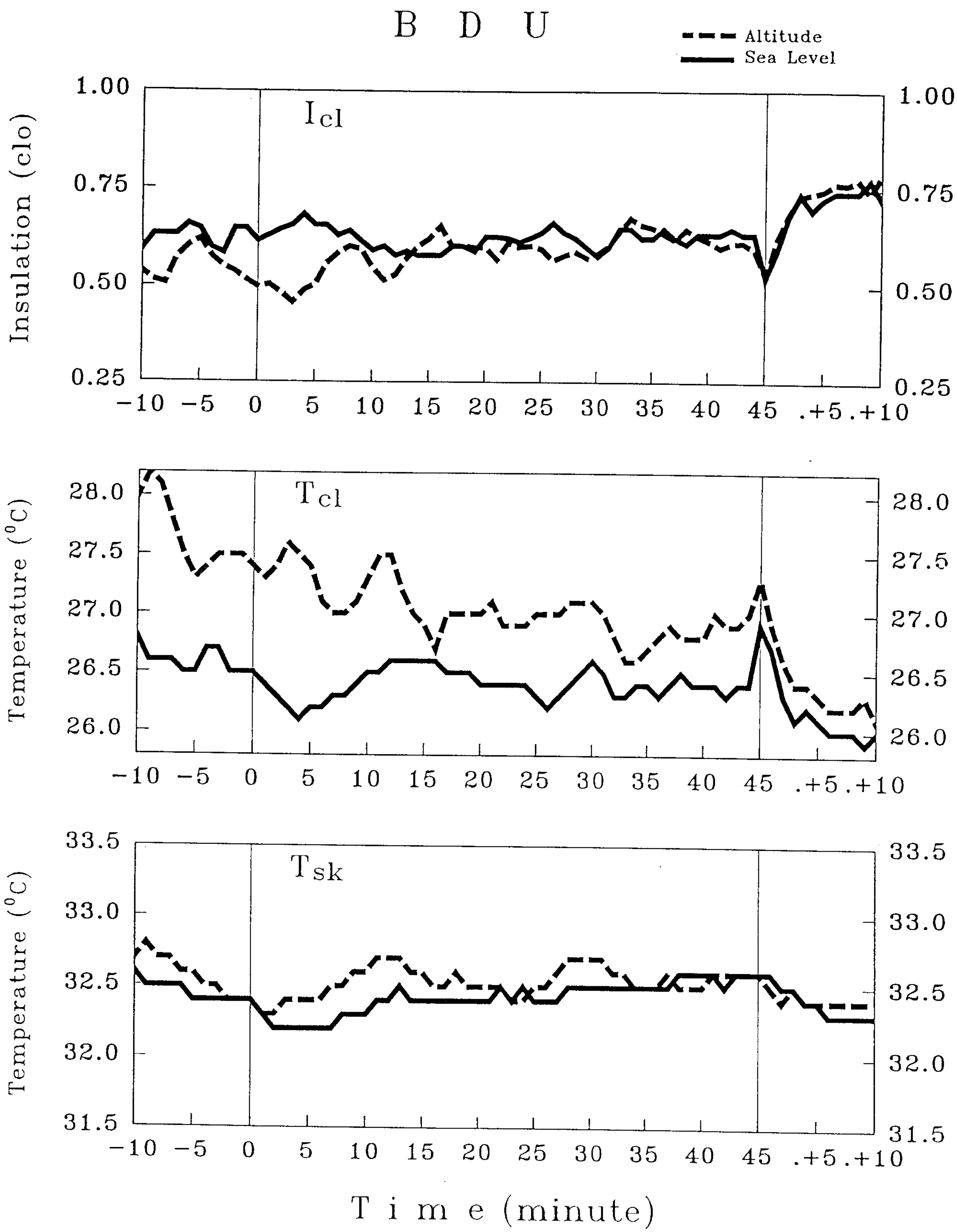
In Figure 4, I_{cl} did not show significant differences between the two environments. The BDU provided the same insulation at altitude as observed at sea level. At the end of the treadmill walk, in both environments, there was an increase in I_{cl} of approximately 0.2 clo. This was due to the decrease in H_{dry} at the cessation of the walking motion. Both Nielsen et al. [1985] and Lotens & Havenith [1991] reported that walking on a treadmill decreased I_a by 30%-50%, translating to a corresponding decrease in H_{dry} when the walking motion stopped.

Figure 4 also shows that there was a noticeable difference in the clothing temperature $\Delta\bar{T}_{cl}$ but not in skin temperature $\Delta\bar{T}_{sk}$. It appears that heat generated by the body flowed from the skin surface to the outer clothing surface just as easily at altitude as at sea level. Negligible ΔI_{cl} resulted in negligible $\Delta\bar{T}_{sk}$, because resistances to heat flow were similar in both environments. At the outer clothing surface, heat dissipation to the ambient air was however affected by the barometric pressure. At higher altitude, decreased air density reduced the efficiency of convective heat transfer, impeding heat dissipation from outer clothing surface, resulting in higher $\bar{T}_{cl}$. Furthermore, it is reasonable to assume that the heat content could not be transported back to the skin surface because of unfavorable temperature gradient, i.e. local skin temperature was higher than local clothing temperature. To summarize, negligible ΔI_{cl} resulted in negligible $\Delta\bar{T}_{sk}$, but the effect of barometric pressure difference resulted in a noticeable $\Delta\bar{T}_{cl}$.

Evaporation occurred primarily from the uncovered head and facial region. Presumably, evaporation could also take place through the clothing apertures such as the collar and sleeve openings. The evaporative heat loss, E_{sk}, for BDU in Figure 5, conformed to the theoretical prediction. As expected, E_{sk} was higher at altitude than at sea level. The ΔE_{sk} began to become significant at the 20-minute mark.

The $\bar{T}_{sk}$ and E_{sk} data also suggest that the altitude induced changes in convection and evaporation balanced each other. Because E_{sk} was higher at altitude, and yet $\Delta\bar{T}_{sk}$ was negligible, the logical conclusion must be that the P_b induced <u>decrease in convective transfer</u> and the P_b induced <u>increase in evaporative transfer</u> were approximately equal in magnitude. Thus, the effects canceled out.

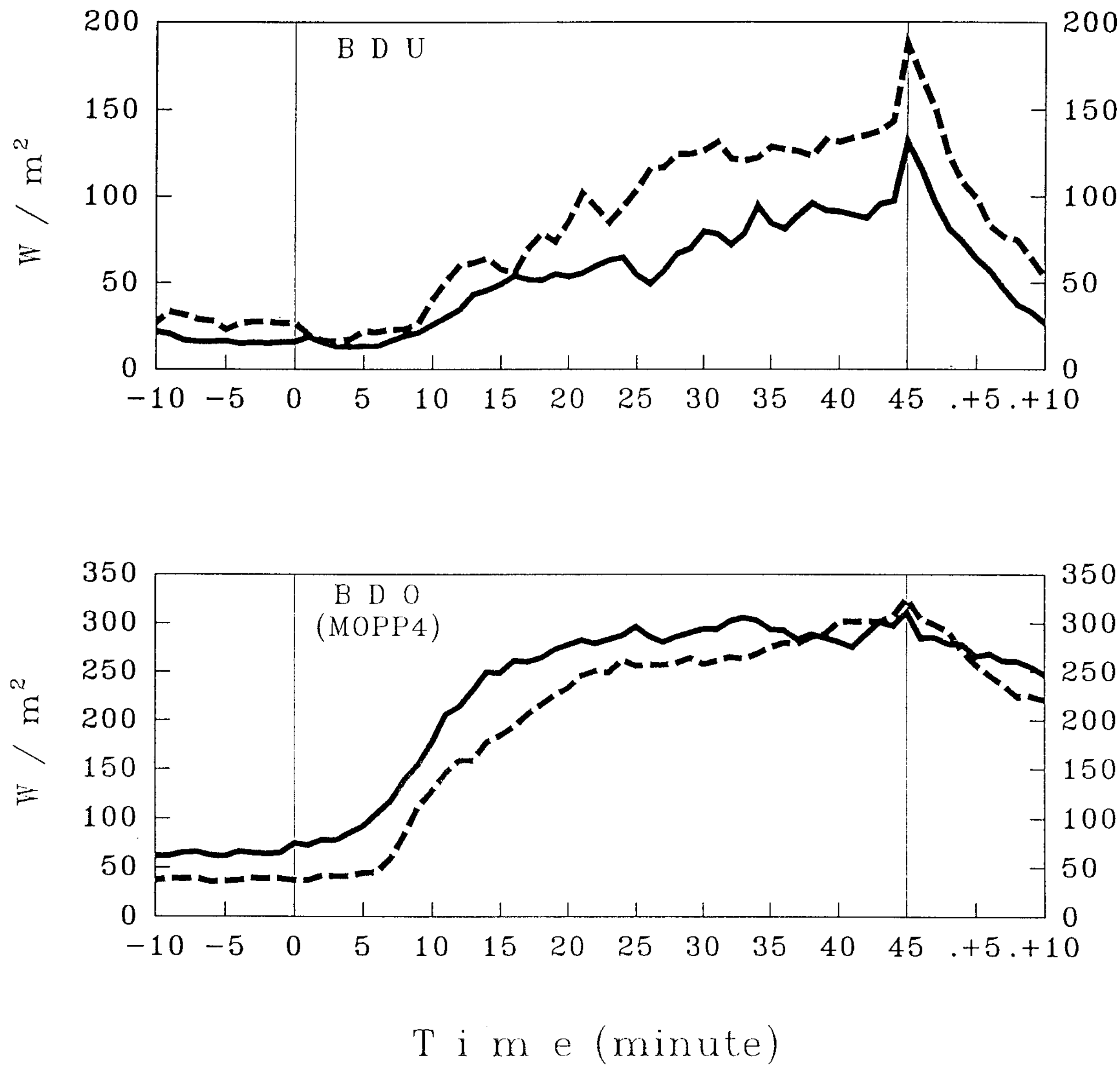
Figure 4



B D U
Altitude
Sea Level
Icl
Insulation (clo)
1.00
0.75
0.50
0.25
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
Tcl
Temperature (°C)
28.0
27.5
27.0
26.5
26.0
Tsk
33.5
33.0
32.5
32.0
31.5
Time (minute)

Figure 5

Evaporative Heat Loss (E_{sk})



BDO

As expected, with the donning of the overgarment in MOPP1, I_{cl} increased considerably from that of the BDU. However, the additional donning of the overboots (MOPP2), mask/hood (MOPP3), and gloves (MOPP4) did not further increase the insulation value of the BDO. Havenith et al. [1990] reported a 53% decrease in clothing insulation when walking against wind. In this study, Figures 6–9 show that walking decreased sea level I_{cl} between 30% to 40%. At altitude, the decrease in I_{cl} was comparable. In general, I_{cl} at high altitude was lower than I_{cl} at sea level. The ΔI_{cl} was approximately 0.2 clo.

Across the MOPP configurations, $\bar{T}_{cl}$ were consistently higher at high altitude than at sea level. The data seem to indicate heat retention by the clothing ensemble. The metabolic heat was transported away from the body and stored in the layers of clothing ensemble. The trapped air mass between the multiple clothing layers of the BDO ensemble provided substantial storage capacity. This stored heat could only dissipate by convection to the ambient environment. The low permeability of the BDO, most likely worsened by its water repellent outer finish, impeded the migration of water vapor to the outer clothing surface. Hence, evaporative heat loss could not operate to dissipate the heat stored in the clothing layers. Only convective heat loss could occur. Lower convective heat transfer in the hypobaric environment resulted in the observed higher $\bar{T}_{cl}$ at altitude.

At altitude, $\bar{T}_{sk}$ was lower than at sea level. The data suggested that, as a result of higher diffusivity, the evaporative heat loss from the skin surface was higher at altitude. The fact that the $\Delta\bar{T}_{sk}$ trend was consistent through Figures 6–9, supports a higher evaporative heat loss at high altitude. Unfortunately, the E_{sk} data could not provide additional support, as it did for the BDU case. Under the BDO, the skin surface (chest region) became completely saturated (**w** = 100%) starting from the 20-minute mark, thus rendered the ΔE_{sk} data (in Figure 5).

$\bar{T}_{sk}$ is also the only parameter for which the MOPP configurations contributed to increasingly larger sea level–altitude difference. For MOPP1 (Figure 6), $\Delta\bar{T}_{sk}$ was negligible. $\Delta\bar{T}_{sk}$ gradually increased through MOPP2 (Figure 7) and MOPP3 (Figure 8). With MOPP4, $\Delta\bar{T}_{sk}$ was as much as 0.8°C higher at sea level than at altitude. With the donning of the overboots, mask/hood and gloves, evaporative heat loss from the skin surface became increasingly impeded, resulting in the increasingly high $\bar{T}_{sk}$ at each succeeding stage of MOPP.

An interesting effect of the high insulation of the BDO is that it very effectively isolated, thermally, the skin surface from the outer clothing surface. The heat and moisture transfers from the two surfaces, skin and outer clothing, became almost independent. The result was the dominance of either convective or evaporative transfer at these sites. In Figures 6–9, the $\bar{T}_{sk}$ data suggest that at the skin site, evaporative heat transfer dominated. Evaporation transported heat away from the skin surface to the clothing ensemble. The hypobaria induced increase in evaporative heat loss was evident, resulting in a lower $\bar{T}_{sk}$ at altitude. However, the heavy insulation of the BDO prevented sweat vapor from migrating to the outer clothing surface. From the outer clothing surface, heat loss was primarily through convection, evaporation was minimal. Hypobaria induced decrease in convective heat loss at the outer clothing surface resulted in higher $\bar{T}_{cl}$ at altitude. Therefore, clothing insulation elicited a lower $\bar{T}_{sk}$, but a higher $\bar{T}_{cl}$ at the hypobaric environment, when compared to the results at sea level.

Figure 6

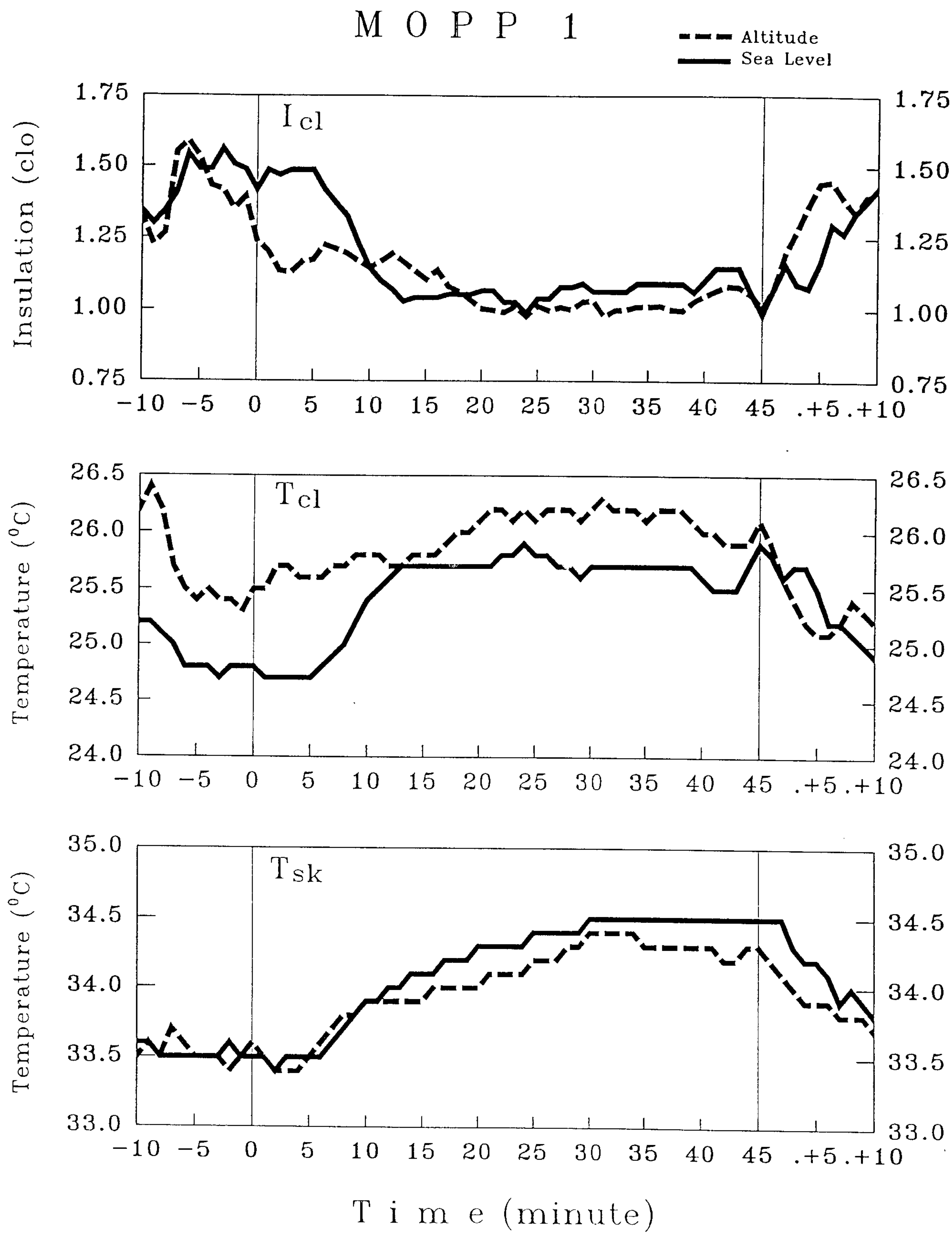
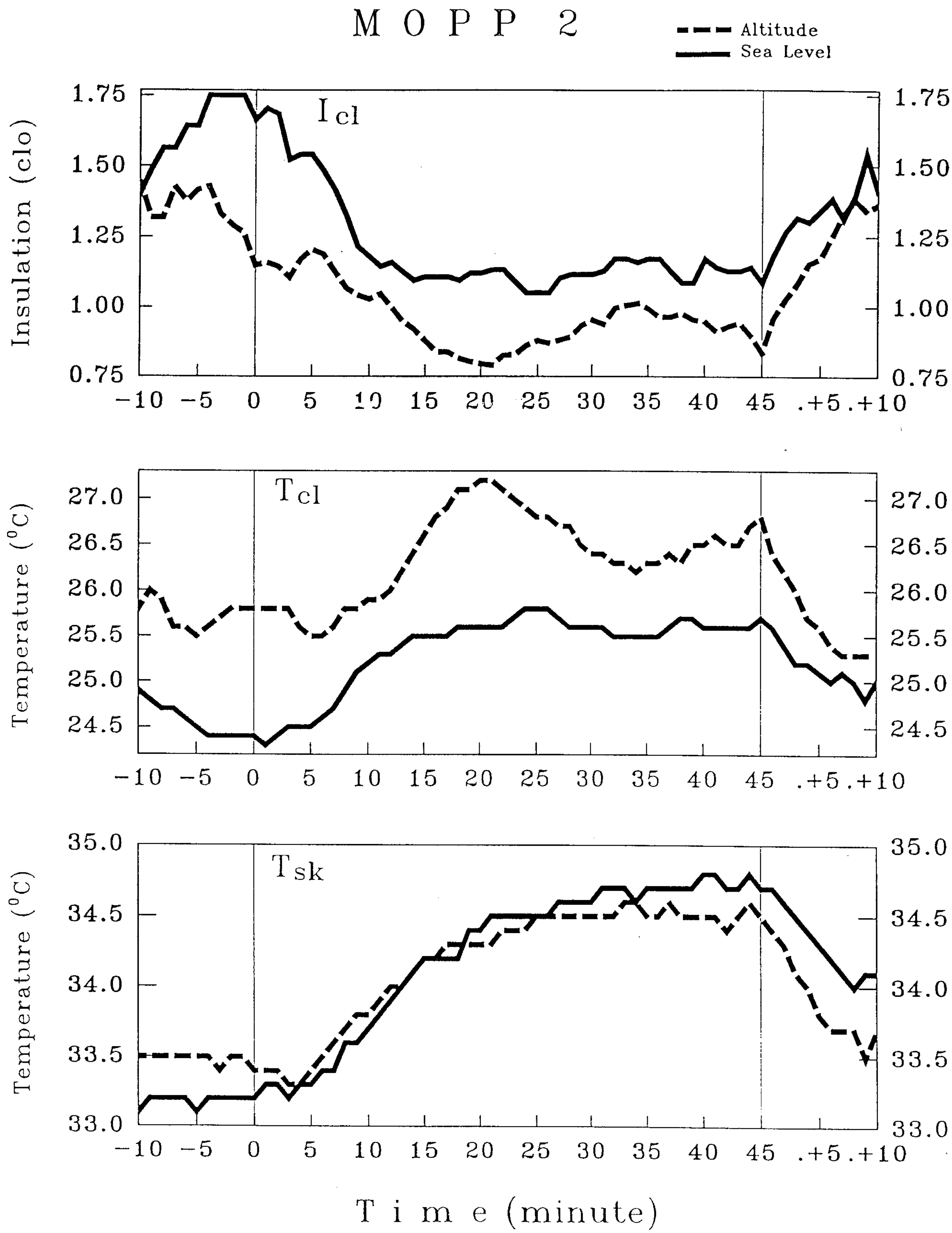
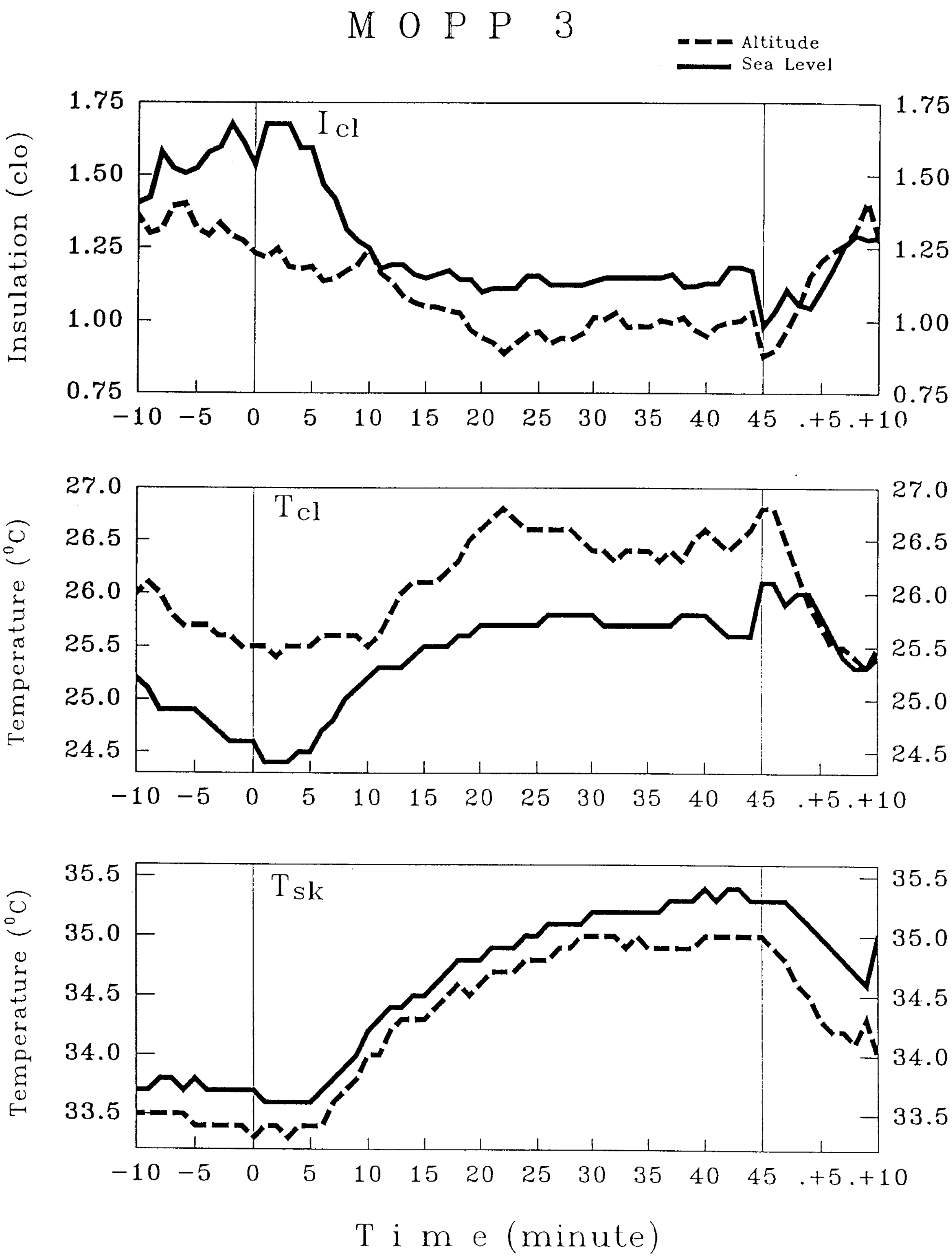

M O P P 1
Altitude
Sea Level
Icl
Insulation (clo)
1.75
1.50
1.25
1.00
0.75
Tcl
Temperature (°C)
26.5
26.0
25.5
25.0
24.5
24.0
Tsk
Temperature (°C)
35.0
34.5
34.0
33.5
33.0
−10 −5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
T i m e (minute)

Figure 7



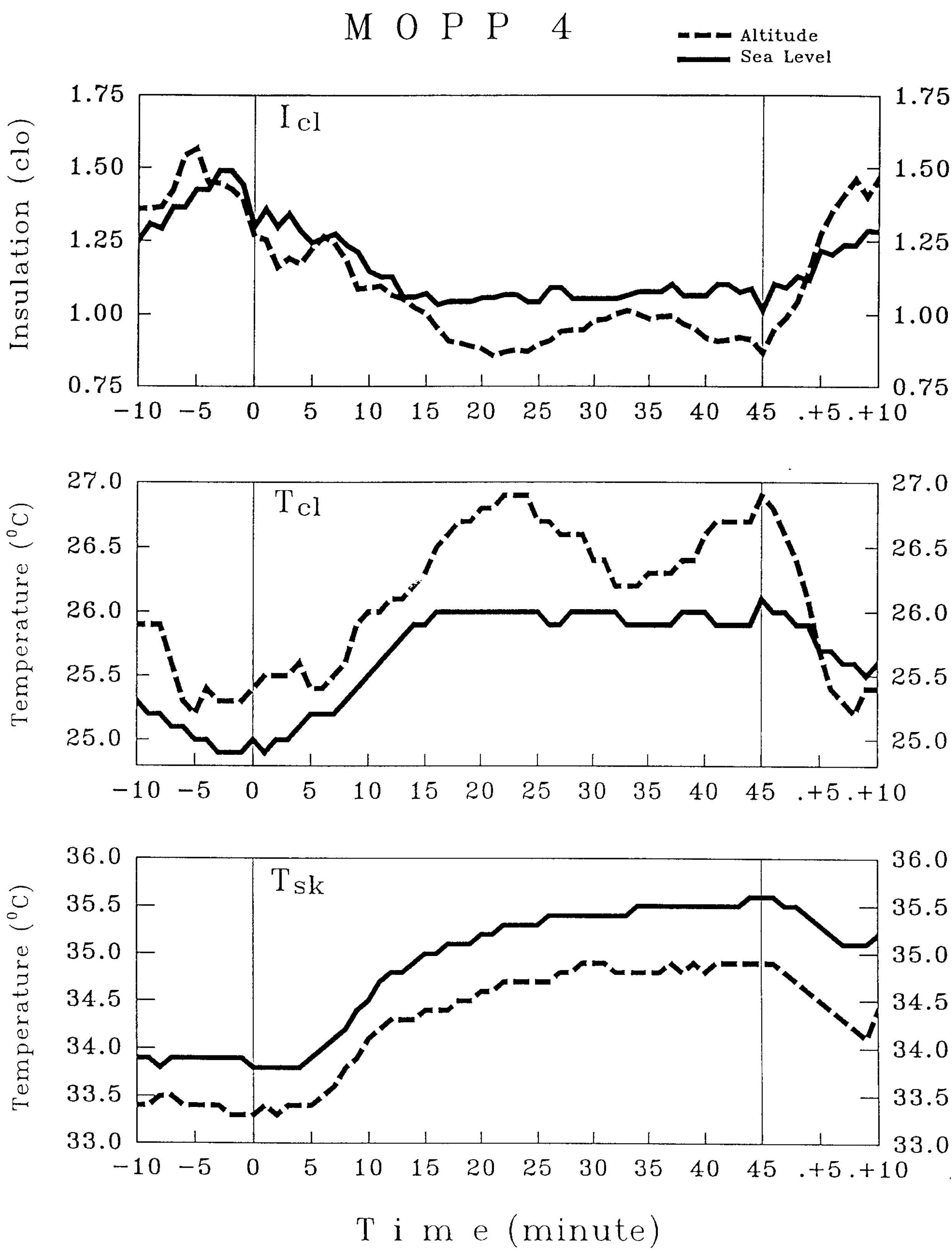
M O P P 2
Altitude
Sea Level
Insulation (clo)
Icl
1.75
1.50
1.25
1.00
0.75
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5.+10
Temperature (°C)
Tcl
27.0
26.5
26.0
25.5
25.0
24.5
Tsk
35.0
34.5
34.0
33.5
33.0
T i m e (minute)

Figure 8



M O P P 3
Altitude
Sea Level
Icl
Insulation (clo)
1.75
1.50
1.25
1.00
0.75
Tcl
Temperature (°C)
27.0
26.5
26.0
25.5
25.0
24.5
Tsk
Temperature (°C)
35.5
35.0
34.5
34.0
33.5
-10 -5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
T i m e (minute)

Figure 9


MOPP 4
Altitude
Sea Level
Icl
Tcl
Tsk
Insulation (clo)
Temperature (°C)
Temperature (°C)
1.75
1.50
1.25
1.00
0.75
27.0
26.5
26.0
25.5
25.0
36.0
35.5
35.0
34.5
34.0
33.5
33.0
−10 −5 0 5 10 15 20 25 30 35 40 45 .+5 .+10
Time (minute)

CONCLUSION

Hypobaria had minimal effects on the intrinsic clothing insulation values. For the less insulative BDU, hypobaria did not affect clothing insulation values. For the more insulative BDO, a maximum difference of 0.2 clo was found between the sea level and altitude environments. We also found that the trapped air mass within clothing layers, not only provided insulation, but also has a large capacity to store metabolic heat.

One interesting effect of high clothing insulation is that it very effectively insulated the skin surface from the outer clothing surface. At one site, the heat transfer mechanisms operated almost independently from the other site. The result was the dominance of either convective or evaporative transfer at these sites. Evaporative transfer dominated at the skin surface. The hypobaria-induced increase in evaporative heat transfer resulted in lower $\bar{T}_{sk}$, at altitude. Heat dissipation from the clothing ensemble to the ambient environment was determined primarily by convection. The heavy BDO insulation prevented moisture from penetrating through the layers of clothing ensemble. At the outer clothing surface, evaporative heat transfer was minimal. The reduced convective heat transfer in the hypobaric environment resulted in higher $\bar{T}_{cl}$, at altitude. Therefore, the combined effects of clothing insulation and hypobaria produced lower $\bar{T}_{sk}$ but higher $\bar{T}_{cl}$ at altitude, when compared to the sea level results.

REFERENCES

Breckenridge, J.R. and Goldman, R.F. Human solar heat load. ASHRAE Trans, 78(I):110-119, 1972.

Chang, S.KW., Santee, W.R. and Gonzalez, R.R. Convective heat transfer in hypobaric environments. Aviat Space Environ Med, (Abstract), 60(5):494, 1990.

Danielsson, U. Convective heat transfer measured directly with a heat flux sensor. J Appl Physiol, 68(3):1275-1281, 1990; .

Field Manual 3-4. NBC protection. Department of the Army, Headquarters, Washington D.C., 29 May 1992.

Gagge, A.P. and Nishi, Y. Heat exchange between human skin surface and thermal environment. In: Handbook of Physiology - Reactions to Environmental Agents. (chap. 5) D.H.K. Lee (ed.), Section Head, American Physiological Society, Bethesda, MD: 69-92, 1977.

Gonzalez, R.R. Biophysics and physiological integration of proper clothing for exercise. In: Exercise and Sport Science Reviews. K.B. Pandolf (ed.), Macmillan Pub. Co., New York: 261-295, 1987.

Gonzalez, R.R. and Cena, K. Evaluation of vapor permeation through garments during exercise. J Appl Physiol, 58(3):928-935, 1985.

Gonzalez, R.R., Kolka, M.A. and Stephenson, L.A. Biophysics of heat exchange in hypobaric environments. Federal Proc, (Abstract), 44:1564, 1985.

Graichen, H., Rascati, R. and Gonzalez, R.R. Automatic dew-point temperature sensor. J Appl Physiol: Respirat Environ Exercise Physiol, 52(6):1658-1660, 1982.

Havenith, G., Heus, R. and Lotens, W.A. Resultant clothing insulation: a function of body movement, posture, wind, clothing fit and ensemble thickness. Ergonomics, 33(1):67-84, 1990.

Lotens, W.A. and Havenith, G. Calculation of clothing insulation and vapour resistance. Ergonomics, 34(2):233-254, 1991.

Nielsen, R., Olesen, B.W. and Fanger, P.O. Effect of physical activity and air velocity on the thermal insulation of clothing. Ergonomics, 28(12):1617-1631, 1985.

Nishi, Y. and Gagge, A.P. Moisture permeation of clothing—A factor governing thermal equilibrium and comfort. ASHRAE Trans 76(I):137-145, 1970.

Nishi, Y., Gonzalez, R.R. and Gagge, A.P. Direct measurement of clothing heat transfer properties during sensible and insensible heat exchange with thermal environment. ASHRAE Trans, 81:183-199, 1975.

Woodcock, A.H. Moisture transfer in textile systems, part I. Textile Res J, 32(8):628-633, 1962.

APPENDIX

The $\bar{T}_{sk}$, $\bar{T}_{cl}$, and I_{cl} data used to plot Figures 3, 4, 6, 7, 8, and 9 (respectively for the six clothing configurations: Nude, BDU, MOPP1, MOPP2, MOPP3, and MOPP4) are presented as Tables A1 to A6, to allowed for subsequent examination.

Table A1 Nude

	Sea Level		Altitude	
minute	Tsk	I tot	Tsk	I tot
-10	31.1	0.454	31.5	0.541
-9	30.9	0.454	31.3	0.542
-8	30.8	0.454	31.1	0.542
-7	30.6	0.455	30.9	0.543
-6	30.5	0.455	30.7	0.543
-5	30.5	0.455	30.6	0.544
-4	30.4	0.455	30.4	0.544
-3	30.2	0.456	30.3	0.545
-2	30.2	0.456	30.3	0.545
-1	30.2	0.456	30.2	0.545
0	30.2	0.435	30.2	0.524
1	30.0	0.436	30.1	0.524
2	29.9	0.436	30.1	0.524
3	29.9	0.436	30.2	0.524
4	29.8	0.436	30.2	0.524
5	29.8	0.436	30.3	0.523
6	29.8	0.436	30.3	0.523
7	29.8	0.436	30.4	0.523
8	29.8	0.436	30.4	0.523
9	29.8	0.436	30.4	0.523
10	29.8	0.436	30.5	0.523
11	29.8	0.436	30.4	0.523
12	29.8	0.436	30.4	0.523
13	29.8	0.436	30.4	0.523
14	29.8	0.436	30.4	0.523
15	29.8	0.436	30.4	0.523
16	29.8	0.436	30.4	0.523
17	29.8	0.436	30.4	0.523
18	29.8	0.436	30.4	0.523
19	29.8	0.436	30.4	0.523
20	29.8	0.436	30.5	0.523
21	29.8	0.436	30.5	0.523
22	29.8	0.436	30.5	0.523
23	29.8	0.436	30.6	0.522
24	29.8	0.436	30.6	0.522
25	29.8	0.436	30.6	0.522
26	29.8	0.436	30.7	0.522
27	29.8	0.436	30.7	0.522
28	29.8	0.436	30.7	0.522
29	29.8	0.436	30.7	0.522
30	29.8	0.436	30.7	0.522

Table A1 Nude (continued)

	Sea Level		Altitude	
minute	Tsk	I tot	Tsk	I tot
31	29.8	0.436	30.6	0.522
32	29.8	0.436	30.6	0.522
33	29.8	0.436	30.6	0.522
34	29.8	0.436	30.6	0.522
35	29.8	0.436	30.6	0.522
36	29.8	0.436	30.5	0.523
37	29.8	0.436	30.5	0.523
38	29.8	0.436	30.5	0.523
39	29.8	0.436	30.5	0.523
40	29.8	0.436	30.5	0.523
41	29.7	0.436	30.7	0.522
42	29.7	0.436	30.7	0.522
43	29.7	0.436	30.7	0.522
44	29.8	0.436	30.7	0.522
45	29.9	0.436	30.8	0.522
+1	29.8	0.456	30.7	0.543
+2	29.8	0.456	30.7	0.543
+3	29.8	0.456	30.7	0.543
+4	29.8	0.456	30.7	0.543
+5	29.8	0.456	30.7	0.543
+6	29.9	0.456	30.6	0.544
+7	29.9	0.456	30.6	0.544
+8	29.8	0.456	30.6	0.544
+9	29.8	0.456	30.6	0.544
+10	29.4	0.457	30.5	0.544

Table A2 B D U

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
-10	32.6	26.8	0.595	32.7	28.0	0.537
-9	32.5	26.6	0.632	32.8	28.2	0.515
-8	32.5	26.6	0.632	32.7	28.1	0.507
-7	32.5	26.6	0.632	32.7	27.8	0.574
-6	32.5	26.5	0.658	32.6	27.5	0.603
-5	32.4	26.5	0.647	32.6	27.3	0.620
-4	32.4	26.7	0.598	32.5	27.4	0.576
-3	32.4	26.7	0.585	32.5	27.5	0.551
-2	32.4	26.5	0.647	32.4	27.5	0.537
-1	32.4	26.5	0.647	32.4	27.5	0.516
0	32.4	26.5	0.616	32.4	27.4	0.498
1	32.3	26.4	0.630	32.3	27.3	0.504
2	32.2	26.3	0.645	32.3	27.4	0.483
3	32.2	26.2	0.656	32.4	27.6	0.458
4	32.2	26.1	0.683	32.4	27.5	0.489
5	32.2	26.2	0.656	32.4	27.4	0.504
6	32.2	26.2	0.656	32.4	27.1	0.559
7	32.2	26.3	0.630	32.5	27.0	0.585
8	32.3	26.3	0.641	32.5	27.0	0.602
9	32.3	26.4	0.616	32.6	27.1	0.595
10	32.3	26.5	0.592	32.6	27.3	0.547
11	32.4	26.5	0.602	32.7	27.5	0.515
12	32.4	26.6	0.579	32.7	27.5	0.529
13	32.5	26.6	0.589	32.7	27.2	0.571
14	32.4	26.6	0.579	32.6	27.0	0.602
15	32.4	26.6	0.579	32.6	26.9	0.621
16	32.4	26.6	0.579	32.5	26.7	0.653
17	32.4	26.5	0.602	32.5	27.0	0.603
18	32.4	26.5	0.602	32.6	27.0	0.604
19	32.4	26.5	0.589	32.5	27.0	0.599
20	32.4	26.4	0.626	32.5	27.0	0.598
21	32.4	26.4	0.626	32.5	27.1	0.568
22	32.5	26.4	0.623	32.5	26.9	0.611
23	32.4	26.4	0.613	32.4	26.9	0.600
24	32.5	26.4	0.623	32.4	26.9	0.603
25	32.4	26.3	0.637	32.5	27.0	0.595
26	32.4	26.2	0.662	32.5	27.0	0.566
27	32.4	26.3	0.637	32.6	27.0	0.579
28	32.5	26.4	0.623	32.7	27.1	0.588
29	32.5	26.5	0.599	32.7	27.1	0.573
30	32.5	26.6	0.577	32.7	27.1	0.585

Table A2 B D U (continued)

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
31	32.5	26.5	0.599	32.7	27.0	0.603
32	32.5	26.3	0.647	32.6	26.8	0.640
33	32.5	26.3	0.647	32.6	26.6	0.674
34	32.5	26.4	0.623	32.5	26.6	0.657
35	32.5	26.4	0.623	32.5	26.7	0.650
36	32.5	26.3	0.647	32.5	26.8	0.634
37	32.5	26.4	0.623	32.6	26.9	0.619
38	32.6	26.5	0.609	32.5	26.8	0.646
39	32.6	26.4	0.633	32.5	26.8	0.628
40	32.6	26.4	0.633	32.5	26.8	0.616
41	32.6	26.4	0.633	32.6	27.0	0.599
42	32.5	26.3	0.647	32.6	26.9	0.610
43	32.6	26.4	0.633	32.6	26.9	0.613
44	32.6	26.4	0.633	32.6	27.0	0.596
45	32.6	26.9	0.524	32.6	27.3	0.528
+1	32.6	26.7	0.593	32.5	26.9	0.622
+2	32.5	26.3	0.680	32.4	26.6	0.686
+3	32.5	26.1	0.735	32.5	26.4	0.732
+4	32.4	26.2	0.696	32.4	26.4	0.738
+5	32.4	26.1	0.724	32.4	26.3	0.746
+6	32.3	26.0	0.741	32.4	26.2	0.764
+7	32.3	26.0	0.741	32.4	26.2	0.762
+8	32.3	26.0	0.741	32.4	26.2	0.773
+9	32.3	25.9	0.772	32.4	26.3	0.738
+10	32.3	26.0	0.724	32.4	26.1	0.790

Table A3 M O P P 1

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
-10	33.6	25.2	1.343	33.5	26.2	1.323
-9	33.6	25.2	1.301	33.6	26.4	1.228
-8	33.5	25.1	1.344	33.5	26.2	1.266
-7	33.5	25.0	1.406	33.7	25.7	1.552
-6	33.5	24.8	1.543	33.6	25.5	1.589
-5	33.5	24.8	1.490	33.5	25.4	1.531
-4	33.5	24.8	1.490	33.5	25.5	1.431
-3	33.5	24.7	1.561	33.5	25.4	1.418
-2	33.6	24.8	1.507	33.4	25.4	1.352
-1	33.5	24.8	1.490	33.5	25.3	1.392
0	33.5	24.8	1.418	33.6	25.5	1.243
1	33.5	24.7	1.486	33.5	25.5	1.204
2	33.4	24.7	1.469	33.4	25.7	1.136
3	33.5	24.7	1.486	33.4	25.7	1.129
4	33.5	24.7	1.486	33.4	25.6	1.165
5	33.5	24.7	1.486	33.5	25.6	1.173
6	33.5	24.8	1.418	33.6	25.6	1.226
7	33.6	24.9	1.370	33.7	25.7	1.212
8	33.7	25.0	1.325	33.8	25.7	1.195
9	33.8	25.2	1.230	33.8	25.8	1.169
10	33.9	25.4	1.145	33.9	25.8	1.145
11	33.9	25.5	1.100	33.9	25.8	1.169
12	34.0	25.6	1.070	33.9	25.7	1.195
13	34.0	25.7	1.029	33.9	25.7	1.166
14	34.1	25.7	1.041	33.9	25.8	1.135
15	34.1	25.7	1.041	33.9	25.8	1.106
16	34.1	25.7	1.041	34.0	25.8	1.137
17	34.2	25.7	1.053	34.0	25.9	1.080
18	34.2	25.7	1.053	34.0	26.0	1.062
19	34.2	25.7	1.053	34.0	26.0	1.032
20	34.3	25.7	1.066	34.0	26.1	1.003
21	34.3	25.7	1.066	34.1	26.2	0.998
22	34.3	25.8	1.026	34.1	26.2	0.990
23	34.3	25.8	1.026	34.1	26.1	1.011
24	34.3	25.9	0.988	34.1	26.2	0.977
25	34.4	25.8	1.038	34.2	26.1	1.013
26	34.4	25.8	1.038	34.2	26.2	0.996
27	34.4	25.7	1.078	34.2	26.2	1.008
28	34.4	25.7	1.078	34.3	26.2	1.000
29	34.4	25.6	1.091	34.3	26.1	1.027
30	34.5	25.7	1.063	34.4	26.2	1.030

Table A3 M O P P 1 (continued)

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
31	34.5	25.7	1.063	34.4	26.3	0.977
32	34.5	25.7	1.063	34.4	26.2	0.998
33	34.5	25.7	1.063	34.4	26.2	1.000
34	34.5	25.7	1.091	34.4	26.2	1.011
35	34.5	25.7	1.091	34.3	26.1	1.010
36	34.5	25.7	1.091	34.3	26.2	1.014
37	34.5	25.7	1.091	34.3	26.2	1.001
38	34.5	25.7	1.091	34.3	26.2	0.998
39	34.5	25.7	1.063	34.3	26.1	1.030
40	34.5	25.6	1.103	34.3	26.0	1.050
41	34.5	25.5	1.146	34.3	26.0	1.068
42	34.5	25.5	1.146	34.2	25.9	1.084
43	34.5	25.5	1.146	34.2	25.9	1.081
44	34.5	25.7	1.063	34.3	25.9	1.056
45	34.5	25.9	0.987	34.3	26.1	1.009
+1	34.5	25.8	1.076	34.2	25.9	1.075
+2	34.5	25.6	1.159	34.1	25.6	1.198
+3	34.3	25.7	1.091	34.0	25.4	1.278
+4	34.2	25.7	1.078	33.9	25.2	1.365
+5	34.2	25.5	1.164	33.9	25.1	1.442
+6	34.1	25.2	1.298	33.9	25.1	1.448
+7	33.9	25.2	1.268	33.8	25.2	1.387
+8	34.0	25.1	1.337	33.8	25.4	1.338
+9	33.9	25.0	1.380	33.8	25.3	1.395
+10	33.8	24.9	1.425	33.7	25.2	1.402

Table A4 M O P P 2

minute	Sea Level Tsk	Sea Level Tcl	Sea Level I cl	Altitude Tsk	Altitude Tcl	Altitude I cl
-10	33.1	24.9	1.404	33.5	25.8	1.440
-9	33.2	24.8	1.490	33.5	26.0	1.318
-8	33.2	24.7	1.564	33.5	25.9	1.319
-7	33.2	24.7	1.564	33.5	25.6	1.427
-6	33.2	24.6	1.644	33.5	25.6	1.377
-5	33.1	24.5	1.644	33.5	25.5	1.416
-4	33.2	24.4	1.751	33.5	25.6	1.429
-3	33.2	24.4	1.751	33.4	25.7	1.331
-2	33.2	24.4	1.751	33.5	25.8	1.293
-1	33.2	24.4	1.751	33.5	25.8	1.265
0	33.2	24.4	1.666	33.4	25.8	1.149
1	33.3	24.3	1.704	33.4	25.8	1.159
2	33.3	24.4	1.685	33.4	25.8	1.145
3	33.2	24.5	1.524	33.3	25.8	1.106
4	33.3	24.5	1.542	33.3	25.6	1.170
5	33.3	24.5	1.542	33.4	25.5	1.205
6	33.4	24.6	1.486	33.5	25.5	1.189
7	33.4	24.7	1.418	33.6	25.6	1.128
8	33.6	24.9	1.326	33.7	25.8	1.068
9	33.6	25.1	1.216	33.8	25.8	1.042
10	33.7	25.2	1.180	33.8	25.9	1.028
11	33.8	25.3	1.145	33.9	25.9	1.046
12	33.9	25.3	1.159	34.0	26.0	0.998
13	34.0	25.4	1.126	34.0	26.2	0.948
14	34.1	25.5	1.095	34.1	26.4	0.920
15	34.2	25.5	1.108	34.2	26.6	0.878
16	34.2	25.5	1.108	34.2	26.8	0.837
17	34.2	25.5	1.108	34.3	26.9	0.837
18	34.2	25.6	1.095	34.3	27.1	0.814
19	34.4	25.6	1.121	34.3	27.1	0.803
20	34.4	25.6	1.121	34.3	27.2	0.795
21	34.5	25.6	1.133	34.3	27.2	0.790
22	34.5	25.6	1.133	34.4	27.1	0.826
23	34.5	25.7	1.091	34.4	27.0	0.827
24	34.5	25.8	1.050	34.4	26.9	0.860
25	34.5	25.8	1.050	34.5	26.8	0.878
26	34.5	25.8	1.050	34.5	26.8	0.869
27	34.6	25.7	1.103	34.5	26.7	0.880
28	34.6	25.6	1.116	34.5	26.7	0.891
29	34.6	25.6	1.116	34.5	26.5	0.932
30	34.6	25.6	1.116	34.5	26.4	0.952

Table A4 M O P P 2 (continued)

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
31	34.7	25.6	1.128	34.5	26.4	0.937
32	34.7	25.5	1.172	34.5	26.3	0.994
33	34.7	25.5	1.172	34.6	26.3	1.005
34	34.6	25.5	1.159	34.6	26.2	1.012
35	34.7	25.5	1.172	34.5	26.3	0.993
36	34.7	25.5	1.172	34.5	26.3	0.963
37	34.7	25.6	1.128	34.6	26.4	0.964
38	34.7	25.7	1.087	34.5	26.3	0.976
39	34.7	25.7	1.087	34.5	26.5	0.954
40	34.8	25.6	1.171	34.5	26.5	0.947
41	34.8	25.6	1.141	34.5	26.6	0.911
42	34.7	25.6	1.128	34.4	26.5	0.930
43	34.7	25.6	1.128	34.5	26.5	0.942
44	34.8	25.6	1.141	34.6	26.7	0.896
45	34.7	25.7	1.087	34.5	26.8	0.835
+1	34.7	25.6	1.185	34.4	26.4	0.960
+2	34.6	25.4	1.266	34.3	26.2	1.025
+3	34.5	25.2	1.317	34.1	26.0	1.081
+4	34.4	25.2	1.303	34.0	25.7	1.154
+5	34.3	25.1	1.342	33.8	25.6	1.173
+6	34.2	25.0	1.383	33.7	25.4	1.251
+7	34.1	25.1	1.313	33.7	25.3	1.332
+8	34.0	25.0	1.395	33.7	25.3	1.380
+9	34.1	24.8	1.539	33.5	25.3	1.340
+10	34.1	25.0	1.411	33.7	25.3	1.364

Table A5 M O P P 3

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
-10	33.7	25.2	1.405	33.5	26.0	1.359
-9	33.7	25.1	1.422	33.5	26.1	1.300
-8	33.8	24.9	1.578	33.5	26.0	1.313
-7	33.8	24.9	1.523	33.5	25.8	1.393
-6	33.7	24.9	1.506	33.5	25.7	1.401
-5	33.8	24.9	1.523	33.4	25.7	1.317
-4	33.7	24.8	1.578	33.4	25.7	1.293
-3	33.7	24.7	1.597	33.4	25.6	1.333
-2	33.7	24.6	1.675	33.4	25.6	1.291
-1	33.7	24.6	1.615	33.4	25.5	1.274
0	33.7	24.6	1.537	33.3	25.5	1.232
1	33.6	24.4	1.675	33.4	25.5	1.216
2	33.6	24.4	1.675	33.4	25.4	1.247
3	33.6	24.4	1.675	33.3	25.5	1.186
4	33.6	24.5	1.594	33.4	25.5	1.178
5	33.6	24.5	1.594	33.4	25.5	1.186
6	33.7	24.7	1.467	33.4	25.6	1.137
7	33.8	24.8	1.418	33.6	25.6	1.145
8	33.9	25.0	1.313	33.7	25.6	1.172
9	34.0	25.1	1.273	33.8	25.6	1.194
10	34.2	25.2	1.249	34.0	25.5	1.247
11	34.3	25.3	1.179	34.0	25.6	1.164
12	34.4	25.3	1.192	34.2	25.8	1.134
13	34.4	25.3	1.192	34.3	26.0	1.087
14	34.5	25.4	1.159	34.3	26.1	1.063
15	34.5	25.5	1.146	34.3	26.1	1.049
16	34.6	25.5	1.159	34.4	26.1	1.047
17	34.7	25.5	1.172	34.5	26.2	1.034
18	34.8	25.6	1.141	34.6	26.3	1.027
19	34.8	25.6	1.141	34.5	26.5	0.968
20	34.8	25.7	1.099	34.6	26.6	0.942
21	34.9	25.7	1.111	34.7	26.7	0.925
22	34.9	25.7	1.111	34.7	26.8	0.887
23	34.9	25.7	1.111	34.7	26.7	0.921
24	35.0	25.7	1.153	34.8	26.6	0.952
25	35.0	25.7	1.153	34.8	26.6	0.962
26	35.1	25.8	1.123	34.8	26.6	0.921
27	35.1	25.8	1.123	34.9	26.6	0.940
28	35.1	25.8	1.123	34.9	26.6	0.936
29	35.1	25.8	1.123	35.0	26.5	0.956
30	35.2	25.8	1.135	35.0	26.4	1.012

Table A5 M O P P 3 (continued)

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
31	35.2	25.7	1.147	35.0	26.4	1.006
32	35.2	25.7	1.147	35.0	26.3	1.028
33	35.2	25.7	1.147	34.9	26.4	0.978
34	35.2	25.7	1.147	35.0	26.4	0.981
35	35.2	25.7	1.147	34.9	26.4	0.980
36	35.2	25.7	1.147	34.9	26.3	1.002
37	35.3	25.7	1.159	34.9	26.4	0.994
38	35.3	25.8	1.118	34.9	26.3	1.012
39	35.3	25.8	1.118	34.9	26.5	0.970
40	35.4	25.8	1.130	35.0	26.6	0.948
41	35.3	25.7	1.130	35.0	26.5	0.985
42	35.4	25.6	1.184	35.0	26.4	0.996
43	35.4	25.6	1.184	35.0	26.5	1.002
44	35.3	25.6	1.172	35.0	26.6	1.033
45	35.3	26.1	0.983	35.0	26.8	0.879
+1	35.3	26.1	1.033	34.9	26.8	0.899
+2	35.3	25.9	1.106	34.8	26.5	0.967
+3	35.2	26.0	1.057	34.6	26.2	1.047
+4	35.1	26.0	1.046	34.5	25.9	1.154
+5	35.0	25.8	1.110	34.3	25.7	1.208
+6	34.9	25.6	1.180	34.2	25.5	1.239
+7	34.8	25.4	1.258	34.2	25.5	1.262
+8	34.7	25.3	1.294	34.1	25.4	1.314
+9	34.6	25.3	1.280	34.3	25.3	1.411
+10	35.0	25.4	1.285	34.0	25.5	1.281

Table A6 MOPP4

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
-10	33.9	25.3	1.253	33.4	25.9	1.360
-9	33.9	25.2	1.307	33.4	25.9	1.360
-8	33.8	25.2	1.292	33.5	25.9	1.366
-7	33.9	25.1	1.364	33.5	25.6	1.424
-6	33.9	25.1	1.364	33.4	25.3	1.542
-5	33.9	25.0	1.424	33.4	25.2	1.565
-4	33.9	25.0	1.424	33.4	25.4	1.450
-3	33.9	24.9	1.489	33.4	25.3	1.446
-2	33.9	24.9	1.489	33.3	25.3	1.426
-1	33.9	24.9	1.441	33.3	25.3	1.391
0	33.8	25.0	1.298	33.3	25.4	1.265
1	33.8	24.9	1.356	33.4	25.5	1.253
2	33.8	25.0	1.298	33.3	25.5	1.161
3	33.8	25.0	1.340	33.4	25.5	1.190
4	33.8	25.1	1.283	33.4	25.6	1.171
5	33.9	25.2	1.244	33.4	25.4	1.223
6	34.0	25.2	1.258	33.5	25.4	1.264
7	34.1	25.2	1.273	33.6	25.5	1.240
8	34.2	25.3	1.235	33.8	25.6	1.182
9	34.4	25.4	1.212	33.9	25.9	1.087
10	34.5	25.5	1.146	34.1	26.0	1.091
11	34.7	25.6	1.128	34.2	26.0	1.096
12	34.8	25.7	1.128	34.3	26.1	1.065
13	34.8	25.8	1.059	34.3	26.1	1.052
14	34.9	25.9	1.059	34.3	26.2	1.022
15	35.0	25.9	1.071	34.4	26.3	1.002
16	35.0	26.0	1.033	34.4	26.5	0.951
17	35.1	26.0	1.044	34.4	26.6	0.907
18	35.1	26.0	1.044	34.5	26.7	0.900
19	35.1	26.0	1.044	34.5	26.7	0.889
20	35.2	26.0	1.056	34.6	26.8	0.879
21	35.2	26.0	1.056	34.6	26.8	0.856
22	35.3	26.0	1.067	34.7	26.9	0.869
23	35.3	26.0	1.067	34.7	26.9	0.876
24	35.3	26.0	1.042	34.7	26.9	0.870
25	35.3	26.0	1.042	34.7	26.7	0.895
26	35.4	25.9	1.090	34.7	26.7	0.908
27	35.4	25.9	1.090	34.8	26.6	0.940
28	35.4	26.0	1.053	34.8	26.6	0.944
29	35.4	26.0	1.053	34.9	26.6	0.945
30	35.4	26.0	1.053	34.9	26.4	0.978

Table A6 M O P P 4 (continued)

	Sea Level			Altitude		
minute	Tsk	Tcl	I cl	Tsk	Tcl	I cl
31	35.4	26.0	1.053	34.9	26.4	0.982
32	35.4	26.0	1.053	34.8	26.2	1.001
33	35.4	25.9	1.064	34.8	26.2	1.012
34	35.5	25.9	1.076	34.8	26.2	0.999
35	35.5	25.9	1.076	34.8	26.3	0.984
36	35.5	25.9	1.076	34.8	26.3	0.992
37	35.5	25.9	1.102	34.9	26.3	0.993
38	35.5	26.0	1.064	34.8	26.4	0.967
39	35.5	26.0	1.064	34.9	26.4	0.950
40	35.5	26.0	1.064	34.8	26.6	0.918
41	35.5	25.9	1.102	34.9	26.7	0.907
42	35.5	25.9	1.102	34.9	26.7	0.911
43	35.5	25.9	1.076	34.9	26.7	0.920
44	35.6	25.9	1.087	34.9	26.7	0.913
45	35.6	26.1	1.015	34.9	26.9	0.868
+1	35.6	26.0	1.103	34.9	26.8	0.947
+2	35.5	26.0	1.092	34.8	26.6	0.987
+3	35.5	25.9	1.130	34.7	26.4	1.044
+4	35.4	25.9	1.118	34.6	26.1	1.150
+5	35.3	25.7	1.218	34.5	25.7	1.273
+6	35.2	25.7	1.205	34.4	25.4	1.349
+7	35.1	25.6	1.237	34.3	25.3	1.406
+8	35.1	25.6	1.237	34.2	25.2	1.460
+9	35.1	25.5	1.285	34.1	25.4	1.401
+10	35.2	25.6	1.284	34.4	25.4	1.464

DISTRIBUTION LIST

2 Copies to:

Defense Technical Information Center
ATTN: DTIC-DDA
Alexandria, VA 22304-6145

Office of the Assistant Secretary of Defense (Hlth Affairs)
ATTN: Medical Readiness
Army Pentagon
Washington, DC 20301-1200

Commander
US Army Medical Research and Materiel Command
ATTN: SGRD-OP
Fort Detrick
Frederick, MD 21702-5012

Commander
U.S. Army Medical Research and Materiel Command
ATTN: SGRD-PLC
Fort Detrick
Frederick, MD 21702-5012

Commander
U.S. Army Medical Research and Materiel Command
ATTN: SGRD-PLE
Fort Detrick
Frederick, MD 21702-5012

Commandant
Army Medical Department Center and School
ATTN: HSMC-FM, Bldg. 2840
Fort Sam Houston, TX 78236

1 Copy to:

Joint Chiefs of Staff
Medical Plans and Operations Division
Deputy Director for Medical Readiness
Army Pentagon
Washington, DC 20310-2300

HQDA
Office of the Surgeon General
Preventive Medicine Consultant
ATTN: SGPS-PSP
5109 Leesburg Pike
Falls Church, VA 22041-3258

HQDA
Assistant Secretary of the Army
(Research, Development and Acquisition)
ATTN: SARD-TM
103 Army Pentagon
Washington, DC 20310-2300

HQDA
Office of the Surgeon General
ATTN: DASG-ZA
5109 Leesburg Pike
Falls Church, VA 22041-3258

HQDA
Office of the Surgeon General
ATTN: DASG-DB
5109 Leesburg Pike
Falls Church, VA 22041-3258

HQDA
Office of the Surgeon General
Assistant Surgeon General
ATTN: DASG-RDZ/Executive Assistant
Room 3E368, Army Pentagon
Washington, DC 20310-2300

HQDA
Office of the Surgeon General
ATTN: DASG-MS
5109 Leesburg Pike
Falls Church, VA 22041-3258

Uniformed Services University of the Health Sciences
Dean, School of Medicine
4301 Jones Bridge Road
Bethesda, MD 20814-4799

Uniformed Services University of the Health Sciences
ATTN: Department of Military and Emergency Medicine
4301 Jones Bridge Road
Bethesda, MD 20814-4799

Commandant
Army Medical Department Center & School
ATTN: Chief Librarian Stimson Library
Bldg 2840, Room 106
Fort Sam Houston, TX 78234-6100

Commandant
Army Medical Department Center & School
ATTN: Director of Combat Development
Fort Sam Houston, TX 78234-6100

Commander
U.S. Army Aeromedical Research Laboratory
ATTN: SGRD-UAX-SI
Fort Rucker, AL 36362-5292

Commander
U.S. Army Medical Research Institute of Chemical Defense
ATTN: SGRD-UVZ
Aberdeen Proving Ground, MD 21010-5425

Commander
U.S. Army Medical Materiel Development Activity
ATTN: SGRD-UMZ
Fort Detrick
Frederick, MD 21702-5009

Commander
U.S. Army Institute of Surgical Research
ATTN: SGRD-USZ
Fort Sam Houston, TX 78234-5012

Commander
U.S. Army Medical Research Institute of Infectious Diseases
ATTN: SGRD-UIZ-A
Fort Detrick
Frederick, MD 21702-5011

Director
Walter Reed Army Institute of Research
ATTN: SGRD-UWZ-C (Director for Research Management)
Washington, DC 20307-5100

Commander
U.S. Army Natick Research, Development & Engineering Center
ATTN: SATNC-Z
Natick, MA 01760-5000

Commander
U.S. Army Natick Research, Development & Engineering Center
ATTN: SATNC-T
Natick, MA 01760-5002

Commander
U.S. Army Natick Research, Development & Engineering Center
ATTN: SATNC-MI
Natick, MA 01760-5040

Commander
U.S. Army Research Institute for Behavioral Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333-5600

Commander
U.S. Army Training and Doctrine Command
Office of the Surgeon
ATTN: ATMD
Fort Monroe, VA 23651-5000

Commander
U.S. Army Environmental Hygiene Agency
Aberdeen Proving Ground, MD 21010-5422

Director, Biological Sciences Division
Office of Naval Research - Code 141
800 N. Quincy Street
Arlington, VA 22217

Commanding Officer
Naval Medical Research & Development Command
NNMC/Bldg 1
Bethesda, MD 20889-5044

Commanding Officer
U.S. Navy Clothing & Textile Research Facility
ATTN: NCTRF-01
Natick, MA 01760-5000

Commanding Officer
Navy Environmental Health Center
2510 Walmer Avenue
Norfolk, VA 23513-2617

Commanding Officer
Naval Aerospace Medical Institute (Code 32)
Naval Air Station
Pensacola, FL 32508-5600

Commanding Officer
Naval Medical Research Institute
Bethesda, MD 20889

Commanding Officer
Naval Health Research Center
P.O. Box 85122
San Diego, CA 92138-9174

Commander
USAF Armstrong Medical Research Laboratory
Wright-Patterson Air Force Base, OH 45433

Strughold Aeromedical Library
Document Services Section
2511 Kennedy Circle
Brooks Air Force Base, TX 78235-5122

Commander
USAF School of Aerospace Medicine
Brooks Air Force Base, TX 78235-5000

Director
Human Research & Engineering
US Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5001

Commander
U.S. Army Natick Research, Development & Engineering Center
ATTN: SATNC-IPS
Natick, MA 01760-5019

Commander
U.S. Army Yuma Proving Ground
ATTN: STEYP-MT-ES
Yuma, AZ 85365-9009

Commander
U.S. Army Test and Evaluation Command
ATTN: AMSTE-TA-S
Aberdeen Proving Ground, MD 21005

Commander
U.S. Army Center for Health Promotion and Preventive Medicine
ATTN: HSHB-MO-A
Building E2100
Aberdeen Proving Ground, MD 21010-5422