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REPORT NO. NADC-86104-60

COLD WATER EVALUATION OF CONSTANT-WEAR ANTI-EXPOSURE SUIT SYSTEMS

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28 JUNE 1985

FINAL REPORT
Airtask No. A531531A/0010/5W0606SL00
Work Unit No. A5311D1-54-RS

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Prepared for
NAVAL AIR SYSTEMS COMMAND
Department of the Navy
Washington, D.C. 20360

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

AD-A173 388

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION	1b RESTRICTIVE MARKINGS N/A
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Distribution is Unlimited; Approved for Public Release
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NADC-86104-60	5 MONITORING ORGANIZATION REPORT NUMBER(S) N/A
6a NAME OF PERFORMING ORGANIZATION Naval Air Development Center 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION N/A
6c ADDRESS (City, State, and ZIP Code) Warminster, PA 18974	7b ADDRESS (City, State, and ZIP Code) N/A
8a NAME OF FUNDING/SPONSORING ORGANIZATION Naval Air Systems Command 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N/A
8c ADDRESS (City, State, and ZIP Code) Washington, DC 20360	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

SUIT

Cold Water Evaluation of Constant-Wear Anti-Exposure Systems

12 PERSONAL AUTHOR(S)
Jonathan Kaufman and Katherine Dejneka

13a TYPE OF REPORT	13b TIME COVERED FROM ________ TO ________	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT

16 SUPPLEMENTARY NOTATION

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Hypothermia, anti-exposure protection, immersion cold stress, constant-wear.

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Constant-wear anti-exposure suit ensembles have been tested to determine the protection they provide against immersion hypothermia. Test conditions were: calm water with a temperature of 7.2°C, air temperature of 0°C, and wind velocity of 7.8 m/sec. Fourteen subjects, 13 males ages 21-40 years, and one female, age 24 years, participated in the study of eight configurations. All configurations were not worn by each subject, and subjects did not have repetitions in a given configuration. Exposure time for each test was a maximum of 120 minutes. The eight configurations tested consisted of the CWU-62/P polytetrafluoroethylene (PTFE) anti-exposure coverall with various combinations of liners. Mean test durations were >109 minutes, with no significant differences among configurations. Data for mean weighted skin temperatures (Tsk), mean change in mean skin temperature (ΔTsk), mean body temperature (Tb), mean change in mean body temperature (ΔTb), and body heat loss (S) indicate significant differences among test configurations. Extensive damage (i.e., 2" tear) in the CWU-62/P coverall/CWU-72/P

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Jonathan Kaufman	22b TELEPHONE (Include Area Code) 215/441-2565 22c OFFICE SYMBOL 60B1

DD FORM 1473, 84 MAR
83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Block No. 19 (Continued)

liner combination produced similar results to the leaking (i.e., 3/32" hole and 2 pinholes) CWU-62/P coverall/ CWU-23/P liner combination, these providing the least protection among tested configurations. While not significant, mean final rectal temperature (Tre) and mean change in rectal temperature (ΔTre) displayed similar trends. These results indicate that the CWU-62/P coverall, with any of the liner combinations tested, provided two-hour protection in calm 7.2°C water, thus meeting the Naval Operational requirements. However performance significantly declined with the extensive leakage. The CWU-72/P olefin liner was also shown to provide a significant improvement in immersion protection over the CWU-23/P cotton/polypropylene liner when wet, based on S, Tsk, Tb and ΔTb.

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INTRODUCTION

Navy aircrew downed in cold water (<15.6°C) require anti-exposure garments capable of providing physiological protection against hypothermia (1). The nature of most modern aircraft requires these garments to be of the constant-wear type. These garments must not cause excessive heat stress during normal flight operations (1, 2), but must provide downed aircrew with two hours of protection in 7.2°C water (1).

An anti-exposure system to meet these requirements has been proposed consisting of the CWU-62/P polytetrafluoroethylene (PTFE) coverall and the CWU-72/P olefin liner. PTFE is a semi-permeable membrane designed to allow the passage of water vapor out of the fabric while preventing water from entering. When compared with other materials, olefin is believed to maintain a greater percentage of its insulative properties when wet. Therefore it has been suggested that the combined use of these materials would represent an improvement in anti-exposure protection.

To determine if the proposed anti-exposure system could provide adequate protection against hypothermia, the CWU-62/P PTFE coverall, worn with several different liner configurations, was evaluated in 7.2°C water for periods up to two hours. Additional tests, simulating damage to the suit system resulting from normal wear and the tears which may accompany through-the-canopy ejection from aircraft, were also completed under the same environmental conditions.

The acquired test data, when combined with information obtained from heat stress studies (3), provides part of the basis for the selection of an effective anti-exposure system.

MATERIALS AND METHODS

SUBJECTS

Fourteen volunteers, ages 21—40, participated in the testing of eight configurations of anti-exposure garments (Table 1) after being informed of the possible risks of cold water immersion.

Prior to commencement of all testing, base line physiological data for each subject were collected, as shown in Table 2, including weight, height, body density, heart rate, and aerobic fitness. All weights were measured using a chair scale (Scale-Tronix, Wheaton, IL, model 6006-SP) accurate to ±10 grams. Percent body fat was anthropometrically determined; skinfold measurements at the biceps, triceps, subscapula and supriliac regions were taken with Lange skinfold calipers (Cambridge Instruments, Cambridge, MD) (4).

Aerobic fitness (VO_2 max) was determined from an Astrand nomograph using maximum average heart rate (bpm) and workload (Watts) and was age corrected (5). Subjects pedalled a Tunturi bicycle ergometer for five minutes at 60 rpm with no workload, followed by six minutes of pedalling at 60 rpm with a workload which increased that individual's heart rate to >130 bpm. Average heart rate for each of the last three minutes was recorded. Aerobic fitness testing of each subject was conducted once per week during performance of cold water trials and after completion of all trials, to monitor changes in subject fitness.

METHODS AND PROCEDURES

To eliminate any possible effects of circadian rhythm, all trials were conducted in the morning. Subject preparation for each trial began with urinalysis and nude weight, followed by examination by a flight surgeon. Urine specific gravity, pH, and content (blood, ketone, bilirubin and protein) were measured for comparison with a post-trial sample. The subject was questioned about his/her current state of health, as well as previous illness or injury while his/her vital signs (blood pressure, oral temperature, respiration and heart rates) were taken by a Navy hospital corpsman.

The subject was instrumented with ECG leads and eleven thermocouples (type 'T') located on the forehead(B), upper chest(C), scapular margin(D), lateral upper arm(E), dorsum of the hand(F), pad of the index finger(G), medial thigh(H), lateral leg(I), pad of the great toe(J), dorsum of the foot(K), and lower back(L). Deep body (core) temperature was measured via a YSI model 407 thermistor inserted 10 cm in the rectum for trials of configurations 6—8 (Table 1). A thermocouple (type 'T') rectal probe was utilized during evaluations of the other five configurations.

Upon completion of subject instrumentation, baseline temperature, heart rate and blood pressure were recorded. After recording baseline data, subjects were dressed in the appropriate liner (dependent upon configuration, see Table 1), two pairs of wool socks and the PTFE coverall. Dry ensemble weight was then measured (except for configurations 6—8). The remaining flight gear was then donned by the subject. During each trial, thermocouple readings were recorded at ten minute intervals by means of a data logger (DigiTec, Dayton, OH, model 3000), while core, toe, and finger temperatures were monitored every two minutes. Themistor-determined core temperature was monitored continuously by a YSI model 47

TABLE 1. Clothing Configurations Worn in the Anti-Exposure Suit Evaluations.

SUIT CONFIGURATION	CONDITION CWU-62/P	UNDERGARMENTS
1	3/32″ hole, mid-back 2 pin holes, navel	CWU-23/P cotton/polypropylene liner CWU-23/P, 44/P thermal underwear
2	3/32″ hole, mid-back 2 pin holes, navel	CWU-72/P olefin liner CWU-43/P, 44/P
3	2″ tear, back shoulder seam*	CWU-72/P CWU-43/P, 44/P
4	undamaged	CWU-72/P
5	undamaged	CWU-43/P, 44/P
6	undamaged	CWU-23/P CWU-43/P, 44/P
7	undamaged	CWU-72/P CWU-43/P, 44/P
8	undamaged	full length olefin liner CWU-43/P, 44/P

FLIGHTGEAR WORN WITH ALL CONFIGURATIONS:

CWU-27/P flightsuit
wool socks (2 pair), flyer's boots
MIL-M-81534 anti-exposure mittens
flight gloves
HGU-33 or SPH-3 helmet
MA-2 torso harness
anti-G suit
LPU-23/P life preserver (inflated) with SV-2 survival vest

*NOTE: CWU-27/P, CWU-72/P, and CWU-43/P, 44/P also have 2″ tear in back shoulder seam.

TABLE 2. Physical Data of Participants in Anti-Exposure Suit Evaluations

SUBJECT	AGE (yr)	HEIGHT (m)	WEIGHT (kg)	BODY FAT (%)	SURFACE AREA (m^2)	VO_2 Max (ml/kg/min)
1 n	34	1.69	66.2	11.7	1.69	27.2
2 l	21	1.68	67.5	19.0	1.76	29.6
3 l, p	26	1.73	67.8	14.9	1.81	32.5
4 l, p, n	29	1.83	81.7	19.8	2.04	25.7
5 l	21	1.82	83.5	22.7	2.04	32.3
6 l, p	35	1.72	68.0	19.9	1.80	26.5
7 l, p	21	1.68	66.0	17.3	1.74	28.8
8 l, p, n	40	1.82	79.2	16.9	2.00	27.8
9 l, p, n	35	1.72	86.7	23.1	1.99	25.4
10 p, n	22	1.81	86.3	20.6	2.06	39.5
11 p	30	1.78	76.3	18.2	1.94	28.7
12 l, p	24	1.70	65.0	18.2	1.76	35.7
13 l, p	25	1.71	73.5	14.9	1.85	36.7
14 p, n	26	1.71	81.0	17.8	1.93	32.1
Mean	27.8	1.74	74.9	18.2	1.89	30.6
Std. Dev.	6.2	0.06	8.1	3.1	0.13	4.4

NOTE: l = participant in tests of configurations 1, 2, 4, and 5.
p = participant in tests of configuration 3.
n = participant in tests of configurations 6, 7, and 8.

MATERIALS AND METHODS (continued)

Telethermometer, with recordings taken every ten minutes. ECG was monitored continuously (Physio-Control, Redmond, WA, model Life Pack 6), while heart rate was recorded every ten minutes.

At the start of a trial, two subjects entered the pool and remained immersed in calm 7.2 ± 0.6°C water for a period up to two hours. Air temperature was maintained at 0.0 ± 1.0°C, with a wind velocity of 7.8 ± 1.2 m/sec. A core temperature of 35°C, finger temperature of 10°C, toe temperature of 0°C, or heart rate greater than 180 bpm warranted removal of a subject from that trial. Subjects were asked to rate their sensation of temperature (neutral—4, cold—1), relative comfort (comfortable—1, very uncomfortable—4), and degree of shivering (no shivering—1, extreme shivering—4) at ten minute intervals by an observer stationed inside the test chamber. This data is reported as the time to the maximum sensation, i.e., tTS1, tCS4, and tSS4, respectively.

Upon removal from the test chamber, all flight gear except the PTFE coverall and under garments were removed to obtain a final ensemble weight. The difference between final and baseline suit weights represented the intake of water by a suit throughout that run. After removal of the remaining garments, the subjects entered the rewarming facility and remained immersed in 40°C water until core temperature stabilized at >36.5°C. Final nude weight and urinanalysis were followed by post-trial examination by a flight surgeon. At this time a questionaire pertaining to any lingering physiological effects of the cold water testing was completed.

Mean skin temperature (Tsk) was calculated using the following equation:

$$(1) \qquad Tsk = 0.07(B) + 0.35[(C + D + L)/3] + 0.14(E) + 0.05[(F + G)/2] + 0.19(H) + 0.13(I) + 0.07[(J + K)/2]$$

where B—L represent the eleven measured skin temperatures (6). Mean body temperature (Tb) was calculated using the following equation:

$$(2) \qquad Tb = 0.33\ Tsk + 0.67\ Tre$$

where Tre represents core temperature and Tsk represents mean skin temperature (6). Change in body heat storage (S) was calculated using the following equation:

$$(3) \qquad S = 0.83\ BM(Tb1 - Tb2)/SA$$

where BM is the subject's body mass (kg), SA represents the Dubois surface area (m^2) (7), and (Tb1—Tb2) indicates the change in body temperature over an interval of time (e.g., 10 minutes) (8).

Ten subjects, including one female, participated in the evaluation of configurations 1, 2, 4 and 5 at a frequency of one trial per subject per week. Eleven subjects (ten male, one female) evaluated configuration 3. Six males tested configurations 6—8, with a minimum of 48 hours between trials. Subject descriptions are given in Table 2.

MATERIALS AND METHODS (continued)

The expected water leakage of a PTFE coverall resulting from normal wear, such as small holes in the fabric or seal tears, was simulated in these tests by placing a 3/32 inch diameter hole in the center lower back of the PTFE suit, along with two pinholes in the front at approximately navel level (Table 1). The location of these holes represents a "worst case" situation in which the holes are in the water at all times; flooding of the suit occurred within 20—30 minutes of immersion.

A two inch tear at the lateral edge of the left shoulder was made in all layers of clothing to simulate the possible damage reported after ejection. Subjects reported complete flooding of the PTFE suit within 15 minutes of immersion. Due to the size and location of the suit tear, water circulated freely in and out of the suit with even slight motion by the subject.

STATISTICAL ANALYSIS

Paired-sample t-tests were performed between all configurations, evaluating configuration effects on physiological parameters. Subject effects were analyzed by a two-way ANOVA, employing a 7 × 5 factorial design with configuration as the other factor. Only data from those subjects who completed testing in configurations 1—5 were used in the ANOVA. Configurations 6—8 were omitted from this ANOVA because of the small number of subjects participating in the testing of all 8 configurations. A similarly designed two-way ANOVA was employed to compare configurations vs. day-of-test effects. A Duncan Multiple Range test was used to identify significant differences between means when significant differences for a given parameter were indicated by the t-tests. Linear correlation analysis was used to identify interaction between parameters.

RESULTS

On the basis of the cold water immersion tests, the CWU-62/P-based anti-exposure system, in any of the configurations tested, provided satisfactory protection to meet the operational requirement (1) of two hour immersions "without suffering permanent damage or impairment" in 7.2° C water. Non-leaking configurations 5, 6, 7, and 8 provided sufficient protection for subjects to have test durations of 120 minutes in all test runs (Table 3). Configuration 4, also a non-leaking configuration, generally provided similar protection (Table 3), though one test run lasted only 100 minutes. Tests involving leaking CWU-62/P coveralls (configurations 1, 2, and 3) produced shorter test durations (Table 3), though the differences with the non-leaking configurations were not significant.

Determination of the whole body heat loss, S, however, indicated significant performance differences among the configurations ($p<0.01$) (Figure 1.) Trials involving configurations 1 and 3 produced significantly higher mean S than the other configurations ($p<0.01$). It should be noted that trials employing a non-leaking CWU-62/P coverall together with a CWU-23/P liner (configuration 6) produced the next largest mean S (Figure 1), though this was not significantly different from the results of configurations 2, 4, 5, 7, and 8. A large mean S reflects poor insulative qualities, which in the case of configuration 3 was expected due to the influx of water through the two inch tear. The mean S determined for configurations 1 and 6 are

TABLE 3. Means and Standard Errors of the Mean (SEM) of Test Parameters

		Configuration							
		1	2	3	4	5	6	7	8
Duration minutes	X	109.4	114.8	116.5	118.0	120.0	120.0	120.0	120.0
	SEM	4.7	5.1	2.4	2.0	0.0	0.0	0.0	0.0
Tre, Final °C	X	36.56	37.21	36.63	37.17	37.33	36.75	36.70	36.90
	SEM	0.18	0.18	0.23	0.21	0.18	0.05	0.36	0.30
Δ Tre °C	X	1.30	0.67	1.40	0.76	0.83	0.95	0.93	0.96
	SEM	0.15	0.13	0.26	0.19	0.13	0.10	0.27	0.28
Task, Final °C	X	17.46	20.29	16.82	20.85	20.28	23.73	23.80	25.30
	SEM	0.32	0.48	0.55	0.62	0.46	0.56	0.88	0.53
Δ Tsk °C	X	14.50	12.33	16.66	9.63	10.13	10.20	8.86	8.52
	SEM	0.53	0.69	0.56	0.71	0.61	0.27	0.88	0.53
Tbd, Final °C	X	30.29	31.63	30.10	31.56	31.70	32.43	32.60	33.06
	SEM	0.18	0.21	0.28	0.30	0.20	0.20	0.30	0.26
Δ Tbd °C	X	5.62	4.43	6.48	3.83	3.95	4.03	3.12	3.42
	SEM	0.18	0.24	0.42	0.27	0.19	0.15	0.37	0.25
S W/m^2	X	184.3	145.2	214.8	124.5	128.9	134.6	107.0	115.9
	SEM	7.6	9.6	14.2	8.5	6.9	6.2	12.7	8.4

TABLE 3. Means and Standard Errors of the Mean (SEM) of Test Parameters (Continued)

		Configuration							
		1	2	3	4	5	6	7	8
HR bpm	X	104	101	98	96	98	75	83	87
	SEM	6.6	4.3	2.6	4.9	4.9	0.8	4.0	4.3
tTS1 minutes	X	28	20	20	44	41	18	20	20
	SEM	7.0	3.7	4.9	11.0	9.9	4.8	5.2	6.3
tTSS4 minutes	X	63	63	52	85	71	80	68	96
	SEM	9.9	10.1	4.7	8.6	8.4	15.0	11.7	7.5
tCS4 minutes	X	59	66	45	75	69	55	80	60
	SEM	7.5	9.6	7.7	8.1	7.0	6.5	13.7	4.5

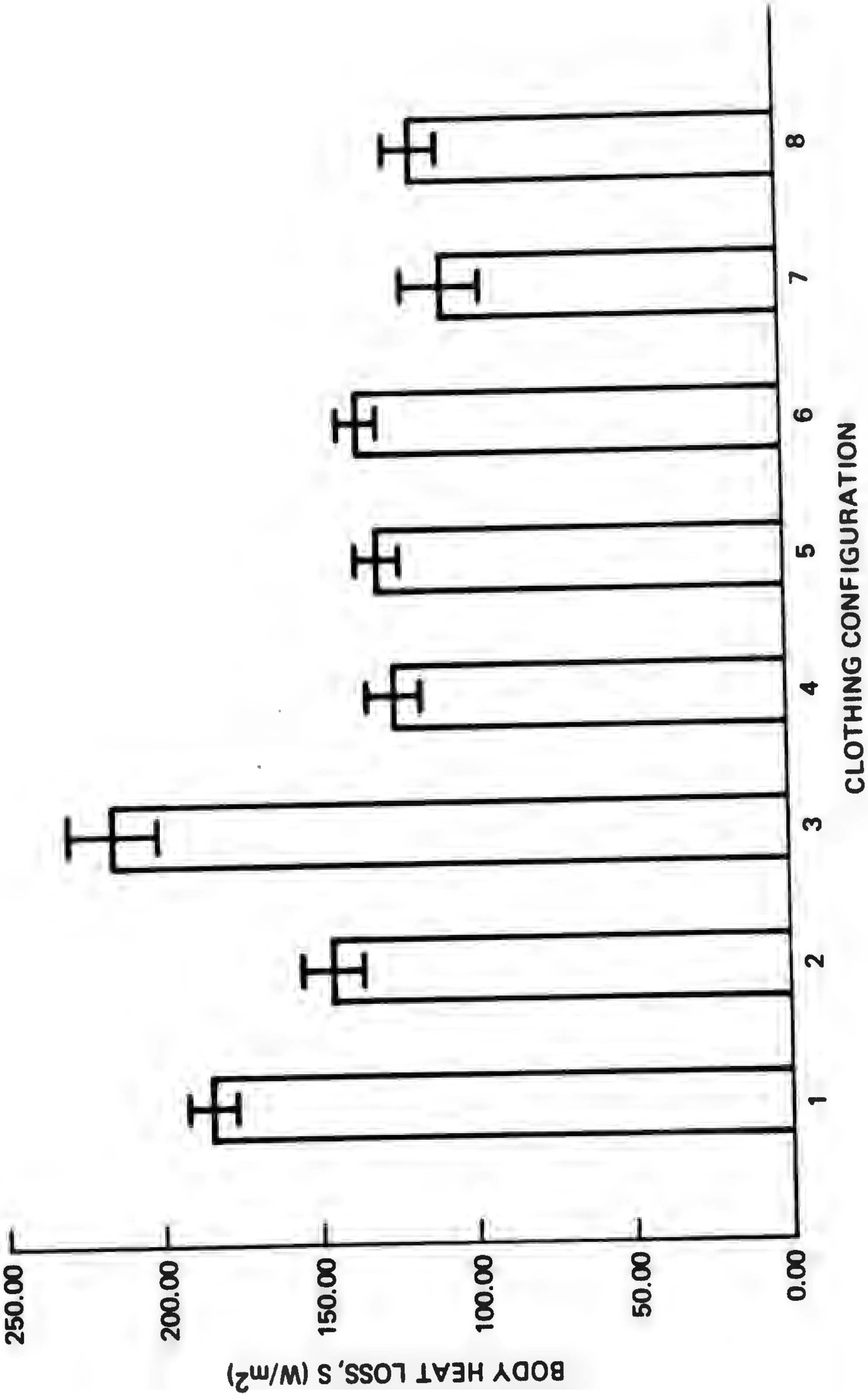

FIGURE 1. Heat Loss Vs. Configuration

RESULTS (continued)

likely the results of relatively poor insulation provided by the CWU-23/P cotton/polypropylene liner when compared with the CWU-72/P olefin liner (19).

The rank ordering of configurations 1 and 3 by mean final Tre (Figure 2) and ΔTre (Figure 3) corresponds to their ranking with regard to other parameters (i.e., S,Tsk, ΔTsk, Tb, and ΔTb), though no significant differences among any of the configurations were observed for mean final Tre or ΔTre. Correspondence in this case is determined by the relative amount of protection provided by a given configuration as measured by the different parameters. Configurations 1 and 3 produced the lowest mean final Tre and largest ΔTre among all configurations, suggesting that these configurations provide the least physiological protection in cold water, a contention supported by the results of other physiological parameters.

Examining the effects of configuration on Tsk, the role of the liner became evident (Figure 4). As with the parameters discussed above, use of configurations 1 and 3 provided the least effective protection against the cold, producing significantly lower mean Tsk ($p<0.01$) than the other configurations. Likewise, configurations 7 and 8, both of which included dry olefin liners, produced significantly higher mean Tsk ($p<0.01$) than the other configurations. No significant differences between configurations 2, 4, 5, or 6 were observed. A very similar pattern was observed for mean Tb, with the use of configurations 1 and 3 resulting in a significantly lower mean Tb ($p<0.01$) and use of configuration 8 in a significantly higher mean Tb ($p<0.01$) (Figure 5). The mean Tb resulting from the use of configuration 7, while not significantly different from configurations 2, 4, 5 or 6, was the highest amongst them.

An evaluation of the data for mean ΔTsk indicates a significantly greater ΔTsk when configuration 3 was worn compared with the other configurations ($p<0.01$). No other significant differences were detected, though use of configurations 1 and 6, both utilizing the CWU-23/P liner, produced greater mean ΔTsk than configurations 2, 4, 5, 7, and 8 (Figure 6). Analysis of the mean ΔTb data produced results which closely parallel the ΔTs results, the primary difference being that use of either configurations 1 or 3 produced a significantly higher mean ΔTb ($p<0.01$) than the remaining configurations (Figure 7). Note that these are the same results observed for mean S.

The final heart rate data indicates a significant difference ($p<0.01$) exists among the test configurations. Configurations 6 and 7 produced significantly lower heart rates ($p<0.05$) than the remaining configurations. Use of configuration 8 produced the lowest heart rate among the remaining configurations, though the difference was not significant (Table 3). This suggests a difference in the level of stress associated with the different configurations, with the wearing of a liner and thermal underwear being least stressful. This might also reflect, however, varying conditions at the termination of the runs (e.g. excessive subject motion), since heart rate can vary moment to moment.

In designating certain configurations "wet" or "dry," it was assumed that water influx would occur across openings in the "wet" configurations, wetting the inner layers of clothing. Conversely, "dry" configurations were assumed to maintain the inner layers in a dry state. Mean water intake for configurations 1 and 2 was 4.12±1.41 kg and 4.17±1.81 kg, respectively. Configurations 4 and 5 had, in general, negligible intake of water, though urination during

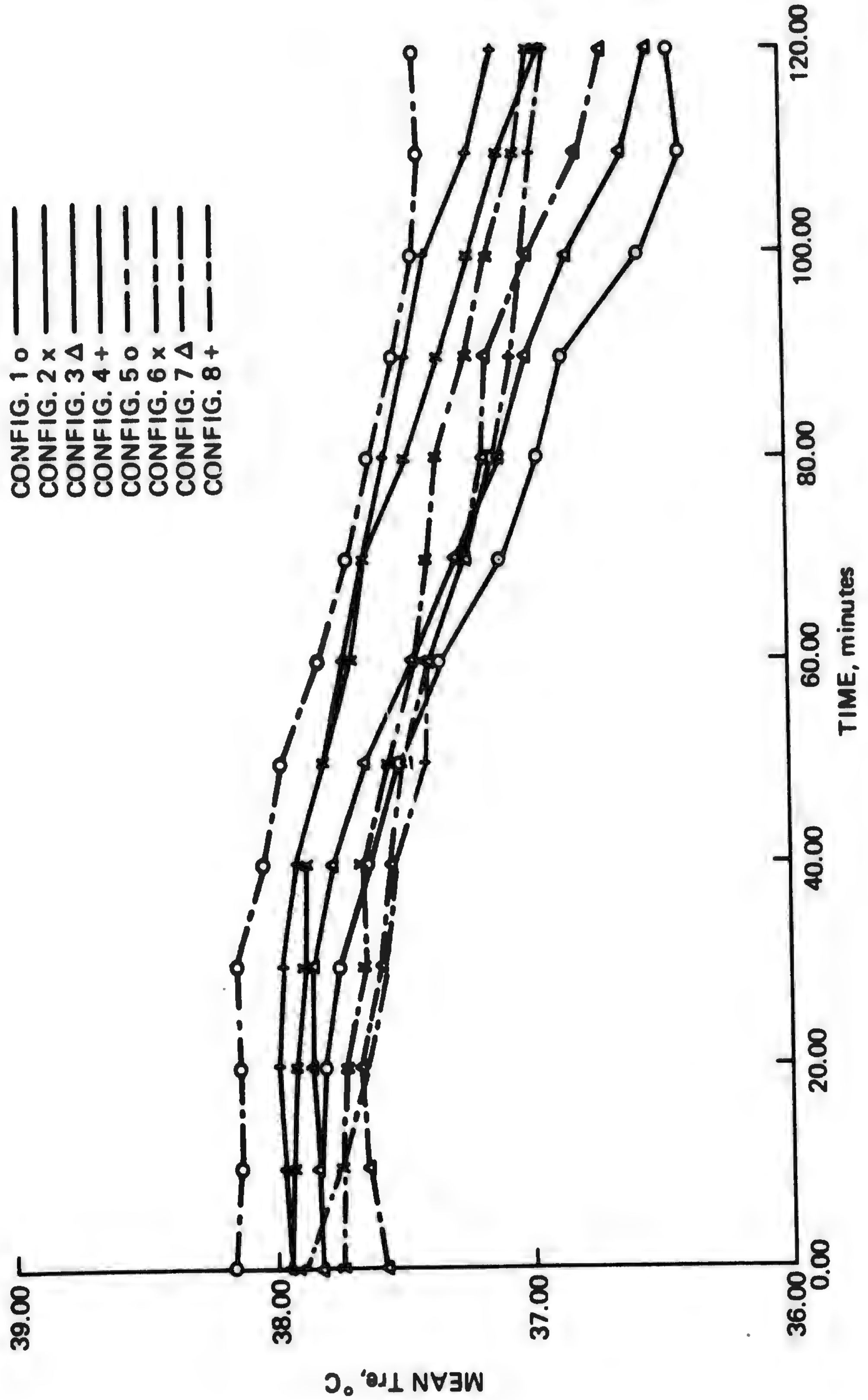

FIGURE 2. Mean Tre Vs. Time

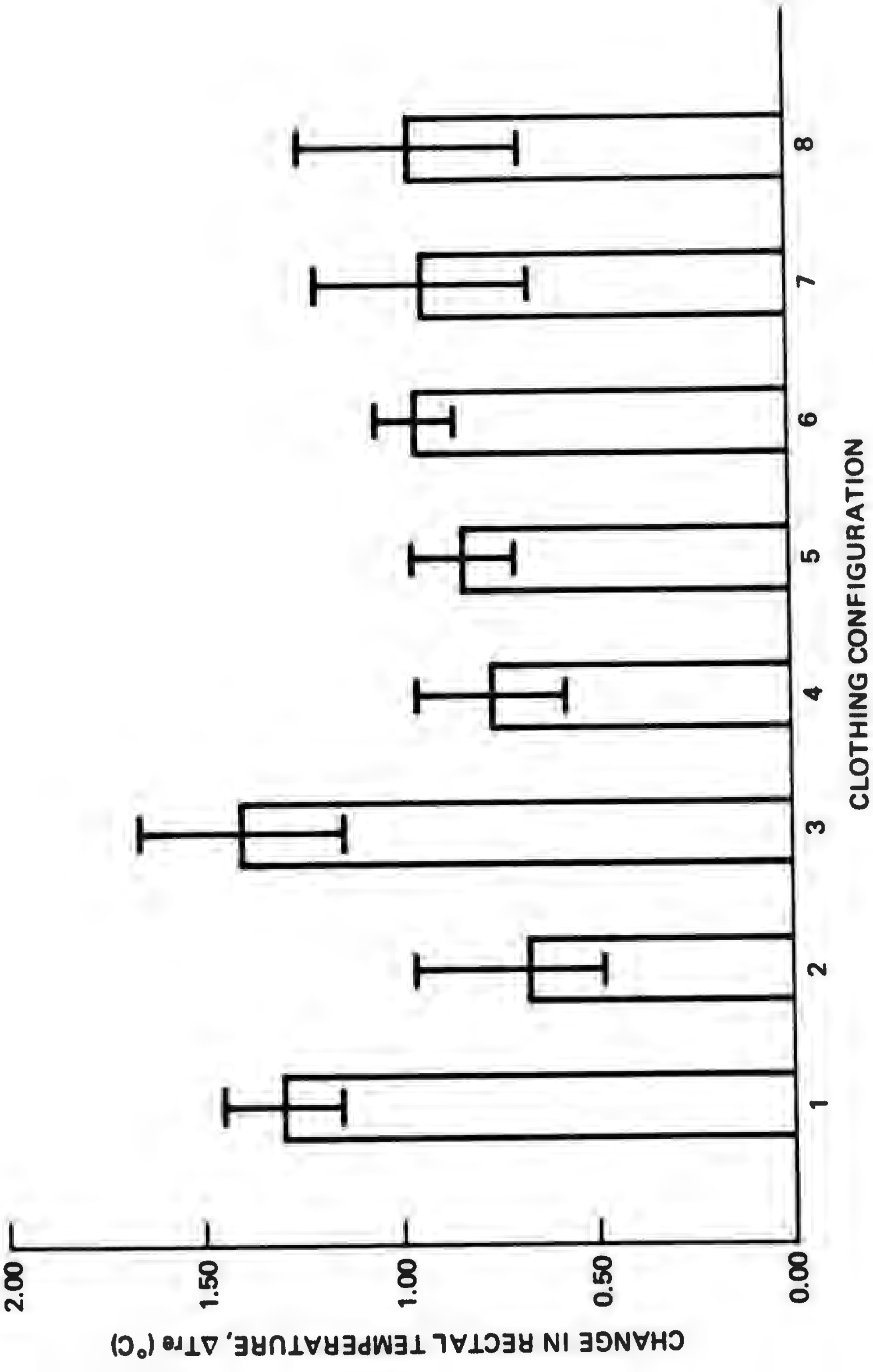

FIGURE 3. ΔTre Vs. Configuration

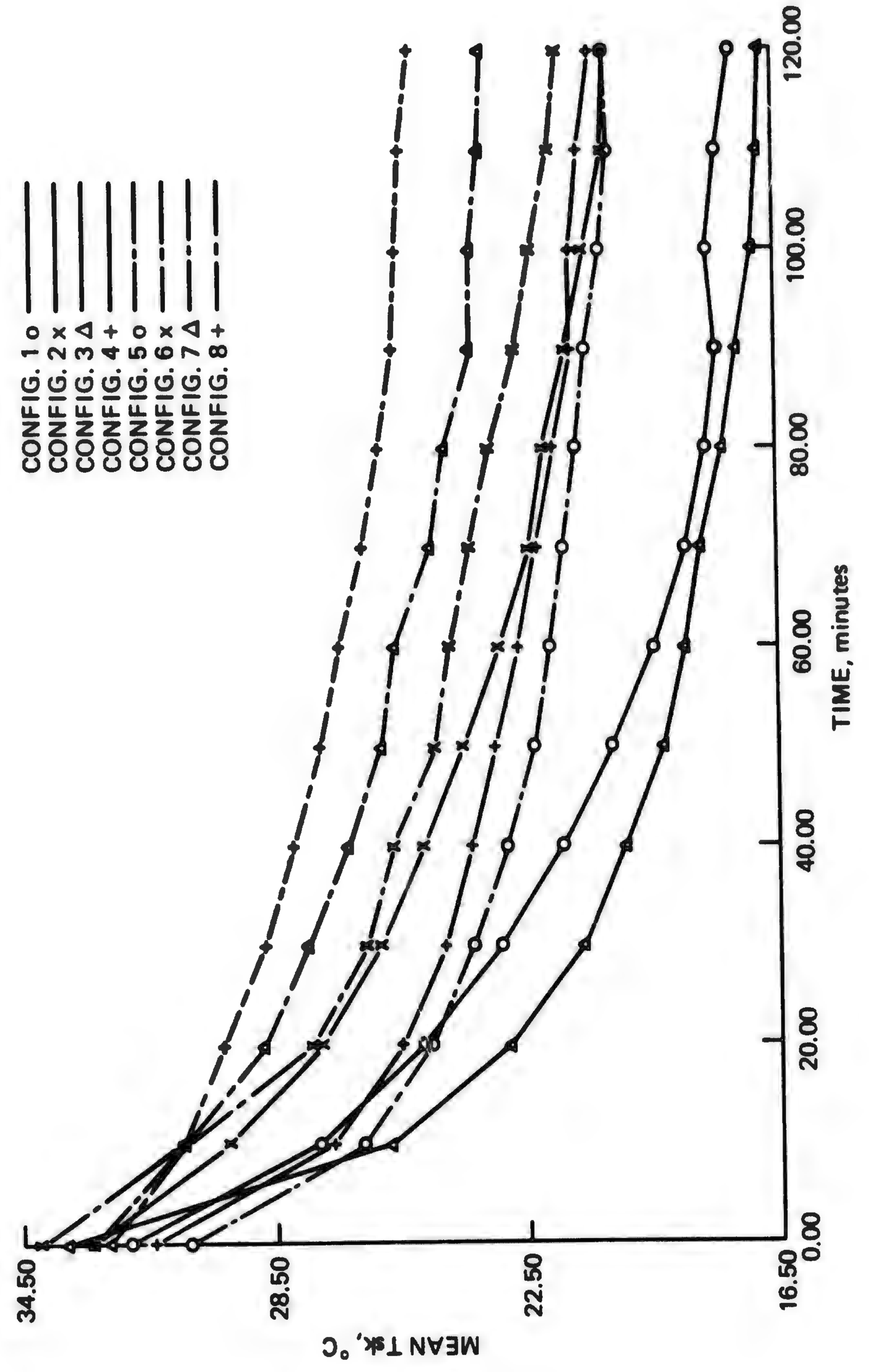

FIGURE 4. ΔMean Tsk Vs. Time

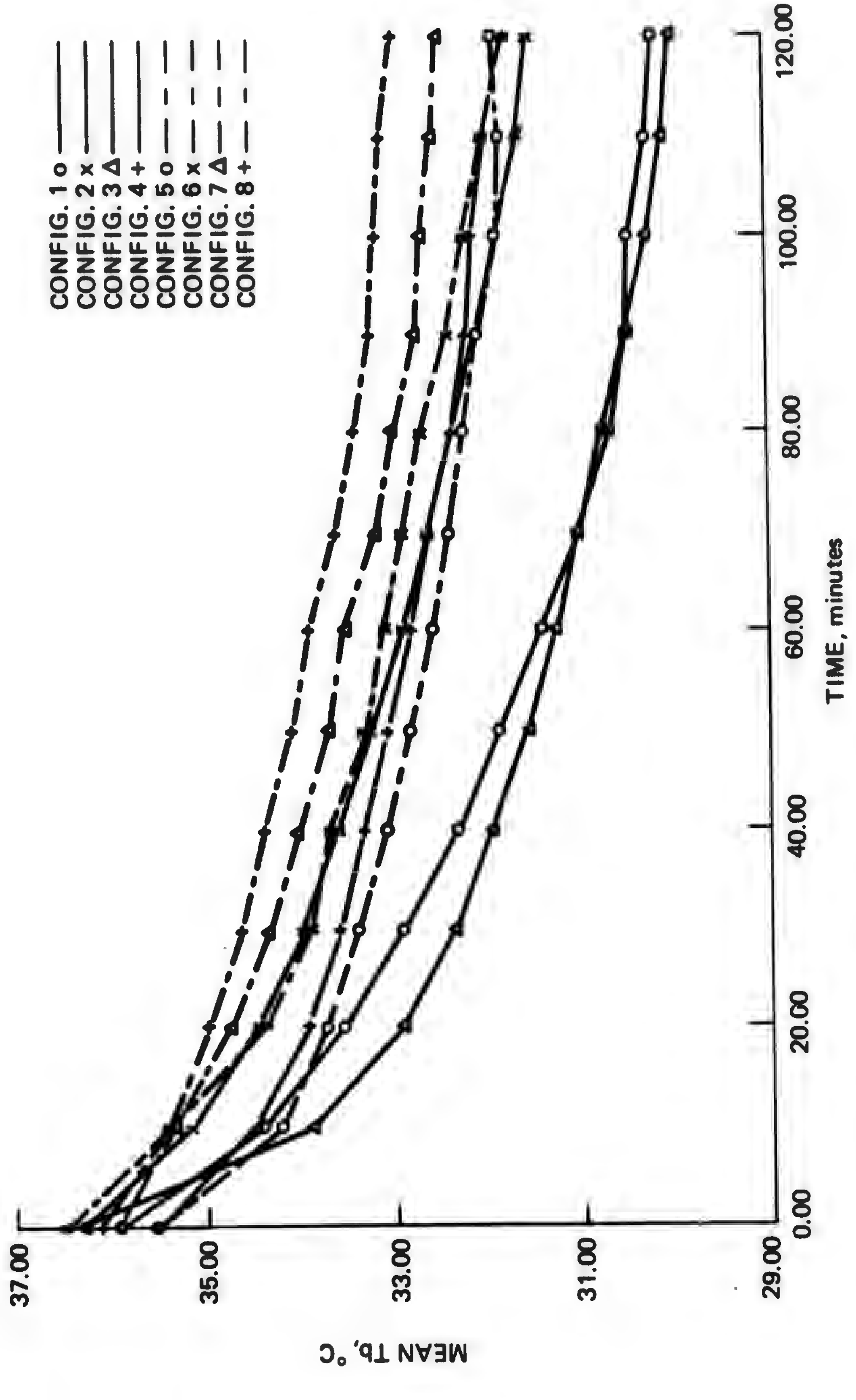

FIGURE 5. Mean Tb Vs. Time

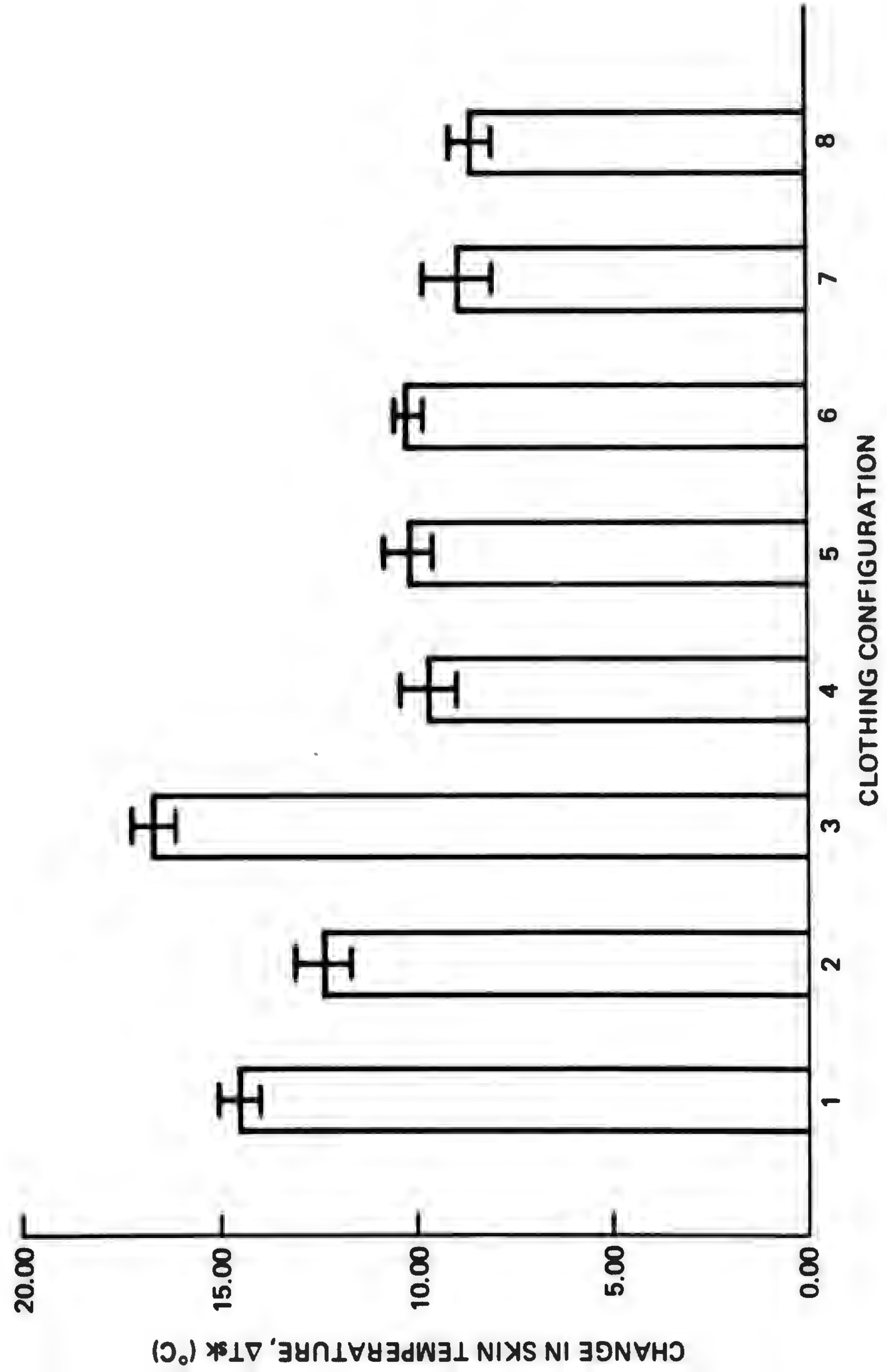

FIGURE 6. ΔTsk Vs. Configuration

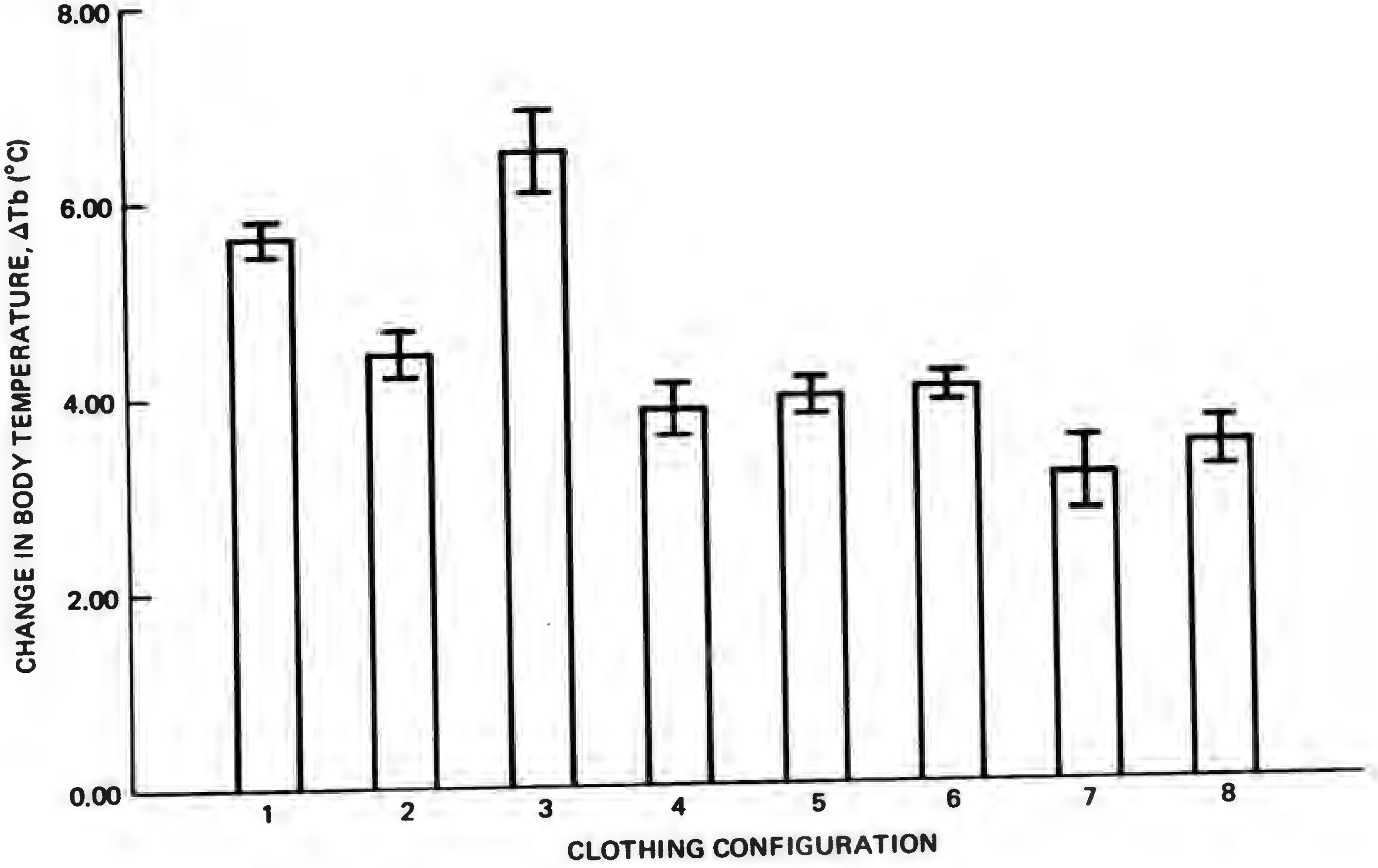

FIGURE 7. ΔTb Vs. Configuration

RESULTS (continued)

runs was believed to occur in two cases. Configuration 3 had a mean water intake of 9.04 ±1.97 kg, which would correspond to its relatively large suit opening. No quantitative data on water intake is available for configurations 6, 7, and 8. Based on visual inspection of the undergarments, these runs had negligible water intake except for a single episode in which a poorly fitted neck seal resulted in complete wetting of the undergarments.

Subject effects were examined by means of a 7 × 5 factorial ANOVA, comparing configurations 1—5 and the seven subjects who completed tests in each of them. On this basis, subject effects were found to be significant in S ($p<0.05$), ΔTre ($p<0.05$), ΔTb ($p<0.05$), tCS4 ($p<0.01$), tSS4 ($p<0.01$), and tTS1 ($p<0.05$). It is interesting that the subjective data (i.e., tCS4, tSS4, tTS1) is only subject dependent and does not reflect the configuration worn. This suggests that observed variability among configurations can be viewed as principally based on physiological reaction to the cold, not psychological reaction to stress.

DISCUSSION

The intent of this study was to determine the thermal protection in 7.2°C water provided by the CWU-62/P PTFE constant-wear anti-exposure coverall and various liner combinations. Since damage to the coverall is expected in 11 percent of all through-the-canopy ejections (Appendix A), as well as the result of normal wear, the CWU-62/P coverall and liners were tested as both leaking and non-leaking systems.

Mean test durations of approximately two hours for each configuration tested indicates that the operational requirement, two hour physiological protection in 7.2°C water (1), is met under the test conditions by all the evaluated configurations. A number of considerations must be discussed, which may affect the performance of any of these configurations in actual survival situations.

The role of subcutaneous fat in thermoregulation is to provide a static layer of insulation which acts to limit heat flow from the body core to the skin surface (9, 10, 11, 12, 13). This is of particular physiological significance at the trunk and thigh, both major sites of heat loss in cold water (9, 12). Increasing % body fat would thus improve heat retention in a cold environment.

Peripheral vasoconstriction also acts to restrict heat flow from the body core to the skin surface cooling (9, 10, 11). Vasoconstriction appears to be dependent upon subcutaneous fat thickness (10), so that persons with less fat would require quicker metabolic responses to maintain Tre (9, 10). Shivering is the major metabolic response to cold, and the extent to which it occurs is widely variable, as observed in this study and others (9).

With a mean % body fat of 18.2 ± 3.1%, the subjects participating in these tests are fatter than the USMC personnel studied by Wright and Wilmore (14) (mean = 16.5 ± 6.19%). Provided that USN/USMC aircrewmen have the same mean % body fat as the general USMC population, this suggests that aircrew personnel using any of the configurations in cold (7.2° C) water would have a lower Tre, and a higher S, than what these test results indicate, due to greater heat transfer from the body core.

DISCUSSION (continued)

Among groups with equal thickness of subcutaneous fat, certain individuals have greater metabolic and vasoconstrictive responses to cold (10). These individuals can thus maintain Tre at lower water temperatures (10, 12). It has been demonstrated in some studies (16, 17) that physical training reduces thermoregulatory responses to cold stress (16, 17), thus reducing the ability to maintain Tre. Conflicting results have appeared in the literature (18), however, which indicate an increased thermoregulatory response among subjects with greater aerobic fitness. It is thus unclear what significance the difference in aerobic fitness between the subjects of this study (30.6 ± 3.86 ml O^2/Kg/min) and typical USN/USMC aircrewmen has for predicting actual performance of the tested anti-exposure suit systems, assuming USN/USMC aircrewmen have comparable aerobic fitness to the USAF aircrewmen studied by Froelicher, et al (15)(approx. 36.7 ± 5.6 ml O^2/Kg/min).

On the basis of these considerations, the test results thus appear to be a reliable indication of the performance of the anti-exposure suit configurations for aircrew under comparable environmental conditions, since variations in thermoregulatory response to cold water appear to result from a complex interaction of factors. Although the thermal effects of subcutaneous fat would indicate that the anti-exposures suit system might not be as effective for aircrew as it was for the test subjects, metabolic responses could more than make up for the relative heat loss (9, 18), particularly if aerobic fitness is shown to have a significant role in such reflexes. Significant individual deviation from the test results under similar conditions could likely be ascribed to the effect of mental state and/or physical condition.

Protective clothing acts to provide an additional layer of insulation to the body, further limiting heat loss across the skin surface. The CWU-62/P PTFE anti-exposure coverall is designed to exclude water from contacting the skin surface, and to maintain a layer of insulating air against the skin. Lippitt and Sexton (19) showed that addition of the CWU-72/P olefin liner increased the level of insulation to approximately 1.4 clo when dry and 0.52 clo when damp. Use of the CWU-23/P cotton/polypropylene liner in place of the CWU-72/P liner provided insulation of approximately 0.68 clo when dry and 0.05 clo when damp (19).

The test results indicate that the CWU-72/P liner does indeed provide greater insulation, and thus protection, under both wet and dry conditions in cold water than the CWU-23/P liner. Since results among all the dry configurations were roughly comparable, it seems that trapped air within the non-leaking CWU-62/P-based system and still water lying within the outer clothing layers provides adequate insulation for two hour survival under the test conditions, regardless of the liner type. However, differences observed between values obtained during testing of both the CWU-23/P and CWU-72/P liners for a number of parameters were statistically significant, particularly among equivalent wet trials (i.e., configurations 1 and 2). These differences would likely be exacerbated with wave action or more serious leakage (20), since the performance of the CWU-72/P liner was significantly degraded when the extent of leakage increased, while a similar degradation in CWU-23/P liner performance was observed for a lesser amount of leakage.

Wave action could significantly reduce the insulation provided by the still water within the outer clothing layer by constant flushing with cold water (19, 21, 22). Movement in cold water increases total body heat loss (9, 12), so that wave action necessitating movement would further increase heat loss. Waves would also increase the likelihood of water leakage

DISCUSSION (continued)

down the neck seal of the CWU-62/P coverall, a problem experienced in these trials and reported in other cold water tests (21). This leakage could result in significantly reducing the dry insulation provided by the anti-exposure garment by flushing the interior with cold water.

Although the suits were purged of air before the subjects entered the water, subjects had a tendency to float relatively horizontal, due to air trapped in the legs of the CWU-62/P. This position caused the neck leakage that was experienced during testing, and would in actual use expose the neck and head to small waves. Wetting of the head and neck would greatly increase heat loss, since they are the body regions of greatest heat loss (approximately 187 W/m^2 and 150 W/m^2 respectively) (9, 23, 24). A reduction in buoyancy of the lower body portion of the CWU-62/P coverall would thus be desirable.

The importance of a constant wind (7.8 ± 1.2 m/sec.) in these tests is indicated by a number of studies which correlate peripheral vasoconstriction with facial cooling (25, 26, 27). Facial cooling would tend to induce generalized vasoconstriction earlier than might otherwise occur and perhaps "vasoconstrictive exhaustion" (11), i.e., cold-induced vasodilation, to be precipitated earlier. Cold-induced vasodilation, by increased blood flow to the periphery, would greatly increase total body heat loss. (9).

Being a constant-wear garment, the CWU-62/P-based system must be tolerated during normal operations as well as providing the necessary protection during immersion. A previous study (3) has indicated the heat stress problems associated with the CWU-62/P coverall, which are exacerbated by the use of a liner. Since configurations 4 and 5 utilized minimal insulation underneath the CWU-62/P coverall, and still met the operational requirement (1), these configurations might appear to be suitable for operational use. Unfortunately, neither configuration has been tested with a leaking CWU-62/P coverall, raising concern over their performance when wet. Configurations 2 and 3, employing both the CWU-72/P liner and the CWU-43/P, -44/P thermal underwear with leaking CWU-62/P coveralls, performed adequately but with significant degradation compared to configuration 7, which employed the same clothing items but with a non-leaking CWU-62/P coverall. This indicates the impact of wetting on the performance of these protective garments, and removing a layer of insulation can only further degrade performance (28). Thus it can be expected that the performance of either configuration 4 or 5 with a leaking CWU-62/P would be diminished, but no experimental data from these tests is available to predict the extent. It can be assumed that configuration 4 would likely perform better when wet, due to the CWU-72/P liner. Configuration 5, however, would probably generate less heat stress because of less insulation about the torso and thighs.

CONCLUSIONS

1) The non-leaking CWU-62/P coverall requires minimal underlying insulation to provide two hours of physiological protection in calm 7.2°C water. However, minor damage resulting from normal wear or by through-the-canopy ejection is considered likely for the CWU-62/P coverall.

CONCLUSIONS (continued)

2) A leaking CWU-62/P coverall can provide two hours of protection in calm 7.2°C water when worn with CWU-43/P, -44/P thermal underwear and either the CWU-23/P liner or the CWU-72/P liner. The extent of leakage significantly affects the performance of a given configuration.

3) Use of a wet CWU-72/P olefin liner results in less total body heat loss, as indicated by the various physiological parameters, than a wet CWU-23/P cotton/polypropylene liner. The liners produce comparable results when used dry.

RECOMMENDATIONS

Results from the testing of the various ensembles discussed above indicate that with a nonleaking CWU-62/P coverall, the type of underlying insulation is unimportant in meeting the Operational Requirement (1) of two-hour protection in 7.2°C water. Because of the potential for heat stress occurring during normal operations, use of minimal underlayers would appear to be the most reasonable approach.

Leakage significantly degrades the insulation provided by the protective ensembles. However, coverall damage is viewed as a possibility, therefore any recommended configurations must provide adequate protection despite leakage. On the basis of the experimental results, and for the above reasons, the following recommendations are made:

1) The CWU-62/P coverall should be worn with both CWU-43/P, -44/P thermal underwear and the CWU-72/P liner. This configuration was shown to meet the Operational Requirement (1) even with extensive damage (2" tear).

2 Further testing of the configurations be performed in a rough water situation. This would serve to better simulate the actual survival conditions, and it would exacerbate the effects of suit leakage.

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