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PHYSIOLOGICAL EVALUATION OF EFFECTS ON PERSONNEL WEARING THE MICROWAVE PROTECTIVE SUIT AND OVERGARMENT

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ABSTRACT

A silverized nylon, open-weave, microwave protective suit and cotton twill overgarment, to be worn over conventional Navy work clothing, was developed to protect personnel working in the high-density radio frequency fields of the larger and more powerful radar scanning systems anticipated aboard Naval vessels and at shore installations. Since total body heat absorption per unit time is a critical factor for the survival of personnel exposed to a microwave field, a physiological evaluation of the protective clothing system was performed to determine if the clothing itself was responsible for any additional thermal stress in a warm environment. For a series of two-hour periods, two male subjects wearing this clothing in a climatic chamber were exposed to a temperature of 85 degrees F, a relative humidity of 45 percent, a wind velocity of 11.5 mph and a solar radiation of 1.6 gm-Cal/m^2/min. The protective clothing system did not place any significant physiological heat stress on personnel in the warm environment as compared to the wearing of conventional Naval work clothing alone. Visual acuity was decreased slightly.

SUMMARY

PROBLEM

The objective of this physiological test series was the determination of the level of thermal stress placed on personnel while wearing an experimental microwave protective suit and overgarment over conventional Navy work clothing in a warm environment. Additional heat stress resulting from the clothing alone would compromise the value of the suit's microwave protection.

CONCLUSION

The wearing of a completely enclosing, silverized nylon, open-weave, microwave protective suit and cotton twill overgarment over conventional Navy work clothing did not place significant physiological heat stress on personnel in a warm environment. Over the two-hour test periods mean rectal temperature rose only 0.7 degree C (1.3 degrees F), body heat storage never exceeded 10.0 Cal/m^2/hr, and sweat production remained approximately 1.0 percent of initial nude weight. Heart and respiration rates and electrocardiogram showed no significant changes. Although visual acuity was decreased slightly, no essential difference in physiological comfort was noted by the test subjects.

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INTRODUCTION

In anticipation of the use of larger and more powerful radar scanning systems aboard Naval vessels and at shore installations, the Navy Clothing and Textile Research Unit, together with the Naval Applied Science Laboratory, was assigned the responsibility for research and development of a clothing system offering protection to personnel working in a high-density radio frequency field. Although the period of exposure was expected to be continuous, it could last briefly (for example, for the inspection, calibration and repair of the antenna or its environs while the radar is in operation) or for long periods (for instance, for the protection of personnel at duty stations located in the path of the rotating microwave beam or its sideloops).

When the microwave reflective material was developed, suit construction and preliminary RF-field testing of the prototype suit was reported by Weinstock (1). Although the suit met all of the basic attenuation requirements of the Bureau of Medicine (1), the need for improvement in several areas became evident. Whenever the suit was worn in the high-density RF field, arcing would occur between two close or contacting layers of the metalized fabric; this was noticed especially in the axillary region, between the legs and, in some cases, around the neck. Plastic gloves were worn to prevent arcing between the fingers or between the suit and metal objects. One instance of actual fusion between two contacting layers of the suit in the neck region was reported (1). This condition was alleviated when a cotton raincoat was donned over the silver impregnated suit during the field exposure trials. Weinstock then concluded that normal cold- or wet-weather gear worn over the suit in conjunction with plastic boots and gloves would offer arcing protection. A lightweight cotton coverall, to be worn with the boots and gloves over the suit during warm weather operations, was subsequently developed. A second problem area was the feeling of warmth while the microwave protective suit alone was worn.

The present study was undertaken to determine the physiological and thermal stress placed on the human body as a result of wearing the microwave protective clothing and overgarment over regular Navy work clothing in warm environments. Cold environments were not considered because body temperature could be controlled by the amount of clothing worn with the microwave coverall.

Electromagnetic waves produce heat in an animal body. If this heat is not dissipated sufficiently, the total body temperature will rise to a critical level, and death will ensue. Medical diathermy, with a frequency of 10-100 MHz per second, is a typical example of the usefulness and penetration of such waves in human tissue. As frequency increases, however, these waves have less chance to penetrate living tissue. They become extremely dangerous by concentrating heat in the cutaneous layers of the body which serve to reflect the microwaves from the surface. In high-density RF fields of 3.0 GHz or above, very little of the radiation actually penetrates into or below the subcutaneous layers. This type of radiation, therefore, does no direct harm to deep tissues because the layer of subcutaneous fat serves as an insulator. The skin becomes overheated and the body responds to dissipate this stress by internal thermoregulatory processes. Tissues that have poor circulation, such as those in the eye, cannot rapidly distribute this heat and are easily damaged.

Susskind (2) believes that body temperature, rather than the dose of microwave energy per second, determines when death will occur. This is confirmed by Deichmann, Bernal, and Keplinger (3), whose studies of survival time in a continuous microwave field at different ambient temperatures showed that death ensued in all exposed rats when the rectal temperature rose to approximately 44 degrees C (111.2 degrees F), regardless of the ambient temperature. The lower the ambient temperature, the greater is the chance of thermal compensation and, therefore, the chance of survival.

If personnel working in high-frequency microwave fields started with an elevated body temperature from the stress of ambient temperature, humidity, or the thermal load imposed by the "protective" clothing system, the margin of safety would be severely compromised. In mammals the maximum safe rectal temperature is considered to be 106 degrees F (4,5). Beyond this critical temperature the nervous system is seriously affected and will not function normally.

Deichmann and his associates (6) have also investigated the thermal stress effects of exposure to an interrupted microwave field (simulating the continuous 360-degree sweeping action of a radar scanner). Using unprotected rats subjected to a constantly rotating microwave frequency of 24 GHz at 300 milliwatts output, they found that the ratio of exposure time to nonexposure time in the field, as the scanner completed its full circle, was critical to the length of total safe exposure. The animals survived 80 minutes of total exposure to the microwave beam during an eight-hour period. The 10:50 exposure ratio gave the animals a chance to dissipate some of the absorbed heat during the nonexposure intervals. Prausnitz and Susskind (7) have confirmed this with mice, but feel that the slight latent period before body temperature decreases, when the mice are removed from the microwave field, reduces their ability to dissipate heat if the exposure-nonexposure cycle is too rapid. This would result in a situation similar to almost continuous exposure.

DESCRIPTION OF EXPERIMENTAL CLOTHING

a. Regular Work Clothing

The Navy standard-issue chambray shirt, denim dungaree trousers, cotton "T" shirt and boxer shorts, cotton socks and leather low quarter shoes were worn by all subjects beneath the microwave suit alone or beneath both the microwave suit and the overgarment.

The regular work clothing served as a control to determine any possible heat stress when the microwave suit or the microwave suit and overgarment were worn over the work clothing.

b. Microwave Protective Suit

The microwave protective suit (Figure 1) consisted of a one-piece coverall with attached hood, hand and foot coverings (1). The complete

Figure 1. Front view of the microwave protective suit worn over standard Navy work clothing. The plastic gloves usually worn with the suit are not shown in order that the configuration of the attached hand covering can be illustrated. NAVCLOTEXTRSCHU Photo RT-93-9.

suit, including extremities, was constructed of a single layer of silverized woven-nylon plain-leno fabric treated with water-repellent and stain-resistant duPont ZEPEL. The fabric weighed 3.8 ounces per square yard and its silver content was 5.4 percent by weight. When 260 denier yarns were used in the warp and filling, the leno weave permitted an air permeability of greater than 600 $ft^3/min/ft^2$. The suit had excellent whole-body-shielding properties in a radio frequency field ranging from 200 MHz to 10 GHz, showing an average attenuation of 27 db. Resistance to electrical conductivity was less than one ohm.

This highly flexible suit was entered through the back by means of an electrically conductive zipper closure (silverized nylon tape) extending from the hips upward to the crown of the skull. The loose fit at the ankles, waist, and wrists could be adjusted by nonconductive Velcro tape fasteners. There was ample room within the hood for the wearing of a "hard hat" safety helmet provided for spacing the metalized fabric from the face. The arms were slit on the medial side between the wrists and elbows to allow for the removal of the hands during standby conditions or in case of emergency situations in which use of the gloves would be detrimental. These openings were secured by silverized Velcro fasteners for conduction.

Nonconductive plastic boots and five-fingered-supported vinyl-dipped gloves were worn with this suit to prevent arcing in the fingers and electrical continuity with the flooring material. The boots served a double purpose because they also prevented wear on the sole portions of the microwave suit.

c. Overgarment

The overgarment (Figure 2) was constructed of 5.5 oz/yd^2 cotton twill with a zipper closure extending from the crotch to the neck. Worn over the microwave suit, it left the hands, feet and head exposed. Its function was the prevention of arcing between the closely adjacent layers of the microwave suit during normal body movements. A draw-string closure was sewn into the garment around the waist to permit conformity to body shape.

For simplicity in reporting results, the clothing is discussed according to the following clothing groups:

Group I--(Control)--Conventional work clothing.
Group II--Microwave protective suit worn over conventional work clothing.

Group III--Overgarment worn over both the microwave suit and the conventional work clothing.

NOTE: Because of exposure to high-intensity ultraviolet and infrared rays emanating from the solar lamps, variable density watch standers' goggles were worn by all test subjects during this series of experiments.

Figure 2. Front view of the overgarment worn over the microwave protective suit. NAVCLOTEXTRSCHU Photo RT-93-8.

PROCEDURE

Two male engineering students volunteered as test subjects for this series of experiments. Ages 20 and 21, of medium build and weighing 64 and 70 kg, respectively, they represented the average Navy man who would normally be performing duties requiring the protective clothing system. Additional physical data can be found in Table I.

TABLE I. PHYSICAL CHARACTERISTICS OF TEST SUBJECTS

Subject	Age	Weight	Height	Body Surface Area
T.V.	20	64 kg	174 cm	1.71 m^2
C.H.	21	70 kg	178 cm	1.84 m^2

Upon donning physiological transducers and experimental test clothing, the subjects entered a conditioning room controlled at 20 degrees C (68 degrees F) and remained there, seated quietly for approximately ten minutes. This period was used for establishing a reference physiological baseline before each exposure to test conditions. When this baseline was established, the men entered the adjacent climatic test chamber and, during a series of nine two-hour experiments, were exposed to a temperature of 29.5 degrees C (85 degrees F), a relative humidity of 45 percent, a wind velocity of 11.5 mph (10 knots) and a solar radiation of 1.6 gm-Cal/m^2/min. To insure uniform values, test environmental conditions were created daily in the climatic stress chamber at least two hours in advance of testing.

Both test subjects wore each of the three clothing groups three times during the test series. Each exposure to the simulated environment lasted two hours and usually took place twice a day, i.e., once in the morning and once in the afternoon. Assignment of individual clothing for each test session was by random order with the stipulation that the three suits had to be worn three times by each subject. This procedure was used to eliminate the influence of either test subject's reaction to a particular clothing system while the other subject might be wearing the same system at the same time. Except for scheduled activity periods during the two-hour tests, both subjects stood quietly talking between themselves. Physical activity was limited because the test design required that the subjects stand either in front of the solar bank or in a "shaded area."

Upon entering the chamber, the subjects climbed up and down a flight of two 9-inch-high steps 50 times. This activity, which simulates a probable activity level for a shipboard radar installation, was done at the subjects' own pace and was equivalent to the workload of climbing the superstructure from a below-deck repair shop to a radar antenna. Upon completion of this exercise period, they remained standing quietly.

After the first hour of the experiment, the subjects again climbed the steps 100 times at their own pace to simulate a round trip from the antenna area to the repair shop for a part. Both men again stood quietly until about three minutes before the termination of the two-hour test when they again climbed the steps 50 times to simulate a return from the antenna to the repair shop.

During those periods, while standing quietly, they were exposed, one at a time, to a bank of solar lamps for five of every fifteen minutes. Consequently, in an hour they were exposed for twenty minutes to the horizontal beam of solar radiation. This exposure was divided into five-minute intervals on each of their front, back, left and right sides. The bank of lamps produced an output of 6750 watts from nine lamps. The spectral energy of the lamps closely matched the spectral energy of the sun and covered a range of 2,300 to 24,000 Å units. When the men stood 127 centimeters (50 inches) from the lamp bank, their clothing received a thermal radiation level of 1.6 gm-Cal/cm^2. At the termination of each period of exposure, each subject walked about 3 meters (10 feet) diagonally from the lamp bank to simulate the sun's passing behind a cloud or a man's working in the shadow of the antenna.

Prior to entering the conditioning room or the test chamber, subjects underwent the following general procedure:

(a) Nude body weight was determined on a Toledo scale accurate to $\pm$ 10 gms.
(b) Weight of all of the clothing worn was recorded separately on the same scale.
(c) Rectal temperature was measured with a clinical thermometer.
(d) Copper-constantan thermocouples were applied to the skin at the following ten locations:

1. Instep
2. Calf
3. Lateral thigh
4. Medial thigh
5. Back
6. Chest
7. Upper arm
8. Lower arm
9. Middle fingertip
10. Cheek

(e) A copper-constantan thermocouple covered with a No. 16 French rubber catheter was inserted approximately 15 cm into the rectum.
(f) A mercury strain gauge belt (8) was strapped around the chest at nipple height; its Velcro fastener was situated over the sternum.

(g) Three Beckman silver-silver chloride electrodes were attached to the sternum in a vertical line between the fourth and sixth rib. The area of electrode placement was washed with a 70-percent propanol solution and the epidermis scratched lightly (without drawing blood or producing an erythema) to reduce the skin resistance.
(h) Experimental clothing was donned according to the test schedule.
(i) The weight of the fully clothed subject was taken on the same scale described above.

Upon completion of the above procedure, subjects entered the conditioning room and attached themselves to the remote instrument connection console. All wire leads were carried from the console to the physiological harness in the suit by means of extension leads passing through the Velcro opening at the right wrist. After remaining quietly for approximately ten to fifteen minutes while the physiological baselines were being recorded, subjects were disconnected and brought into the test chamber where they were reconnected to a remote connection console wired in parallel with its counterpart in the conditioning room. Both units sent signals through a master thirty-two pole/four position stepping switch into an Offner Type R ink-rectilinear oscillograph which recorded heart and respiration rates and the electrocardiogram. Thermocouple leads were sent through the same switch into an Esterline Angus 48-point recorder with program printing.

The parameters of the heart and respiration rates, the electrocardiogram, and the skin and rectal temperatures were monitored on each test subject every ten minutes and as necessary for the length of the experiment. The full cycle of 22 temperature measurements was completed in 66 seconds.

When the two-hour exposure period was completed, the subjects returned to an anteroom where they were immediately weighed, with and without clothing, while a rectal temperature measurement was simultaneously taken with a clinical thermometer. Following this, the clothing was also weighed separately.

In addition to monitoring of the above parameters, the following measurements were also calculated:

(a) Mean skin temperature--computed every 10 minutes as the weighted average of the 10 skin thermocouples according to the formula described by Hardy and Dubois (9).
(b) Body temperature--computed every 10 minutes as 0.8 times the rectal temperature plus 0.2 times the weighted skin temperature (10).
(c) Total weight loss--difference between initial and final nude weights.
(d) Evaporative weight loss--difference between initial and final clothed weights.
(e) Evaporative ratio--weight lost by evaporation divided by total weight loss expressed as a percentage.

(f) Body weight deficit--total weight loss divided by initial nude weight expressed as a percentage.

(g) Body heat storage Q's--computed from the following equation:

$$Q's\ (Cal/m^2/hr) = \frac{\text{Body Temp. } (^{o}C) X (0.83) \text{ specific body heat X wgt. of subject (kg)}}{\text{surface area } (m^2)}$$

Besides the above tests being conducted, control values of the visual acuity of seven additional subjects were established and compared with those when the microwave suit was worn. The seven men, members of the Facility technical staff, ranged in age from 29 to 43.

Visual acuity was measured by use of the armed forces Clinical Visual Acuity test charts at the standard distance of 20 feet from the subject. Each person read two different cards: a randomly selected card while wearing the microwave protective suit and the remaining card when not wearing the suit (control). All subjects were checked with and without the suit for red-green color perception by the use of the armed forces Pseudo-Isochromatic Plates for Testing Color Perception.

A General Electric Type DW-60 Radiation Meter was used to determine the amount of solar radiation transmitted through the clothing materials, individually or in combination. Clothing held at chest height was exposed to the solar radiation bank at the same distance as test subjects were exposed. The radiation meter was held approximately 1.0 cm behind the material to determine the amount of transmission and the same distance in front of the garment to determine the degree of reflection. The difference between the control reading (exposure to the same condition without clothing) and the sum of the reflected plus the transmitted light was considered the amount of heat absorbed by the clothing. All readings were taken in gram-calories per square centimeter per minute.

RESULTS AND DISCUSSION

Temperature

Figures 3, 4, and 5 show the mean rectal, skin, and body temperatures of the two test subjects while wearing the control work clothing (dashed line), the microwave suit over work clothing (solid line) and the overgarment over both the work clothing and microwave suit (broken line) under test conditions previously described. It should be noticed that the rectal temperature did not vary more than 0.2 degree C from its mean 37.4 degrees C (99.3 degrees F) reading during the two-hour period while subjects wore standard work clothing alone. When subjects donned the microwave suit over work clothing, their rectal temperatures rose 0.5 degree C during the baseline period and the first 10 minutes of the experiment. At that time the temperature leveled off and remained near a mean reading of 37.4 degrees C (99.3 degrees F), almost identical to wearing work clothing alone. When the overgarment was worn over both work clothing and microwave suit, the mean rectal temperature was similar to that

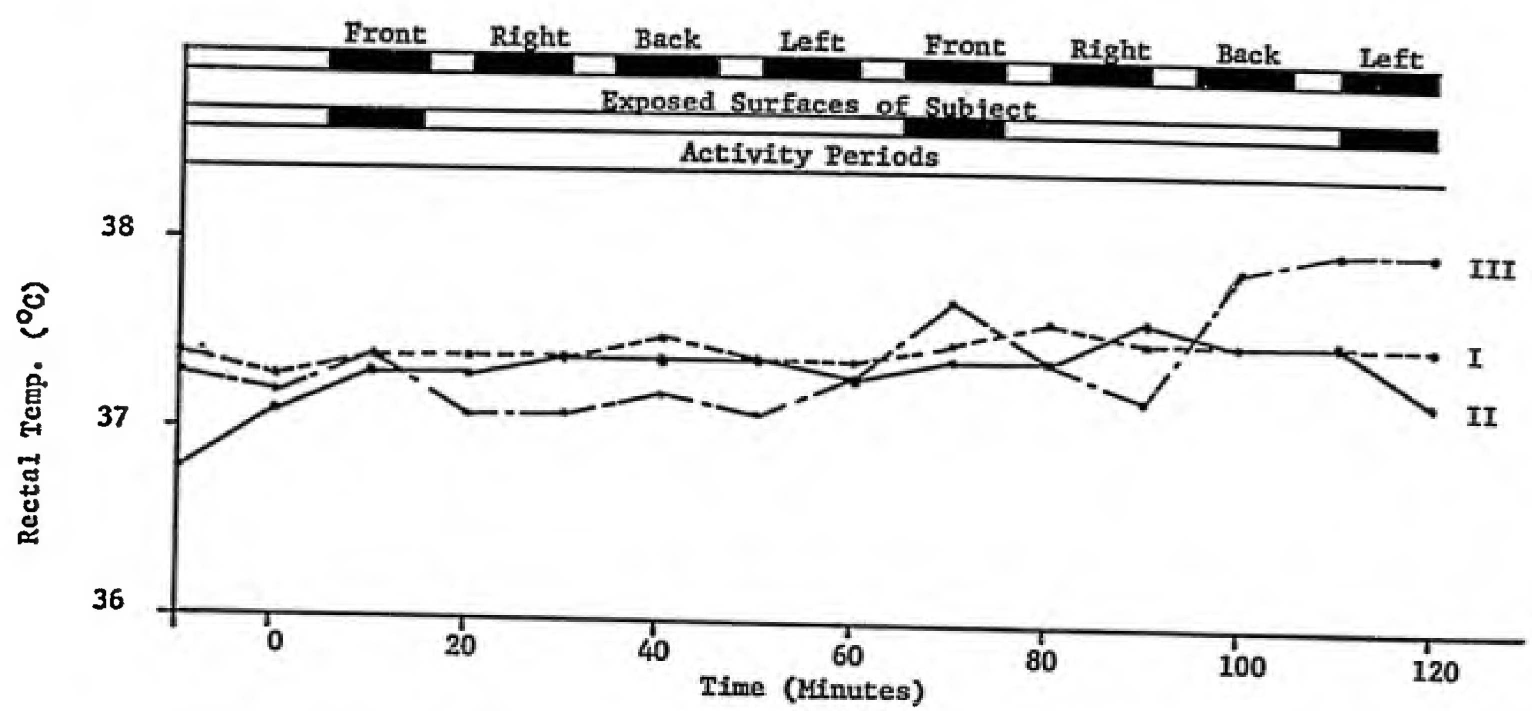

Figure 3. Mean rectal temperatures of test subjects while wearing (a) conventional Navy work clothing (Group I), (b) microwave protective suit over this conventional work clothing (Group II) and (c) overgarment over both the microwave suit and the work clothing (Group III).

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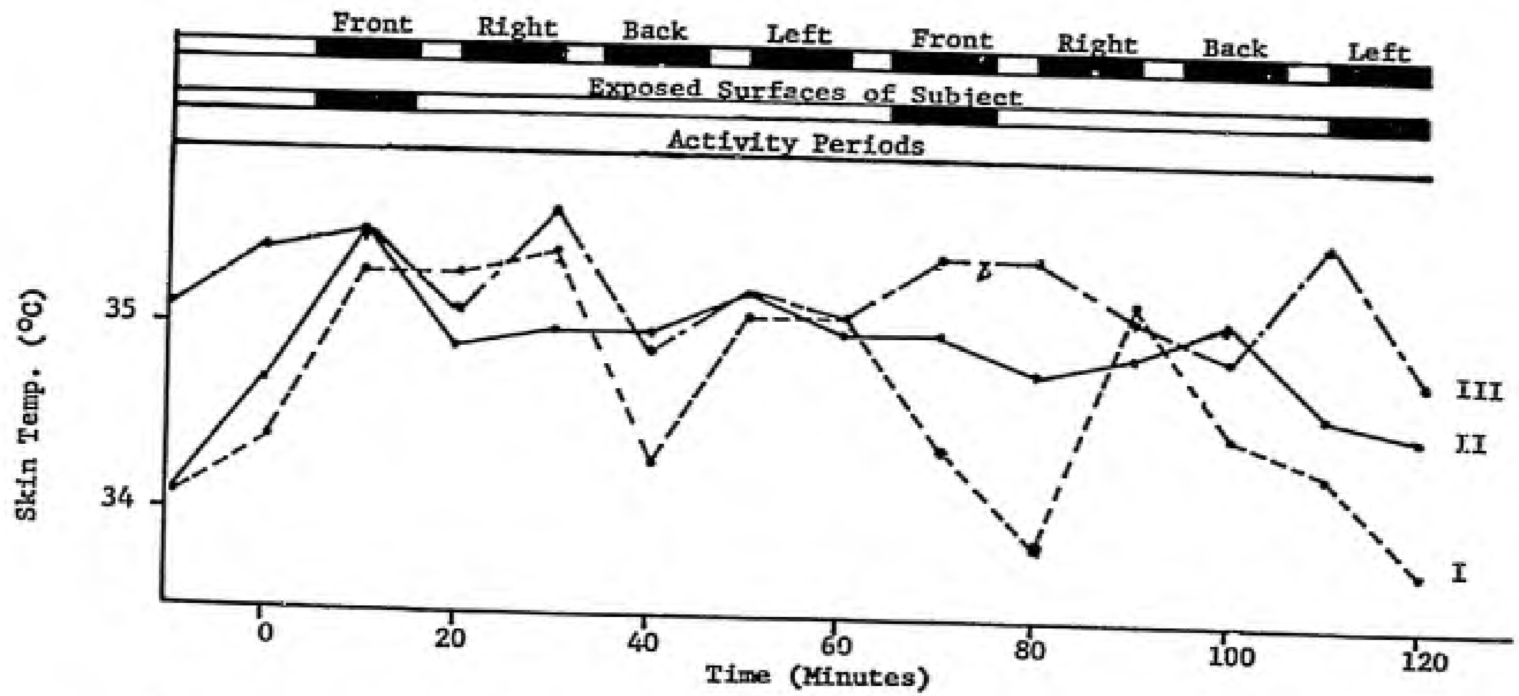

Figure 4. Mean skin temperatures of test subjects while wearing (a) conventional Navy work clothing (Group I), (b) microwave protective suit over this work clothing (Group II) and (c) overgarment over both the microwave suit and the work clothing (Group III).

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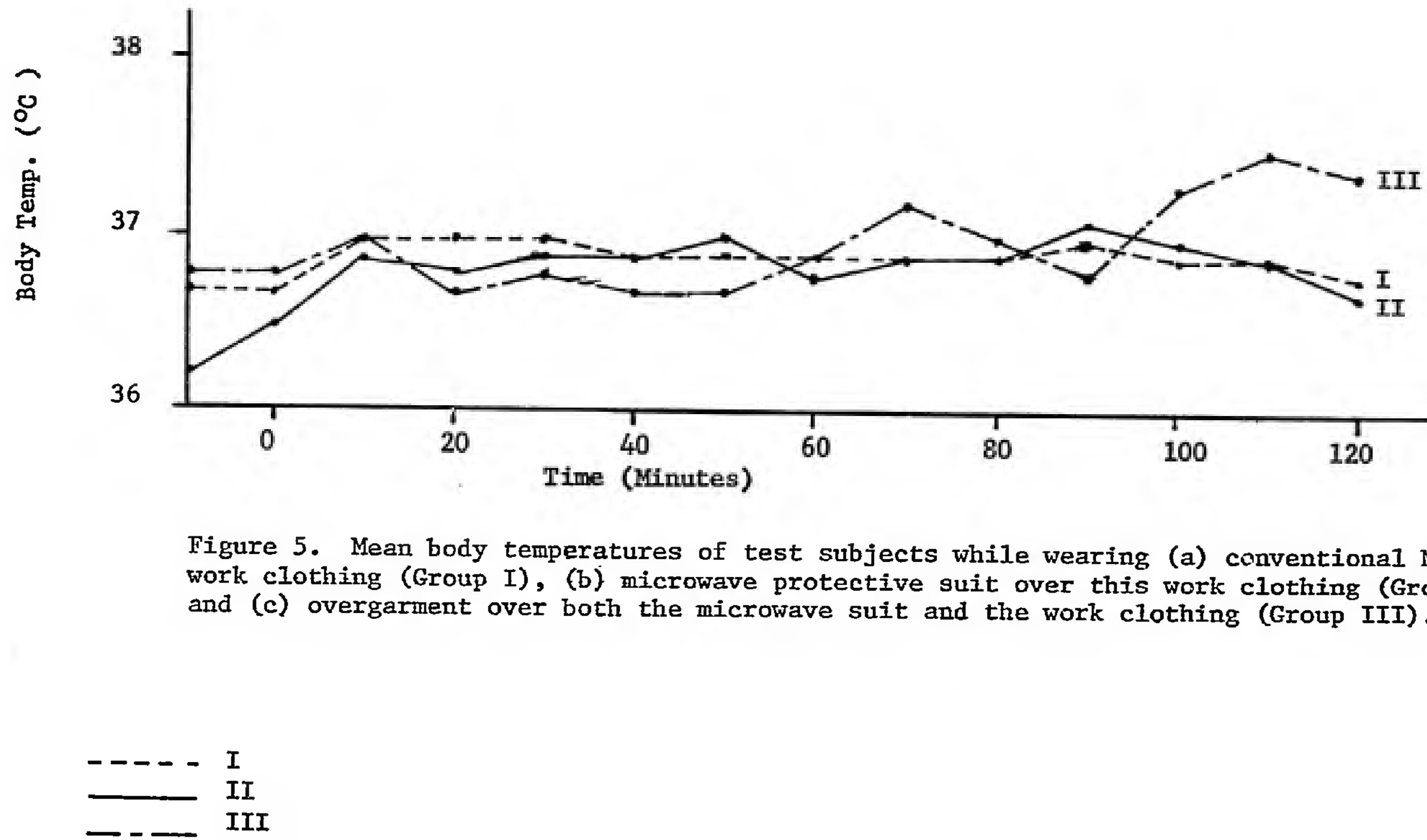

Figure 5. Mean body temperatures of test subjects while wearing (a) conventional Navy work clothing (Group I), (b) microwave protective suit over this work clothing (Group II) and (c) overgarment over both the microwave suit and the work clothing (Group III).

observed when work clothing alone was worn during the baseline period and first 10 minutes of the test. After the first 10 minutes, the rectal temperature fell to 37.1 degrees C and remained there until the exercise period at the end of the first hour when a temperature of 37.7 degrees C was recorded. A second rise in this mean rectal temperature of 37.4 degrees C was observed at 100 minutes when it plateaued at 38.0 degrees C (100.4 degrees F) for the 20-minute remainder of the test.

The first peak in rectal temperature while the three garments were worn simultaneously can be attributed to the stair-climbing activity performed at the end of the first hour of the test. It must be pointed out, however, that this phenomenon was not noticeable during the initial activity period at the start of the test, perhaps because the second workload was twice as heavy as the first. Another reason might be that too few calories were produced by the initial exercise or enough heat absorbed from the ambient environment to satisfy the specific heat requirements needed to raise the body temperature. The second peak and plateau in rectal temperature was evidenced in only one test subject wearing Group III clothing and did not appear when the experiment was replicated by the same subject. If that high reading were discarded, the other readings would average within 0.2 degree C of the rectal temperature when only work clothing was worn.

Except for those peaks in rectal temperature observed while subjects were wearing the overgarment over other clothing, there was no significant difference (by a statistical analysis of variance) in rectal temperature during the wearing of the microwave protective clothing and the anti-arcing coverall over regular work clothing (Group III) as compared to the wearing of either work clothing alone (Group I) or the microwave suit and work clothing (Group II).

The mean skin temperature, Figure 4, was more stable during the two-hour tests while Clothing Group III was worn than while the work clothing alone was worn. Fluctuations were produced in the mean skin temperature while the work clothing was worn because the solar radiation exposed areas of the skin and most of the radiation was transmitted through the chambray shirt and dungarees (0.6 gm-Cal/cm^2/min). The difference between skin temperatures during activity periods when work clothing alone was worn can be attributed to the evaporative cooling produced by sweating. Exercise was light during the first period and no facial perspiration was noticed. During and after the second exercise period, sweating was profuse because the degree of activity was more severe.

Each subject was exposed to the horizontal rays of solar radiation for a period of five minutes on each side of the body to prevent possible sunburning effects or damage to the eyes. Mean skin temperature rose approximately 1.5 degrees C when the subjects faced the lamps or had their right sides exposed. This was caused by the location of the thermocouples on the body. For convenience, thermocouples were attached to the right side of the body only. Therefore, when a subject was turned toward the lamps in such a way that his face or chest was directly in line with the radiation, the thermocouples were reading higher temperatures on those surfaces exposed. The lower temperatures, recorded when the back or left side was exposed, are due to fewer thermocouples measuring the direct exposure of the radiation. Mean skin temperature for the two-hour period was 34.7 degrees C (94.5 degrees F) when the work clothing alone was worn.

Figure 4 illustrates that, when the microwave suit was worn over work clothing, the mean skin temperature of 35.0 degrees C (95.0 degrees F) was consistently higher and more uniform than when work clothing alone was worn. Peak temperatures appeared only when the face or back was exposed during the first hour, but not during the second hour. This uniformity of temperatures probably results from the conduction of the total heat load over the body by the silverized material. When evaporative cooling occurred, skin temperature showed a slight drop because of sweat production during exercise. This drop was not as severe as the decrease seen with work clothing alone, because it was modified by the uniform heat distribution of the microwave suit.

When the overgarment was worn over both work clothing and microwave suit, the initial baseline for skin temperature was higher, 35.4 degrees C (95.7 degrees F), than that of the other clothing systems. As the test session progressed, however, the skin temperature actually fell 0.6 degree C. Skin temperatures averaged 35.2 degrees C (95.4 degrees F) for the two-hour tests, with a peak during the first and second hours only when the right side was exposed.

The plotted averages of successive 10-minute-interval temperature measurements taken at the 10 skin locations did not reveal any "hot spots" resulting from the clothing that could not be explained by the changes in the angle of incidence of the radiation on the body. This conclusion was substantiated by subjective comments from each person tested. Figure 6 indicates that the wearing of plastic boots over shoes during the evaluation of the microwave suit and the overgarment showed a consistent 1.6 degrees C rise in the skin temperature of the foot as compared to that when shoes alone were worn. Some mositure was found in the plastic boots each time they were worn.

Beyond the cyclical fluctuations resulting from intermittent exposure to the solar lamps, the temperature of the hand always decreased about 1.0 degree C during the two-hour-test series. Measurements obtained beneath the plastic glove of Group II clothing were not consistent with those obtained from Group III clothing (approximately 1.4 degrees C higher). Yet, temperature readings of the exposed hands of subjects in Group I clothing were similar to those in Group II clothing. The vinyl gloves fit loosely over the microwave suit. As the temperatures of the hands increase, the large wrist openings and the natural finger movements provide sufficient air circulation to remove the evaporating sweat, thereby cooling the area. Since the gloves overlapped the overgarment, the size of the wrist openings was reduced considerably. This restricted air circulation and resulted in higher hand temperatures with clothing in Group III.

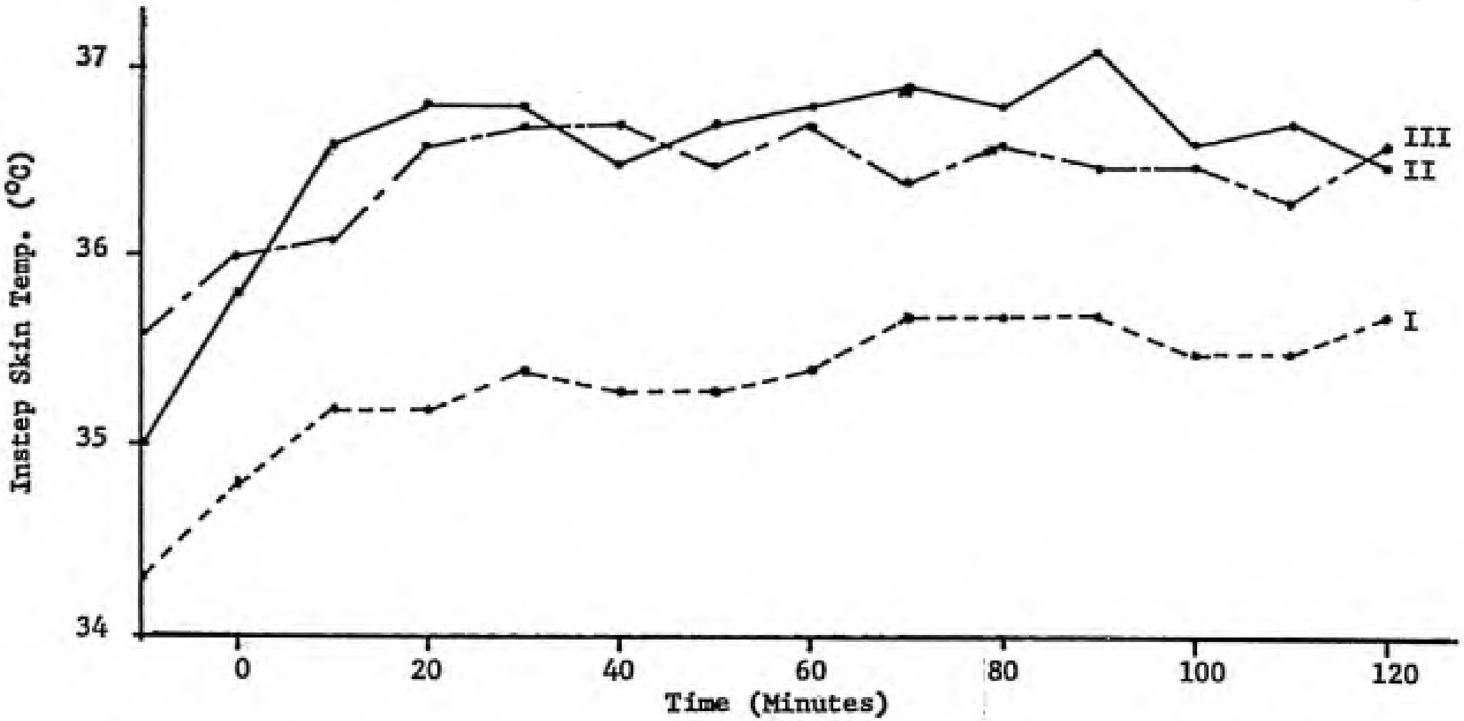

Figure 6. Mean temperatures of instep while test subjects were wearing the three clothing groups. Note at least 1.0°C rise in instep skin temperature while plastic boots (Groups I and II) were worn as compared to leather shoes alone (Group I).

Figure 5 indicates that mean body temperatures for all subjects wearing any one of the three clothing groups were within 0.3 degree C. The rise in body temperatures during the last 20 minutes while Clothing Group III was worn was seen in one subject only once and did not appear on replication. Since this result was included in the data, however, the elevated reading was plotted. If the doubtful rectal temperature were eliminated, the range of body temperatures would be within 0.2 degree C for all clothing tested. During the first hour mean body temperatures were lower when Clothing Group III was worn, compared to Group I or II. The body temperature findings were almost identical when Groups I and III were used.

Body Heat Storage

Table II shows that wearing coventional work clothing under test conditions caused a mean heat gain of 1.4 $Cal/m^2/hr$ in the test subjects. When the microwave suit was worn over conventional work clothing, heat storage reached a level of 4.3 $Cal/m^2/hr$. A value of 10.0 $Cal/m^2/hr$ was noted while the subjects wore Group III clothing. Although replicate values were not consistent for each individual who wore a particular clothing group, there was a definite trend indicating an increase in body heat stored as more garment layers were worn. An examination of the range of values observed with each clothing group indicated considerable overlapping (i.e., -5.5 to +4.9 for Group I, -6.5 to +14.1 for Group II, and -4.0 to +31.3 for Group III). The single 31.3 observation was high because of the use of the questionable rectal temperature measurement mentioned previously. If that value were discarded, the mean heat rise when the three uniforms combined (Group III) were worn would be 2.9 $Cal/m^2/hr$. Because of this overlapping of individual values, no definite conclusions can be made as to whether one group of clothing increases body heat more than another. Since the actual amount of heat stored per unit time was so low, even when the questionable high of 31.3 $Cal/m^2/hr$ was used, the thermal stress resembled the heat storage of a person casually walking at one mile per hour. Even this heat load would be easily dissipated by normal sweating.

Work levels imposed during this test are considered typical of those that a person wearing this suit would be expected to perform. Upon arrival at the microwave source, only minor repair, inspection or watch standing would ordinarily be performed while the unit is in operation. Therefore, the heaviest work would be reaching the site of the antenna.

Heart Rate and Respiration

Changes in heart rate during activity and quiescent periods are shown in Figure 7. During the initial activity period the rise and fall of the heart rate were almost identical for the three clothing groups. However, during the second activity period, at the end of the first hour, the decline in heart rate was different for each type of clothing. The oxygen debt, incurred with exercise, required a more extended repayment period when multiple layers of clothing were worn than it did when work

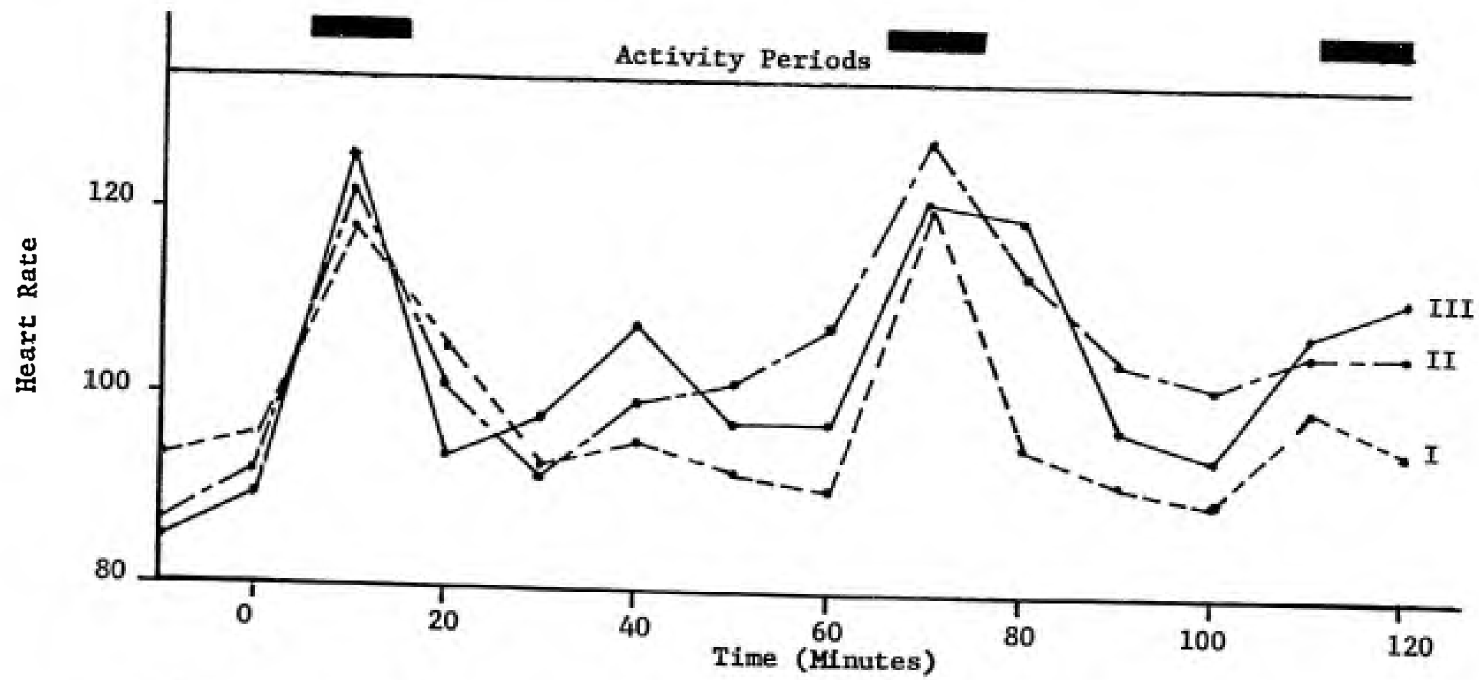

Figure 7. Mean heart rates of test subjects while wearing (a) conventional Navy work clothing (Group I), (b) microwave protective suit over this work clothing (Group II), and (c) overgarment over both the microwave suit and the work clothing (Group III).

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clothing alone was worn. This accounted for the elevated heart rate which occurred for several minutes beyond the termination of activity. It must be remembered that these test subjects were college students unacclimated to this temperature and accustomed to a partially sedentary way of life. The only intercollegiate sporting activity in which they participated was fencing. Because they were out of training prior to and during this test series, it is understandable that their heart rates would be elevated for a longer period of time than those found in well-acclimated, active individuals.

There was a trend toward a slight increase in heart rate as the test progressed (see Table II). This rise was well below the upper limit of 180 beats per minute for exercising subjects under thermal stress, as described by Newburgh (11). Even during activity periods, individual heart rates never rose above 156 beats/minute. Eichna and his associates (12) found that well-conditioned men were able to work with a rectal temperature of 39 degrees C (102 degrees F) and a heart rate of 150 beats/minute. The results obtained in this test series demonstrated that there is a wide margin of safety for both heart rate and rectal temperature no matter which of the clothing groups is worn. No gross changes were seen in any electrocardiograms taken during this test series.

The respiration rate showed no significant change with any clothing combination. It remained near 21 to 22 breaths per minute except during exercise periods when it climbed to 30 per minute.

Sweat Production

Table II indicates that, while wearing standard work clothing, test subjects lost an average of 313 grams of weight per hour in the form of sweat, insensible perspiration and respiratory carbon dioxide output over oxygen intake. This was slightly increased to 340 grams/hour when they wore the microwave suit on top of work clothing. When subjects wore the overgarment over other clothing systems, they lost an average total weight of 368 grams/hour. On an initial nude weight basis, this loss would result in an average total-body-weight deficit of 0.94 percent for Clothing Group I and of 1.10 percent when Clothing Group II was worn for the full two-hour test period. Even if it is assumed that the total weight loss was due only to loss of water, on the basis of the measured percentage of weight loss in these tests, a person could perform at the same level of activity for about six hours under these same conditions while wearing Clothing Group III over work clothing. This time period could be indefinitely extended if wearers were permitted fluid intake periodically. The six-hour time period is based on the fact that fairly uniform dehydration of test subjects would reach approximately 3 percent by that time. Weiner (13) reported that men will show some distress and irritability at this level. Adolph (14) reports that heat exhaustion symptoms will not usually occur until dehydration reaches 4.5 to 5.0 percent. On this basis, work activity could still continue for a while without additional water intake. The greater water loss causes a concentration of blood and decreased blood volume, thus adding a greater burden to the heart and increasing peripheral resistance in blood vessels. The resulting poor oxygen exchange with peripheral tissue would also cause fatigue and affect the sweating mechanism, thus leading to higher heat storage.

TABLE II. SUMMARY OF PHYSIOLOGICAL DATA

Physiological Parameter		Group I*	Group II**	Group III***
Body Temperature	Initial	37.1	36.6	37.0
(Degrees C)	Final	37.2	36.8	37.7
	Difference	0.1	0.2	0.7
Rectal Temperature	Initial	37.5	36.8	37.3
	Final	37.5	37.2	38.0
	Difference	0.0	0.4	0.7
Heat Storage ($Cal/m^2/hr$)		1.4	4.3	10.0
Respiration	Initial	21.0	21.0	21.0
(per minute)	Final	20.0	22.0	22.0
Heart Rate	Initial	94.0	87.0	86.0
	Final	96.0	106.0	112.0
Total Weight Loss (Kg/hr)		0.313	0.340	0.368
Weight Deficit (for two-hour test)		0.94%	1.02%	1.10%
Evaporative Weight Loss (Kg/hr)		0.263	0.236	0.255
Evaporative Ratio (Percent)		84.2	69.4	69.3

* Group I--Conventional work clothing.

** Group II--Group I plus microwave coverall, plastic boots and gloves, and construction helmet.

*** Group III--Group II plus overgarments.

On the basis of percentage of sweat actually evaporated there is no difference whether the microwave suit is worn with or without the overgarment (see Table II). Evaporative efficiency is lower with these garments (69.3 percent) than with work clothing alone (84.2 percent), because the whole body is enveloped in the open-weave silverized leno cloth while the hands and feet are covered additionally with impermeable vinyl gloves and boots. This open weave permits a large volume of evaporated sweat to pass through the material. It also allows a large volume of circulating dry air to get close to the body surface and absorb the moisture. Any sweat that condenses on the metallic cloth is probably re-evaporated because of the relatively uniform distribution of heat by the microwave suit.

Visual Acuity

The seven additional personnel were tested for visual acuity when wearing the microwave suit and, for control purposes, were retested without it. The standard Snellen Eye Charts and the armed forces Pseudo-Isochromatic Plates for Testing Color Perception were used. There was no noticeable decrement in color perception. Though the subjects could read to a control level of 20/20 or 20/15 on the Snellen Chart normally, when wearing the microwave suit, their vision was reduced to values above 20/30 without mistakes or 20/25 with a 50-percent error. This reduction occurred because the brim of the construction hat caused the microwave suit to surround the face in an almost vertical plane about 7.0 cm in front of the cornea. The approximately 0.8-mm spacings between the suit fibers at that distance would subtend an arc of 32 feet, much larger than the 5-foot arc sizing of the letters at 20 feet. It is believed that visual acuity is reduced about 9 percent because of decreased illumination to the eye. Studies described elsewhere in this report indicate that a large percentage of light striking the silverized microwave suit is reflected back or absorbed, thereby reducing the amount of light coming through the material to the eyes. This reflectivity may cause a slight distortion in the image pathway, resulting in the noticeable reduction in perception. Since the thin fibers are well within the near point of visual accommodation of adults, they offer little or no hindrance to vision.

Solar Radiation Characteristics of Clothing

The values of experimental clothing transmission, reflection and absorption of heat from the solar radiation source is shown in Table III. When the sensing instrument was exposed to the heat source at the same distance as the test subjects, a control reading of 1.8 gm-Cal was recorded. The amount of solar radiation received when the subjects stood away from the lamps amounted to 0.2 gm-Cal/cm^2/min. Consequently, as more layers of clothing are added, less heat is transmitted and more is absorbed by the material. The silverized surface of the microwave suit actually reflects very little heat. It primarily absorbs the radiation and equally distributes it over the suit's surface. Reflection of heat from the green overgarment (0.4 gm-Cal) is equivalent to reflection from the blue chambray shirt. Each garment has a different material and type of construction but both are exposed to the same conditions. Therefore, it would serve little purpose to change the color of the overgarment in the hope of reducing heat load.

TABLE III. SOLAR RADIATION CHARACTERISTICS OF TEST CLOTHING

Material	Transmission*	Reflection*	Absorption*
None (Sensor Control)	--	--	1.80
Chambray Shirt	0.60	0.40	0.80
Microwave Suit	0.50	0.20	1.10
Overgarment	0.20	0.40	1.20
All 3 combined	0.05	0.20	1.55
Goggles (Closed)	1.10	0.10	0.60

* All values in gram-Cal/cm^2/min.

Test Subjects' Comments

The chief criticisms of the microwave protective suit were: tight fit around the chin, restriction of head rotation when an enclosed helmet is worn, inconvenient location of the zipper in relation to the overgarment zipper, and decrease in visual acuity. Since both subjects showed abrasions on their chins caused by the rubbing of fabric seams against the skin, wearing the work helmet did not keep the silverized fabric from intermittently touching them. When the head was rotated to either side, the fit of the suit prevented the helmet from turning with the head. This can be corrected by the use of a chinstrap on the helmet. When earphones were used for communications, they had to be worn over both the helmet and the microwave suit. The decrease in visual acuity reported by the test subjects is covered more extensively in a previous section of this report. Both subjects reported feeling more comfortable wearing Clothing Group III than Group II; this was borne out in the test results. No essential difference in physiological comfort was noted between Clothing Groups II and III and conventional work clothing.

APPENDIX A

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13. ABSTRACT

A silverized nylon, open-weave microwave protective suit and cotton twill overgarment, to be worn over conventional Navy work clothing, was developed to protect personnel working in the high-density radio frequency fields of the larger and more powerful radar scanning systems anticipated aboard Naval vessels and at shore installations. Since total body heat absorption per unit time is a critical factor for the survival of personnel exposed to a microwave field, a physiological evaluation of the protective clothing system was performed to determine if the clothing itself was responsible for any additional thermal stress in a warm environment. For a series of two-hour periods, two male subjects wearing this clothing in a climatic chamber were exposed to a temperature of 85 degrees F, a relative humidity of 45 percent, a wind velocity of 11.5 mph and a solar radiation of 1.6 gm-Cal/m^2/min. The protective clothing system did not place any significant physiological heat stress on personnel in the warm environment as compared to the wearing of conventional Naval work clothing alone. Visual acuity was decreased slightly.

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