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TACTICAL IMPLICATIONS OF THE PHYSIOLOGICAL STRESS IMPOSED BY CHEMICAL PROTECTIVE CLOTHING SYSTEMS

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At the beginning of WW I, Fritz Haber (later famous for the "Haber Process"), a German chemist and subordinate of Prof. Nernst at the University of Berlin, initiated a program to utilize chemicals as anti-personnel weapons. Despite discouragement from the German General Staff, who considered the idea unworkable, by April of 1915 about 170 tons of Chlorine gas were emplaced in 5,700 cylinders along a 3½ mile front, opposite a junction where British lines joined those of French Algerian troops. Early on 22 April, Allied troops noted a green cloud being blown toward them. Within a few hours, this initial gas attack had killed 5,000 and gassed 15,000 Allied troops, while the Germans had captured 6,000 men and completely breached the Allied lines at this point. Fortunately for the Allies, the German army was completely unprepared for such an effect and could not exploit the breach. The Allies immediately appointed a French Army battalion surgeon, Andre Mayer, to organize defensive measures. His invention of the first military gas mask initiated the 55 years of collaboration on protective equipment between physiologists and chemical warfare experts which led to this report.

Although gas warfare was widely used by both sides in WW I, it caused less than 1.4% of the total fatalities and only about 5.7% of the casualties; however, while only about 4% of the U.K., French and German casualties were from chemical agents, this figure rose to almost 12% for Russian troops, who lacked protective equipment. Protection was primarily provided by respirators and normal clothing, although special decontamination troops were issued two layer cotton uniforms whose outer layer had been impregnated with 45% rosin in 55% rosin oil; worn with oiled, cotton gloves, this system provided about 40 minutes of chemical protection. The users of this early protective equipment had physiologic problems and in December 1918, the following guidance appeared in AEF #1433 "Defense Against Gas" over General Pershing's signature:

a) troops need "practice in wearing the respirator for longer periods"..."6-8 hours of weartime may be necessary."

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15

b) "thorough training and drill of troops in use of protective appliances to enable them to adjust them and to perform normal duty while wearing them" is required.

In 1922, the U.S. General Staff restricted the Chemical Warfare Service to improving defensive techniques and by 1924, research had developed an impregnite for clothing, "CC-2", a chloramide deposited in a chlorinated parrafin binder. A Herringbone Twill uniform, impregnated with CC-2 was accepted in 1928 and remained as the Standard Chemical Protective uniform until 1943, when, because of poor storage life, "CC-3" was produced. Gas mask technology had been preserved and advanced at Edgewood Arsenal, Md., although from 1927 through 1938 less than 20,000 masks per year were produced. A rubberized hood (M-5) was developed to be worn over the mask for protection against bacterial agents. A gas mask with the M-5 hood and with long cotton gloves, with impregnated ankle length underwear and sox worn under the impregnated chemical protective uniform, provided about 90% protection against bacterial agents. In the late 1930s, China had accused Japan of using chemical agents and, after reassuring Russia of Allied retaliation if the Germans initiated gas warfare, by the close of 1942 development of protective clothing was given a higher priority; the U.S. Army was to be provided with improved protective equipment, including CC-3 impregnated clothing, by June 1943. Despite this official assessment of the threat of chemical warfare, after two years of training during WW II, 30% of all U.S. units were judged deficient in defense against chemical warfare. Chemical protective clothing was worn by various units during training and by troops during the Normandy invasion. Some heat exhaustion probably occurred in troops wearing chemical protective clothing during WW II but there are few reports of it. In the summer of 1944, the Allies became alerted to the potential danger of low level aerial spray attacks and by 1945 were aware of the German development of nerve gases, but this threat ended with the war.

During the Berlin crisis of 1958, awareness of Russian capability reinitiated concern about U.S. chemical protective systems. As a result of reported difficulties incurred in training with protective clothing, field trials were scheduled at Camp Pickett, Virginia, to identify whether or not the reported problems were physiological and to compare the then Standard A, 2 layer impregnated chemical protective uniform with a new system in which a button in liner, impregnated with CC-3, was worn as part of a multiple layer system which provided wide range climatic and other protection by appropriate selection of layers. The Camp Pickett trial with troops wearing these systems began with a road march on a hot, humid morning in 1959. It ended 30 minutes later when, after the early collapse of three heat casualties, it became obvious the trials could not be completed and that there was a high risk of heat stroke, which carries a 50% fatality incidence. This paper details the subsequent laboratory studies, delineates the physiological problems, describes subsequent, successful field evaluations and suggests some of the tactical limitations imposed by wearing current chemical protective systems.

METHODS

A multidisciplinary approach has been evolved to assess the interactions between the environment, the uniform worn, the man and his military mission. Studies are conducted at five different levels of analysis; with each level providing information which can be related to the others, as follows: 1) the physical heat transfer characteristics of the uniform materials are measured using classical heated flat plate theory and also a unique "sweating" flat plate; 2) complete protective clothing ensembles, with and without such additional items as gas masks, hoods, gloves, helmets or packs, are evaluated on a "sweating" copper manikin for the heat transfer characteristics of the uniform system; the values obtained are used in biophysical calculations in a programmed computer model to predict the soldier's tolerance limits; 3) carefully controlled physiological trials are carried out in climatic chambers with military volunteer subjects dressed in these uniforms, to validate or refine the computer predicted tolerance limits; 4) controlled, small scale studies are conducted in the field; with military units wearing specified clothing systems and carrying specified loads under conditions of environment, terrain and march rate where physiological problems are anticipated based upon experience in climatic chamber trials; 5) studies with these clothing systems are carried out, collaboratively, during field maneuvers. scheduled by CDC or others. Specific details of the methodology for the laboratory studies (i.e. physical plate material studies, biophysical copper man evaluations and tolerance predictions and physiological chamber validation experiments) are presented below. The methods used in field studies are adapted for each problem, are therefore difficult to generalize and will be included in discussing the results.

The "clo" unit:

Some years ago physiologists working in the field of clothing and the associated heat transfer from a man, developed a technique to determine how much heat would pass through a garment by thermal radiation and convection from the skin (3). The difference between a man's skin temperature and the ambient temperature was taken as a gradient across which, to avoid a change in body temperature, he had to eliminate the difference between his metabolic heat production and the heat he could lose by evaporation of sweat from his skin or of water from his lungs. The non-evaporative component was assumed to go through the clothing by normal radiation and convection heat transfer. They then defined the insulation of a clothing system, plus the overlying still air layer, in terms of a "clo" unit and derived a system of units such that the dry heat transfer (i.e. convective plus radiant) per unit gradient from skin to ambient temperature (°C) would be 5½ kilocalories per meter square of surface per hour, per clo; that is:

$$H_{Dry} = \frac{5.55 \text{ kcal m}^2 \text{ hr}}{\text{clo}} \text{ per } {}^{o}C \qquad \text{EQUATION 1}$$

This physical equation states that heat flow equals the driving force, in this case a temperature gradient, divided by the resistance, expressed here in "clo". This basic approach for radiation-convection heat loss yields a quantitative assessment of how good a given uniform is for a resting man in cold weather since radiation and convection are major avenues of heat loss in the cold. However, for a working man in the cold, evaporation of sweat becomes an important avenue of heat loss. Furthermore, radiation and convection heat loss decrease with increasing ambient temperature while evaporative cooling rises. Thus, the "clo" value alone is insufficient in the heat.

The permeability index, "i_m":

A similar form of equation can be used to predict evaporative heat transfer:

$$H_{Evap.} = \frac{5.55\ S\ (p_s - p_a)}{clo} \qquad \text{EQUATION 2}$$

Eq.(2) is a form of the psychrometric (i.e. slung) wet bulb thermometer equation, where the "clo" value is the insulation of the air layer around the thermometer. The gradient for evaporative transfer is the difference between the vapor pressure at the surface (p_s) and the ambient vapor pressure (p_a) in millimeters of mercury (mm Hg). Using the slope (S) of the wet bulb lines on a psychrometric chart, which is about 2°C per mm Hg, a vapor pressure difference can be converted to an equivalent temperature gradient. One can then determine the evaporative heat loss from a square meter of surface with a given water vapor pressure; e.g. at 35°C (the skin temperature of a sweating man) there would be a vapor pressure of 42 mm Hg at the skin and the gradient will thus be 42 mm minus the ambient air vapor pressure. The late Dr. Alan Woodcock of this laboratory proposed that the evaporative heat transfer for a nude man, or for any clothing system, could be expressed as the ratio of the actual evaporative heat loss, as hindered by the clothing, to that of a wet bulb with equivalent "clo" insulation (15). He suggested expanding Eq. (2) to include this "permeability ratio index (i_m)" so that:

$$H_{Evap.} = \frac{5.55\ i_m\ S\ (p_s - p_a)}{clo} \qquad \text{EQUATION 3}$$

The index of evaporative loss (i_m) could range from 0, for a system with no evaporative transfer, to 1 for a system which had no more impedance to evaporative heat transfer than the usual wet bulb thermometer. The conventional wet bulb, of course, is a slung (i.e. rapidly moving) wet bulb where the still air barrier is greatly reduced. Since a soldier is surrounded by a relatively undisturbed air layer, "i_m" seldom approaches 1.0 for a man, but tends to be limited in still air to about 0.5.

Determination of "clo" and "i_m":

Figure 1A includes a diagram of the flat plate apparatus used in measurement of the "clo" insulation value. The apparatus consists of a test section (A), surrounded on all four sides by a guard section (B) with another guard section (C) beneath the entire upper plate (A+B). All three sections are instrumented with plate temperature sensors, heating elements and thermostats. The sample to be tested (D) is placed on the surface and the entire assembly is placed in a constant temperature cabinet. In operation, power to the guard sections is controlled so that their surface temperature is identical to that of the test section. Thus there is no gradient for heat loss from the bottom or edges of the test section (A). After equilibrium is established, the power required by the test section equals the heat lost through the insulation and can be expressed as kcal/m^2-hr per degree of gradient from plate surface to ambient air temperature. This can be converted to the corresponding "clo" insulating value for the sample plus the adhering air layer, using Eq.(1). If a thin cotton "skin" is placed on the plate surface and a water level is maintained at the surface of some small holes drilled in sections A and B, then the "skin" wicks out enough water to maintain a constant saturated surface pressure. A constant ambient vapor pressure is maintained in the measuring chamber and power requirements measured just as for the dry plate. The permeability index value (i_m) can be determined for a given sample plus its adhering air layer by means of Eq.3. Figure 1A also shows the "sweating" flat plate and its water supply in the constant temperature and humidity chamber with its control and recorder panel. The flat plate determinations of clo and i_m are primarily of use in selection of the fabrics to be used in a clothing system. The effects on heat transfers of different weaves, perforations, different finishes or treatments, the effects and best arrangement of multiple layers, etc. all can be established using the sweating flat plate (1). Heated, dry and "sweating" cylinders have been developed to mimic the cylindrical shape of the body. These are useful in studying wind penetration through clothing, and effects of spacer materials, but there are factors of drape, fit, and shape which are difficult to simulate even on a cylinder. Also, a complete uniform is made up of a number of different components, protecting various parts of the body, so that evaluation of a complete clothing system requires a more sophisticated model than a cylinder (2).

<u>The Copper Man:</u>

The solution has been the development of life sized, heated copper manikins. Figure 1A shows a manikin with his "sweating" cotton skin. The heat provided to the manikin to maintain a constant skin temperature can be measured and the ambient temperature and vapor pressure of the test chamber can be controlled; skin and air temperature and vapor pressure are measured. Thus the radiant-convective heat loss and the evaporative heat loss caused by a given gradient of temperature and vapor pressure can be calculated for any clothing system worn. This technique has been in use for the last five years. Using the insulation and evaporative transfer indices, "clo" and "i_m", with some physiological knowledge, tolerance times can be predicted, for a given task, for men in the chambers and in the field. One solves the equation that heat stored by the body must be the difference between the heat produced at work, and that lost by evaporation and by radiation and/or convection through the clothing system. Since the average soldier has 1.8 m^2 of surface area, by estimating his skin temperature (T_s), total non-evaporative heat transfer can be calculated for any given ambient dry bulb temperature (T_a in ^oC) as:

$$H_{Dry} = 10(T_s - T_a)/clo \quad \text{(kcal-man-hr)} \quad \text{EQUATION 4}$$

One can similarly calculate the maximum evaporative heat transfer through clothing for any given ambient vapor pressure (mm Hg) as:

$$H_{Evap} = 20\ (42 - P_a)\ i_m/clo \quad \text{(kcal-man-hr)} \quad \text{EQUATION 5}$$

where a 35°C skin temperature has been assumed for the sweating man. If heat production is known, after allowing for respiratory heat loss and any solar heat load gain, one can calculate whether the man can eliminate all the heat he is producing or whether some of it will be stored in his body. Indeed, using the specific heat of human tissue (0.83 kcal/kg-°C), it can be calculated that the body temperature of a 70 kg (154 lb) soldier will increase by 1°C (1.8°F) for each 58 kcal that must be stored (i.e. 0.83 x 70). This allows prediction of tolerance as the time to reach a given body temperature. A computer program has been devised which incorporates many of the significant physiological, physical and environmental factors involved in human heat transfer. If the appropriate values for clothing, environment and metabolic heat production are supplied, the model will predict the body temperature response of an individual under the chosen conditions. However, the predicted responses are frequently checked by actual environmental chamber exposures of men.

Physiological Chamber Trials:

Standard protocols have been developed for these trials; one requires 2 fifty-minute walks, separated by a ten-minute break, followed by a one-hour rest. Figure 1C shows subjects in an environmental chamber, during a rest period. The men are seated on benches placed on one of the large 4 man treadmills. Each subject is wearing a different garment since, as usual, a Latin square randomization of garment, day and subject was used. Each subject is wearing a rectal catheter, to measure deep body temperature, and a 3 point skin temperature harness. Two connecting cables from each man are led outside the chamber to the instrumentation shown in Fig. 1D. Each subject's rectal temperature is indicated continuously on one of the eight meters at the base of the master timer. Skin temperatures are recorded sequentially on the recorder, along with the rectal and chamber temperatures. Each point printed is simultaneously encoded and punched on the digital punch tape system shown at the right. This tape is used in computer data reduction and analysis and the agreement with predicted responses can be checked.

RESULTS AND DISCUSSION:

Values obtained for the fatigue and overgarment materials with the flat plate technique are present in Table I; it has so far been impossible to run the impregnated 2 layer system. The plate technique, which is a pure measure of fabric thermal properties (without flexibility or weight effects on drape)exhibits the greatest differences in thermal properties between materials. These large differences in material "clo" and "i_m" are considerably damped when comparing uniforms made from the materials, as seen in the copper manikin values also included in Table I. Thus, while flat plate values are useful in selection of materials for clothing development, it is difficult to predict uniform system characteristics solely on the basis of flat plate measurements.

TABLE I. Flat plate values of protective materials and the corresponding sweating copper manikin values for the Fatigue, the 2 layer CB (US2CB) and overgarment (USOG) systems.

Plate Materials Values:	U.S.Stnd Fatigues	US2CB	USOG
clo	0.66	--	1.19
i_m	0.66	--	0.48
i_m/clo	1.00	--	0.41

Manikin Values w/ and w/o mask, hood and gloves:	Fatigues		US2CB		USOG	
	w/o	w/	w/o	w/	w/o	w/
clo	1.33	1.48	1.50	1.87	1.60	1.90
i_m	0.50	0.38	0.40	0.38	0.42	0.36
i_m/clo	0.37	0.26	0.27	0.20	0.27	0.19
95°F 50% RH						
Loss *(kcal/hr)	150	108	112	86	111	80
Tol Time *(hrs)	1.3	.9	.9	.8	.9	.8

*prediction for worst possible case of still air, subject doing hard work (450 kcal/hr) and clothing not becoming wetted by sweat.

The copper manikin "clo" values reflect both material thickness and the trapped air insulation between the skin and clothing as a function of material stiffness, i.e. drape. Because the skin to air temperature gradient for non-evaporative heat loss is small in the heat, the important value is the i_m/clo; this indicates the obtainable fraction of the maximum sweat evaporative cooling possible in a given environment without wind, since these manikin values are still air determinations. Thus, a man wearing just the fatigue uniform can obtain about 37% of the maximum cooling possible (i_m/clo = 0.37), while with either of the two protective uniforms, only 27% is available.

Predicted heat loss (dry plus evaporative, Eq. 4 and 5) is included in Table I, with the estimated time to a 50% heat casualty level for troops doing hard work under conditions of 95°F, 50% relative humidity. These predictions are derived from chamber studies of the physiology of unclothed men, resting (10) or working (12) in the heat where body heat storage of about 80 kcal was enough to make a number of these volunteers stop; a heat storage of about 160 kcal resulted in heat exhaustion in 50% of those who continued while almost no one could tolerate 220 kcal. Hard work in a 95°F, 50% RH environment is so severe a combination that even wearing just the usual fatigue uniform, the predicted tolerance time is less than 1½ hours; in reality, the fatigue uniform would rapidly become sweat soaked and this, in combination with any natural ambient air motion, would result in a considerably longer tolerance time than this predicted value. The protective uniforms, however, can not readily wet out with sweat, and while the air permeability of the overgarment is high enough to allow additional cooling from any wind, the 2 layer uniform is relatively impermeable to wind.

Figure 2A presents the mean body heat storage (ΔS) for 7 volunteers walking at 3.5 mph in a 1965 study at 95°F, 50% RH (6). Five different uniform ensembles were worn as specified in the legend, which indicates the corresponding clo and i_m/clo values; subjects wore underwear, socks and combat boots, but not packs, gas masks etc. Heat storage is almost identical when wearing the fatigue or tropical combat uniform, both of which have a copper manikin i_m/clo value of 0.34. Heat storage when the men wore either of these uniforms under the overgarment (i_m/clo = 0.22 and 0.23) is also nearly identical, while when the overgarment is worn alone (i_m/clo =0.27), the mean heat storage clearly is greater than that in the 0.34 i_m/clo uniforms and less than that with the 0.22 i_m/clo systems. The circled numbers represent the subjects remaining, as individual volunteers stopped; the general reliability of 80 kcal of heat storage as a critical lower level for subjective tolerance is well supported. It is also obvious that the relative ranking of physiologic stress suggested from the simple physical measurements with the sweating copper manikin, is valid. Figure 2B presents results of the latest chamber evaluation in which the thermal effects of the gas mask, hood and gloves were studied. Three clothing ensembles were studied: the utility fatigue uniform, the latest protective overgarment (recommended for standardization in March 1970) and the now Standard B, 2 layer impregnated protective system. The copper manikin values included in the legend, suggest that there has been little real progress in developing clothing systems with respect to the heat problem. However, the mean physiologic responses (8 Ss) of skin temperature ($\overline{T}_s$) and rectal temperature (T_r) do show the significant advantage afforded by the air permeability available in the overgarment; the skin and rectal temperatures of subjects wearing the overgarment with mask, hood and gloves are identical to their responses in the 2 layer system without these items.

Any clothing item which blocks passage of liquid or vapor from the outside to the skin surface must also block evaporative cooling from the skin. However, the thermal effect of the mask, hood and gloves per se can be seen to be negligible in the fatigue uniform, with other areas of the body apparently compensating for the loss of evaporative cooling from the hands and head; there is a significant thermal effect when these items are worn with the overgarment and a still greater effect with the 2 layer system since, with these two uniforms, little or no additional cooling can be obtained from other body areas to compensate. When men wore the fatigue uniform, adding the mask, hood and gloves significantly increased sweat production, and the men were able to evaporate enough of the extra sweat so that total evaporative cooling was increased. When either of the protective ensembles was worn, the production of additional sweat upon addition of the mask, hood and gloves was limited, perhaps because of a depression of sweating produced by skin wetness, as well as because the sweat production rates without mask, hood and gloves were already nearly maximal. There was about a 7% drop in sweat evaporation when the mask, hood and gloves were added to the overgarment and a 20% drop when these items were worn with the 2 layer protective system. Thus, while the copper man based predictions are useful in ranking clothing systems, they obviously should be supplemented by physiological chamber trials to assess the effects of body motion, wind and the efficiency of sweating as shown above.

Men walking on treadmills under controlled conditions cannot indicate all the problems that will occur in troops attempting to perform their military missions in the field. While thermal effects resulting from the addition of packs, body armor, helmets, weapons etc. have been measured both on copper manikins and in physiologic chamber studies (5,9) the problems associated with military tasks other than marching, and with solar heat load, terrain and wind variation are impossible to reproduce indoors. Results of the initial chamber studies conducted after the aborted Camp Pickett field study, indicated that when wearing chemical protective uniforms, "soldiers should be heat-acclimatized and physically conditioned if they are to be required to do moderately heavy work for one hour" and that "to test the clothing out-of-doors where solar radiation must be considered, the temperature should be within a range from 70° to 90°F with humidity between 30 and 75%" (4). Accordingly, a controlled field trial of the 2 layer protective ensemble, an integrated (protective liner) ensemble and the (non-protective) utility fatigue uniform was conducted at Ft. Lee, Va. The results supported the chamber findings as to the advisability of heat acclimatizing individuals wearing protective clothing, and confirmed the finding that soldiers doing moderately heavy work in a fully encapsulated condition had a severe tolerance limitation at temperatures above approximately 75°F. The study concluded that "inability to dissipate the heat generated, limited tolerance time to about 30 minutes for hard work in the sun and this is the price that must be paid by the wearer for CBR protection as presently developed" (4).

When the CDC Experimentation Center (CDEC) at Fort Ord, Calif. was directed, in 1962, to investigate operational decrements that might occur with encapsulation, the USARIEM findings cited above were presented to indicate that a summer field study at Fort Ord would not involve long term exposure but could result in significant heat casualties during the first few hours. A continuing program was initiated by CDC to obtain physiologically significant meteorological measurements (especially the WBGT index calculated as 0.7 x naturally convected wet bulb temperature + 0.2 x black globe radiant temperature + 0.1 x shaded dry bulb temperature (13) and a carefully planned field research study was carried out by USARIEM, in collaboration with the CDEC, at Ft. Clayton, Panama in January 1963. The tactical exercises studied were chosen by the CDEC Infantry staff to represent the more vigorous tasks performed by combat arms elements and included: Rifle platoon in the Attack; 81 mm Mortar in the Attack; 4.2 inch Mortar in the Attack; Infantry squads in the Defense; 105 mm Howitzer in Fire Support; these exercises involved between 5 and 30 men and were replicated from 4 to 8 times each. Specialized tasks involving 2 to 4 men were also studied, including a Radar section, a Battalion Maintenance Section, a Rifle Company Headquarters, a Communications Section and an Engineer mine removal squad. Tactical scenarios, prepared by CDC experts in the appropriate combat arms, were adjusted, collaboratively with USARIEM experts, so that they would yield maximum information on physiological tolerance and yet retain as much tactical realism as possible. Figure 2C represents the results of one day of the Rifle Platoon in the Attack problem; the tactical play and WBGT conditions are given across the top of the graph of the mean rectal temperature of the men remaining at each period. Frank heat exhaustion casualties are indicated at the time each occurred, by open circles, while closed circles represent men removed from action at a rectal temperature of 103°F by medical monitors. This level has been established as one which would result in a significant incidence of heat exhaustion but minimal risk of fatality. The 50% unit survival time for an encapsulated rifle platoon was 90 ± 10 minutes in this typical infantry scenario. However, Figure 2C reveals little rise in rectal temperature during the first 50 minutes of light activity, but that it began to rise sharply from the beginning of the approach march. The 50% casualty level occurred after 30 to 40 minutes of moderately heavy work, with massive heat casualties being incurred during the actual assault.

The overall experience during these field maneuvers is summarized in Figure 2D, where the predicted time to 50% heat casualties is presented as a function of work rate, for men a) wearing the 2 layer protective uniform as open as possible, with only the gas mask ("open suit") or b) wearing mask, hood and gloves, with the uniform completely buttoned up ("closed suit") (13). During hard work at these WBGTs the additional cooling possible in the open suit condition has little effect; the internal heat generated by the men is too great for these minor differences. Moderate work poses little problem at WBGTs below about 75°F, while light activity can be performed readily at WBGTs below about 85°F. It appears that simply adding 10 degrees to the WBGT as an allowance for complete encapsulation, permits use of the usual WBGT guidelines that apply to troops training in regular uniforms; TB Med 175 sets 85°F WBGT as the initial danger level for unseasoned troops during training in conventional uniforms.

Men carrying heavier loads or covering more ground during an exercise were shown to have a greater risk of becoming heat casualties, as were men in poorer physical condition, particularly fatter individuals. Apart from the better overall physical condition of men who had been acclimatized by working in the heat, in field studies with protective clothing, heat acclimatization *per se* appeared to be of little benefit. A major benefit of heat acclimatization results from evaporation of the extra sweat produced by acclimatized men; extra sweat production appears to be of limited benefit with these protective systems, which limit sweat evaporation. Further, unlike chamber or controlled field trials where the work rate is established by the investigator, troops on maneuvers adjust their work to compensate for poor physical condition or lack of acclimatization.

These findings were detailed in military medical journals (13), are being incorporated in the appropriate field manual (FM 21-40) and are available as a USARIEM technical report (11). A recent U.S. Marine Corps assessment of the latest protective uniforms, worn during an amphibious assault in a tropical environment (in which USARIEM collaborated) is essentially in agreement with these earlier findings (16); so are U.K. and Canadian studies as well as reported Russian work (14). Guidance from USARIEM and adherence to the guidelines (11) derived from these studies on heat effects (4,5,13,16), has provided safety for engineering and service tests of these items by USATECOM at Ft Lee and Ft Benning, and has contributed to the successful completion of a number of classified studies on non-thermal problems experienced by troops wearing protective clothing during military operations. The conclusions of these studies on the physiological problems of soldiers attempting to conduct their military operations in a toxic environment, where protective encapsulation must be worn are presented below. However, it should be noted that the systematic method outlined for analyzing the interaction between a man, his environment, his work and his clothing was not developed solely to study chemical protective systems, but has had more general objectives and applications. It has been used to assess a wide variety of military problems involving clothing such as air crew uniforms (6), naval wet and dry diving suits (8), body armor (9) and thermal flash protective ensembles (5), as well as such civilian items as football uniforms (7), raincoats (6) and conventional clothing (8); it is currently being applied in studies on improving the human environment by heating and/or air conditioning.

CONCLUSIONS:

The tactical implications of wearing current standard chemical protective ensembles are clear. They apply as well to all foreseeable protective uniforms except those incorporating forced ventilation with filtered ambient or conditioned air. Even at low temperatures, there are obviously performance decrements for tasks requiring delicate work as a result of the loss of manual dexterity and tactile sensation wearing gloves. Vision in the mask, particularly downward vision, is limited producing problems when moving in jungles or through marked areas and in identification, while some optical sighting devices will require redesign to be used at all. Auditory as well as oral communication is also impeded by gas mask wear. These problems can be only partially overcome by training or redesign. A more serious non-thermal problem is the respiratory impedance of the gas mask; in each study, some of the troops report difficulty in breathing during hard work. This reoccurred in the latest field study, in addition to a new problem, seasickness primarily in those individuals wearing the gas mask during the amphibious landing. While the limited field data obtained (16), suggested that these problems may be both psychological and physiological, they can be reinvestigated in the laboratory.

Tolerance time for troops fighting in protective clothing even in temperate climates will be severely limited by heat stress at WBGT conditions above 75°F. The heat problems that will occur at WBGT above 75°F will have greatest impact on troops doing hard work. Infantry on an approach march or in an assault will have about 30 minutes of tolerance before a long rest break in the shade is necessary. Soldiers with unusually heavy loads, e.g. mortar men, radio telephone operators, recoiless riflemen or any individual carrying a load of more than 40% of his body weight, will seldom complete an approach march of 2 miles or more and will straggle far to the rear.

Such individuals, as well as those men in less fit physical condition (particularly if overweight or with a hangover) will have the greatest difficulty completing their mission and are more apt to be heat casualties. Unit leaders, who cover more ground in checking on the progress of their men, are also at greater risk unless transport is provided.

Conserving the soldier by transporting him, or at least as much of his load as possible, until he must go into action is far more important when protective clothing is worn than usual. Mechanized infantry will be far more effective than regular infantry. Mechanized armor and artillery crewmen may have some heat problems during sustained missions, e.g. when manhandling heavy ammunition at high rates of fire, but even then rotating the heavier jobs between crew members can help solve the problem. Engineer companies can also usually rotate personnel between the heavier tasks. The troops will suffer the most severe degredation of their tactical performance when fully encapsulated. For such units, the rest time required for recovery after work rapidly becomes longer than the time available for their military mission, as ambient temperature rises above 75°F WBGT (11); indeed fully encapsulated troops in full sunlight or in a desert environment will have heat problems even at rest.

The addition of a drinking device to the M17A1 mask can alleviate the problems of dehydration if drinking is vigorously encouraged by commanders during any prolonged encapsulation, so these problems have not been discussed. The risk of chemical attacks and of not having protection already in place before the onset of such an attack, has also been ignored in this presentation. It seems reasonable to conclude that in the heat, although the threat of chemical attack may force a unit leader to have his troops wear protective uniforms, donning mask, hood and gloves should be delayed until a chemical attack is imminent.

RECOMMENDATIONS:

Short of developing and standardizing ventilated chemical protective clothing, the only solutions in a hot climate are tactical. When possible:

a) avoid operations during daytime heat
b) maintain a high level of physical condition and eliminate the unfit troops from action
c) transport the soldier and his load by vehicle
d) rotate the heaviest tasks
e) avoid masking until the threat is imminent
f) assure adequate water intake by command control
g) allow 30 minute or longer rest periods, in the shade whenever possible

Above all, be aware that men wearing chemical protective clothing will have a significant performance decrement in the heat.

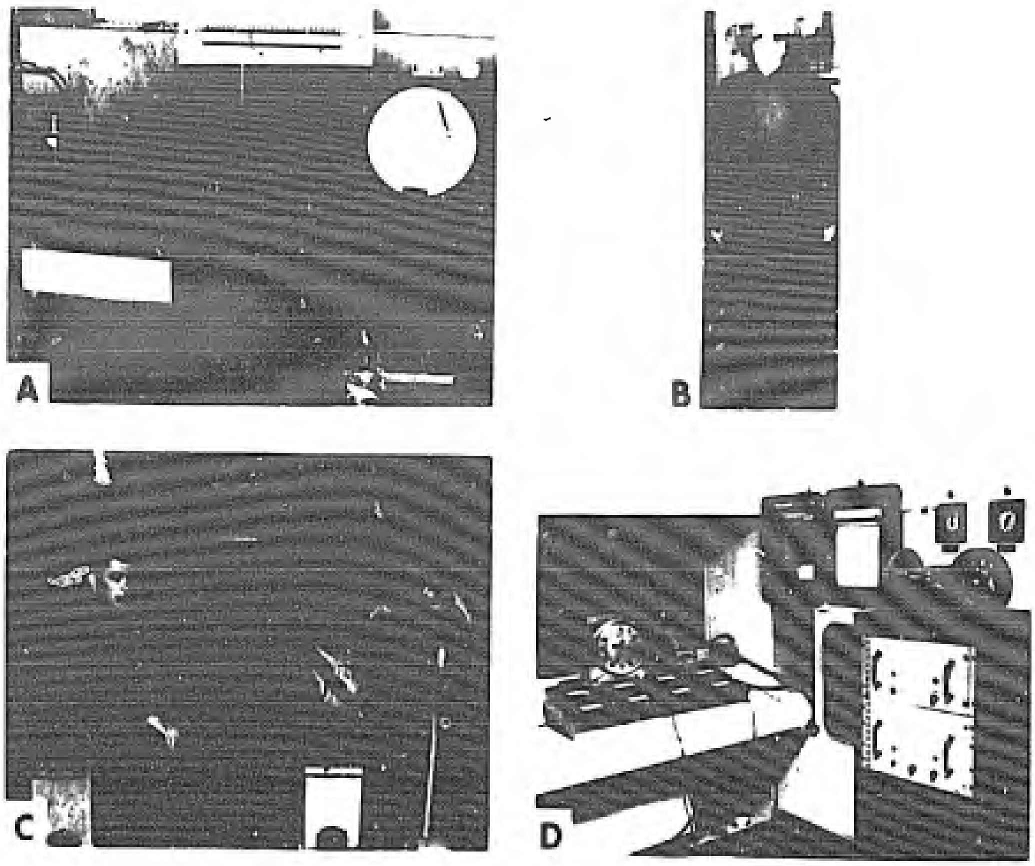

FIGURE 1. Laboratory Test Methodology

A. The "sweating" flat plate apparatus for assessing materials characteristics; the insert in the upper center, diagrams the test section (a), upper (b) and lower (c) guard sections and the position of the material (d) to be evaluated.

B. The sweating copper manikin used to assess non-evaporative ("clo") and evaporative ("i_m") heat transfer characteristics of a complete uniform ensemble.

C. Volunteer subjects, each with a different clothing ensemble, seated in the climatic chambers on benches placed on the 4-man treadmills during a rest break. The cables leading overhead from each subject carry rectal and skin temperature information.

D. The physiologic data collection instrumentation just outside the test chamber includes the individual meters for continuous safety monitoring of rectal temperature (just below the timer), a multipoint recording system for skin, rectal and environmental temperatures and a paper tape punch system to convert the data to a form for subsequent computer reduction and analysis.

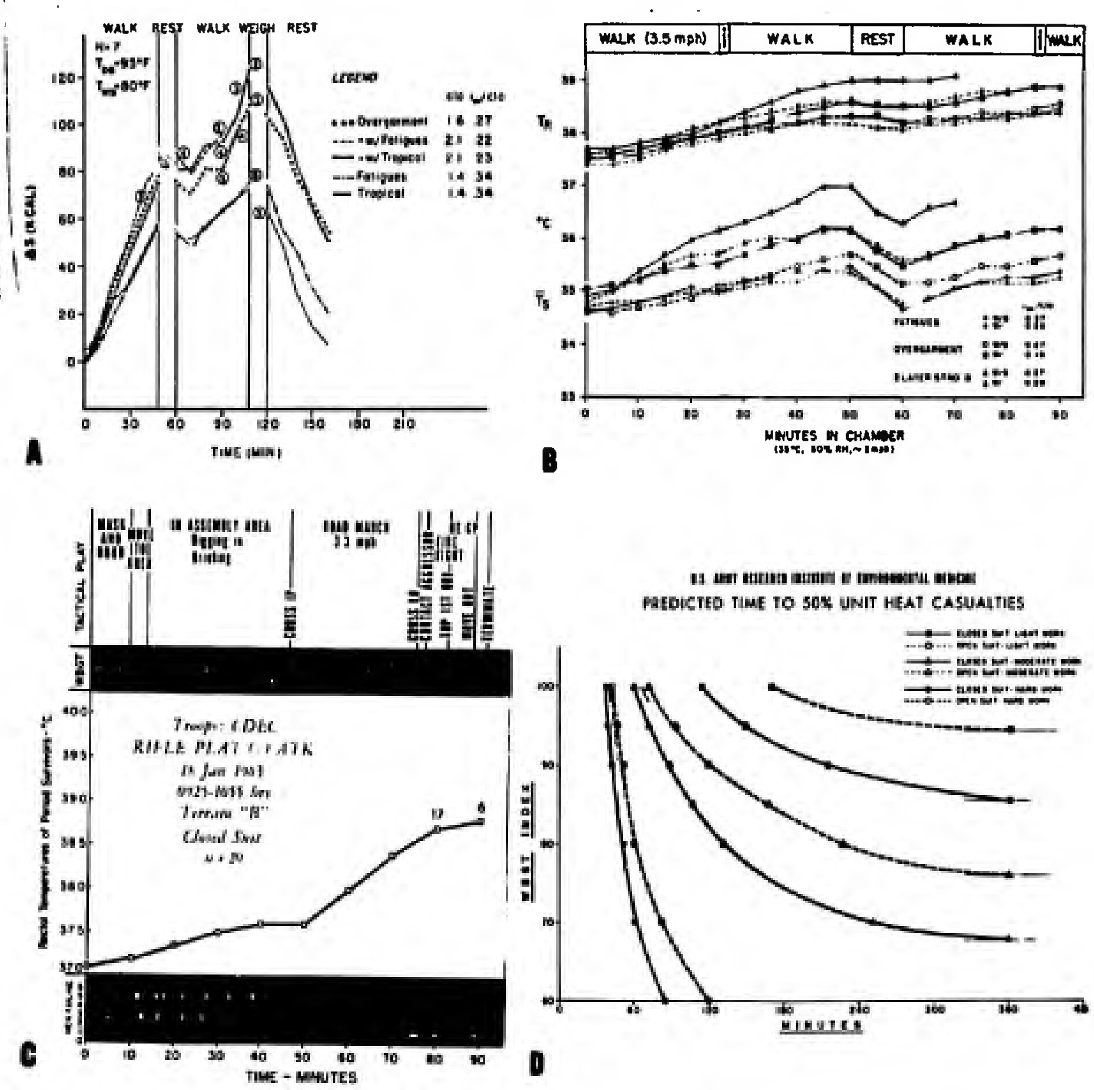

FIGURE 2. Typical physiological responses of men wearing protective clothing and predicted time limits for military operations.

A. Body heat storage of men in a chamber study. Copper manikin clo and i_m/clo values are given for each ensemble. Circled numbers represent men remaining at each point.

B. Mean rectal (T_r) and skin (T_s) temperatures of 8 subjects at 95^oF, 50% RH wearing Fatigues or the chemical protective 2 layer or overgarment system, with or without mask, hood and gloves.

C. Mean T_r of soldiers during field maneuvers. Tactical play is detailed across the top, above the WBGT environmental conditions. Heat casualties (•) or men removed for unsafe T_r levels (o) are also shown.

D. Predicted tolerance for men at 3 levels of work, wearing protective clothing systems "OPEN" with just the gas mask, or "CLOSED", tightly buttoned up, with mask, hood and gloves.

REFERENCES

1. Fonseca, G.F. Moisture transfer through perforated impermeable foam insulations. Textile Res. J. 37: 1072-1076, 1967.
2. Fonseca, G.F. and J.R. Breckenridge. Wind penetration through fabric systems. Textile Res. J. 35: 95-103, 1965.
3. Gagge, A.P., A.C. Burton and H.C. Bazett. A practical system of units for the description of heat exchange of man with his environment. Science 94: 428-430, 1941.
4. Goldman, R.F. Tolerance time for work in the heat when wearing CBR protective clothing. Mil. Med. 128: 776-786, 1963.
5. Goldman, R.F. Physiological effects of wearing a rubberized net overgarment in the heat. Text. Res. J. 33: 764-766, 1963.
6. Goldman, R.F. Systematic Evaluation of Thermal Aspects of Air Crew Protective Systems. In: Proc. of the 24th annual meeting Aerospace Research & Development (AGARD) Brussels, Oct. 1967.
7. Goldman, R.F. The effects of football equipment on heat transfer. In: Physiological Aspects of Sports and Physical Fitness (ed. B. Balke). Amer. Coll. of Sports Medicine, 1968.
8. Goldman, R.F. Design and use of clothing. In: Proc. NATO Advanced Study Institute on Human Factors, Palermo, Oct. 1969.
9. Goldman, R.F. Physiological costs of body armor. Mil. Med. 134: 204-209, 1969.
10. Goldman, R.F., E. Green and P.F. Iampietro. Tolerance of hot wet environments by resting men. J. Appl. Physiol. 20: 271-277,1965.
11. Goldman, R.F. and R.J.T. Joy. Prevention of heat casualties in men wearing chemical-biological protective clothing. Tech. Rpt. U.S. Army Res. Inst.of Environmental Med.,Natick, July 1967.
12. Iampietro, P.F. and R.F. Goldman. Tolerance of men working in hot, humid environments. J. Appl. Physiol. 20: 73-76, 1965.
13. Joy, R.J.T. and R.F. Goldman. A method of relating physiology and military performance. Mil. Med. 33: 458-470, 1968.
14. Manets, F.I., P.F. Sevostyanov, A.F. Dudnikov and A.A.Kondrashov. Defense against weapons of mass destruction. Moscow, 1967.
15. Woodcock, A.H. Moisture transfer in textile system. Textile Res. J. 32: 628-723, 1962.
16. Yarger, W.E., P.L. Schwartz and R.F. Goldman. An assessment of CBR protective uniforms during an amphibious assault in a tropical environment. U.S. Navy Medical Field Research Lab. Rpt. XIX No. 17, Camp LeJeune, No. Carol. Nov. 1969.

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