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CURRENT APPROACHES TO RESOLVING THE PHYSIOLOGICAL HEAT STRESS PROBLEMS IMPOSED BY CHEMICAL PROTECTIVE CLOTHING SYSTEMS (U)

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INTRODUCTION:

There is a long history of Army research addressing the question of the limitations of men wearing chemical protective clothing in the heat. The results, beginning with a study carried out by the Harvard Fatigue Lab at Camp Sibert, AL in the early 1940's (1), have been extremely consistent in indicating that men encapsulated in chemical protective clothing cannot work for extended periods in the heat.

The relationship between ambient temperature and tolerance time for totally impermeable systems for men at moderate work levels can be clearly delineated. Safe work times, wearing a completely impermeable garment with all apertures closed (gas mask, hood and gloves worn), range downward from 8 hours at an ambient temperature of 30°F, as shown in Table I, (2-7).

Table I. Safe "Closed" Suit Times for Moderate Work (250 kcal/hr); data from ref (2-7) as presented by Custance (8)

Environmental Temperature (°F.)	Wearing Time (Closed Down)
30° or less	8 hours
30° - 50°	5 "
50° - 60°	3 "
60° - 70°	2 "
70° - 80°	90 mins.
80° - 85°	60 "
85° - 90°	30 "
90° or more	15 "

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Less impermeable clothing, particularly when worn with open apertures (i.e., without gloves, hood or mask) give somewhat longer unit tolerance times, as a function of work rate, as shown in Fig. 1 (9).

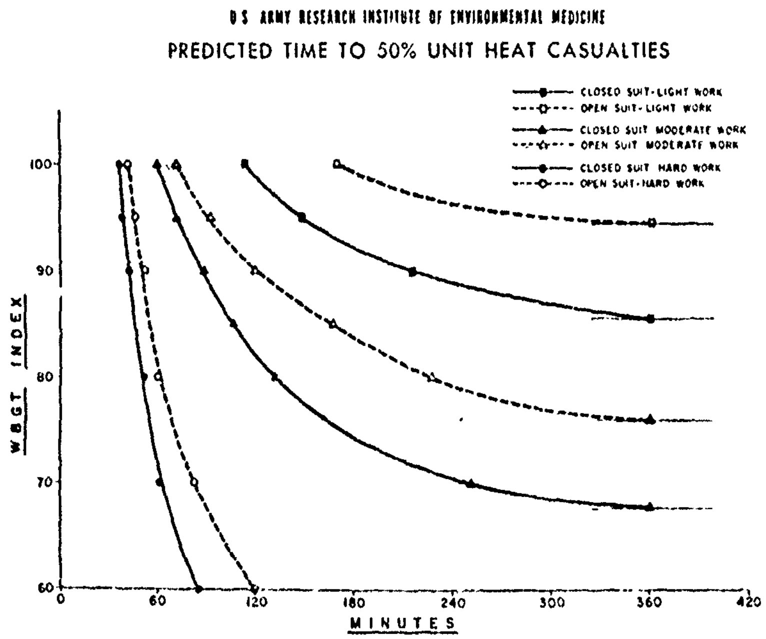

Fig. 1 Prediction graph for 50 per cent unit survival time for CB protective uniforms with reduced water vapor permeability. "Light work" is 200 kcal/hr., and "hard work" is 300 kcal/hr.

There are only 4 possible solutions to the problem; the first 3 involve modifications of the impermeable nature of the clothing, or adjustments in its ability to eliminate heat, while the fourth involves complete redesign of tactical operations to permit adequate recovery time between short work periods. Methods for accomplishing the latter were detailed in a presentation at the 1970 West Point Army Science Conference (10, 11). Possible modifications of chemical protective clothing include the use of more permeable garments incorporating a charcoal layer for adsorption of agent, after wicking it across as much clothing surface as possible to minimize the dose presented at a given spot on the surface of the garment. This approach, as incorporated in the current US Army Standard A Chemical Protective Suit has been evaluated extensively (12).

A second approach is to provide ventilating filtered air within a totally impermeable clothing system, as currently done in the new Engineer Ordnance Demolition (EOD) Suit (13, 14). The final clothing approach is to use a wettable cover over a totally impermeable garment. This approach was originally used in the Toxicological Agent Protective (TAP) Uniform in the 1950's and 60's, and is currently the approach used in the Israeli Defense Forces.

The extension of tolerance time allowed by the first approach, i.e., the current US Standard A charcoal-in-foam protective overgarments, can be assessed by comparing the 50% tolerance values for moderate work presented in Fig. 1, with the values presented for the totally impermeable system in Table I, which also represent moderate work levels. With the second approach, viz, the air ventilating EOD garment, tolerance is essentially unlimited as a function of ambient temperature, per se, but becomes simply a function of the ambient humidity and the extent to which the body can produce sweat. In essence, the soldier wearing such a garment is no worse off than he would be working in the ambient environment in conventional clothing and, in most cases, is substantially better off because of the great amount of air ventilation afforded over the body and the associated increase in the man's ability to evaporate sweat.

The third approach, use of a wettable cover over an impermeable garment, is less well defined with regard to its range of applicability. The remainder of this brief presentation will be concerned with clarifying the range of environmental conditions, and other factors under which such an approach can significantly reduce heat stress.

The amount of body cooling which can be derived from a wetted cover depends on the rate of water evaporation and its effectiveness in removing heat at skin level. Approximately 0.6 kcal of heat is absorbed in evaporating one gram of water, but part of this heat of vaporization is supplied by the air in contact with the cover, thus reducing the amount extracted from the body. Rate of evaporation from the cover depends on air movement and the difference between the vapor pressures at the cover surface and the environment. The most rapid evaporation takes place with high air movement and low humidity. Little evaporation will occur under calm conditions with humidity near 100%, especially if air temperature is above 90°F(31°C). However, studies at our Institute using an electrically-heated manikin show that, in only a slightly less severe environment (30°F, 90% relative humidity and normal room air movement) up to 100 grams of water per hour can be evaporated from a cover worn over a moderately heavy impermeable garment. At 80°F, 25% humidity this figure increases to almost 400 grams per hour, representing an evaporative heat removal of 230 kcal/hr.

The effectiveness of this surface evaporative cooling in extracting heat from the man (i.e., from the skin rather than from the air) is a function of air movement and the insulation value, or thickness, of the protective ensemble. Efficiency for a typical single-layer garment plus cover ranges from 30 to 40% in calm air, to about 15% for winds above 10 mph. For any given air temperature and humidity, maximal body cooling will be obtained at some intermediate wind speed, where the rate of evaporation from the cover is high enough to compensate for the loss in cooling efficiency caused by the air motion.

Based on this analysis and copper manikin results, plus experience in the field with a wettable cover ensemble, it appears that important reductions in heat stress on the totally encapsulated soldier may be realized using this approach. In a typical tropical environment increased heat dissipation of 70-100 kcal/hr, or up to 25% of an active soldier's average heat production, may be expected. The benefit would be much higher in a desert environment with its low humidity. In most cases, the added heat removal here would be sufficient to compensate for solar heat load on the man, in addition to removing some of his metabolic heat. However, the problem of availability of water for wetting the cover, may act as a deterrent for successful application of this approach. Under typical field conditions with moderate humidities (50%) and air movement, upwards of 1 liter per hour will be evaporated if the ensemble surface is completely wet. This figure could easily double in a desert environment. It is apparent that the logistics associated with supply of enough water to maintain cover wetness over an extended period would be quite formidable for even a moderate size combat force.

SUMMARY:

Possible improvements over totally impermeable chemical protective clothing for use in toxic environments have been characterized along three approaches: partially permeable garments impregnated with detoxifying or adsorbing substances; impermeable systems supplied with filtered ambient air ventilation; impermeable systems with wettable covers. Although the latter approach has much to recommend it, logistics of required water is a distinct problem. The only other alternatives, short of air conditioned clothing ensembles, is by intelligent, informed command control of work-rest ratios, or actual replacement of units as they approach tolerance limits, during operations in environments above 75°F WBGT.

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