

# **THERMAL MANIKIN EVALUATION OF A CHEMICAL PROTECTIVE ENCLOSURE FOR BATTLEFIELD-INJURED SOLDIERS.**

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## **INTRODUCTION**

Modern combat operations in a chemically contaminated environment were first experienced during World War I. Among all combatants on the European Western Front alone from 1915-1918, chemical weapons such as phosgene, chlorine, and mustard gases accounted for approximately 1.3 million casualties and 91,000 deaths (1). During the more recent Iran-Iraq conflict from 1980-1988, Iraq employed the limited use of several types of chemical warfare agents on both civilian and military targets (2). To protect injured soldiers on a contaminated battlefield, the U.S. Army has been utilizing a Chemical Protective Patient Wrap (CPPW) since 1986. Several biophysical and physiological evaluations were conducted to assess the added thermal burden imposed when fully encapsulated in the CPPW in various environmental conditions. Cadarette, et al (3) found that military test volunteers could not complete a 2 hr encapsulation in two prototype CPPW at 49°C/17% RH. In that test, the two CPPW designs afforded adequate human O<sub>2</sub> and CO<sub>2</sub> exchange, but resulted in gradually elevated core temperatures. In a later study, Stephenson, et al (4) found that volunteers could tolerate a full 6 hr encapsulation at 24°C/20% RH in a new prototype CPPW that used protective textiles with lower air permeability values. This current study used a thermal manikin and a predictive model to investigate the biophysical properties and predicted tolerance times of a simulated patient to encapsulation in a hot, dry environment on three CPPW.

## **METHODS**

A sweating, thermal manikin (TM) was used to quantify the thermal insulation (clo) and moisture permeability index ( $i_m$ ) of the current-issue and two prototype CPPW which incorporated new protective materials and active ventilation capabilities (Figure 1). The current-issue CPPW has an impermeable bottom material with a laminated, permeable top material. The two prototypes have a similar construction but with newer laminated and non-laminated top materials. Prototypes were tested with and without a battery powered fan that provided positive-pressure, filtered, ambient air to the interior of the CPPW. TM testing was done in accordance with applicable ASTM standards with additional testing at two higher wind speeds to provide necessary model input. TM results were used to derive the evaporative cooling potential ( $i_m/clo$ ) of the CPPW and predict a safe tolerance time (min) using a mathematical model (5). Among other physiological responses, the model predicts core temperature over time as a function of metabolic heat production, anthropometry, environmental conditions, and the resistive characteristics of the protective material layers surrounding the individual. Tolerance time was

based on a body core temperature ( $T_c$ ) limit of  $38.5^\circ\text{C}$ , representing the point where approximately 25% heat casualties can occur (6). Tolerance times were predicted for the current and two prototype CPPW with ventilation on and off when occupied by a patient in midday sun and complete shade at  $48.9^\circ\text{C}$  and 20% RH.

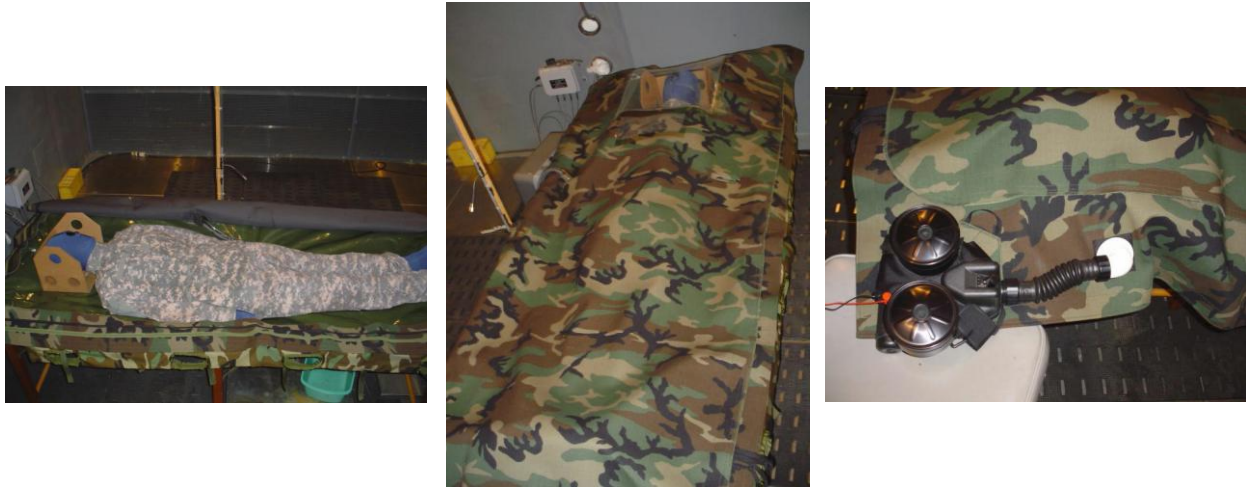


Figure 1. Photographs showing the thermal manikin (left), the CPPW ventilation system (right), and the fully-closed CPPW (center).

## RESULTS

Figure 2 shows that both prototypes had a 5% lower average thermal resistance (clo) value than the current CPPW when tested with a non-operational ventilating fan at  $0.5\text{ m}\cdot\text{s}^{-1}$  wind speed. This difference increased to an average of 9% when the fan was operating. These differences were similar when measured at the two higher wind speeds of 1.4, and  $2.4\text{ m}\cdot\text{s}^{-1}$ .

Figure 3 shows that the current-issue CPPW and both prototypes, when not actively ventilated (i.e., fan “off”) did not differ greatly in  $i_m/\text{clo}$  (range=0.095 to 0.120) when tested at three wind speeds. However, when the two prototypes were tested with an operational ventilating fan under the same conditions,  $i_m/\text{clo}$  was increased by an average of 24%.

Table 1 summarizes predicted tolerance times based on the  $T_c$  limit of  $38.5^\circ\text{C}$  of the three CPPW in mid-day sun and shaded desert conditions. When placed in mid-day sun, neither of the prototype CPPW provided any tolerance time advantage over the current-issue CPPW with the  $T_c$  limit reached on average at 66 min. Simply placing the CPPW in full shade increased the tolerance time across all test configurations to an average of 173 min. Finally, when placing either prototype CPPW in a shaded desert environment of  $48.9^\circ\text{C}$  and 20% RH, active ventilation increased tolerance times a further 23%, to an average of 222 min compared to the current-issue CPPW.

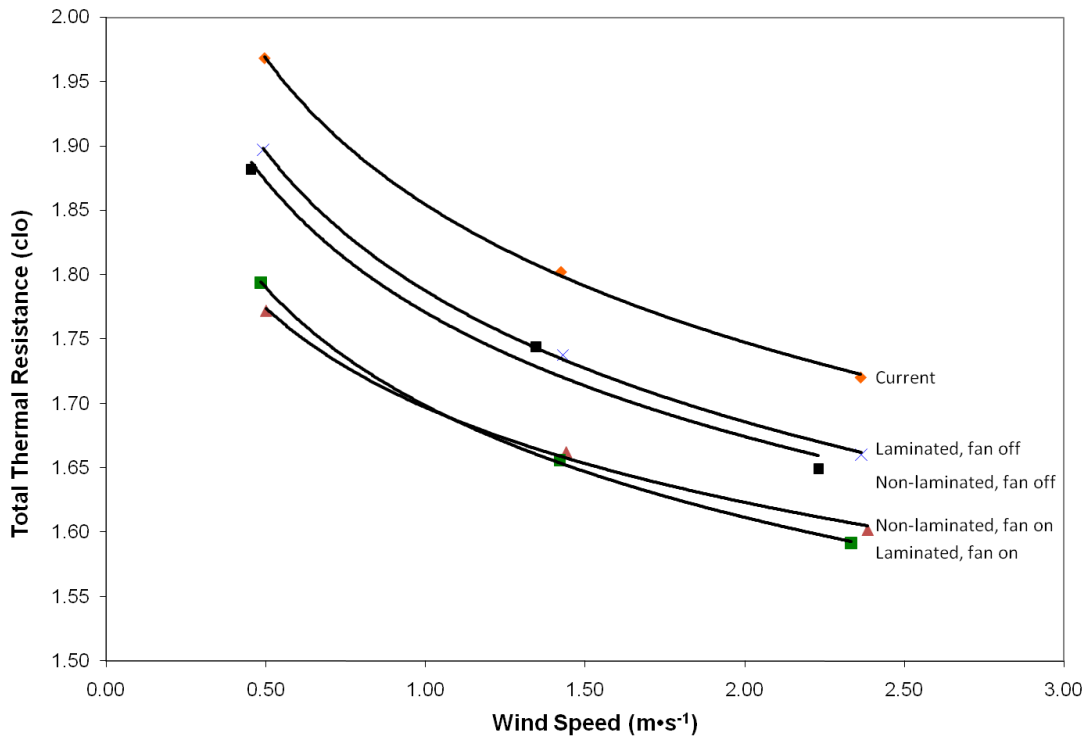


Figure 2. Total thermal resistance (clo) of the current, laminated and non-laminated (fan “off” and “on”) prototype CPPW at different wind speeds using a supine thermal manikin.

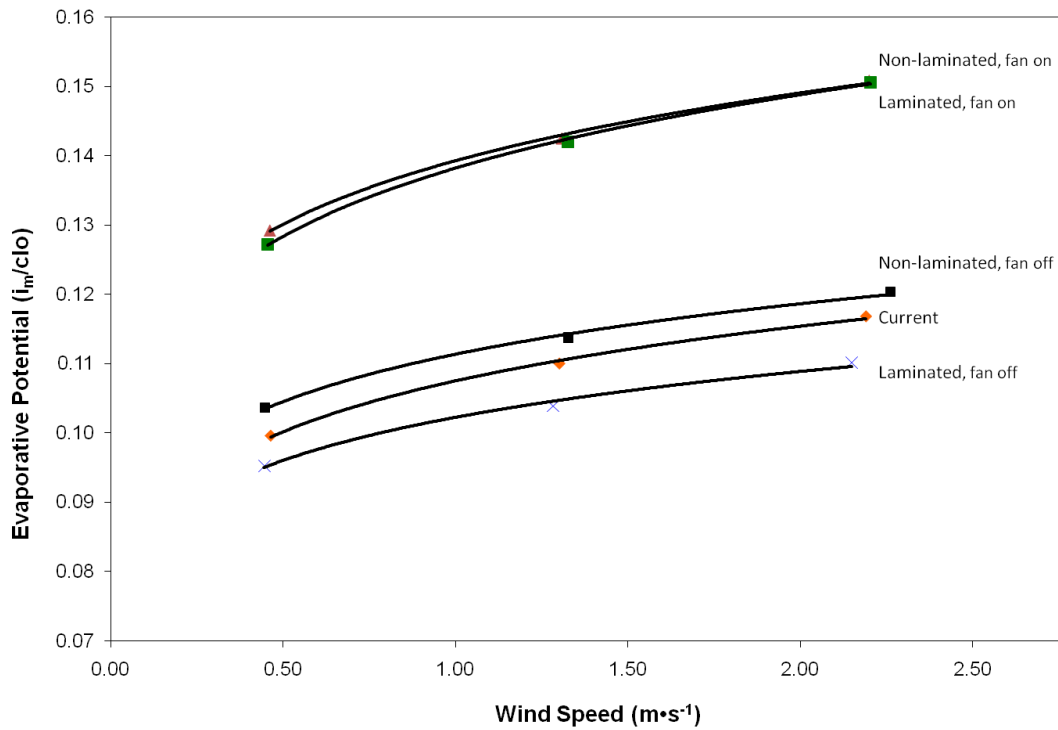


Figure 3. Evaporative cooling potential ( $i_m/clo$ ) of the current, laminated and non-laminated (fan “off” and “on”) prototype CPPW at different wind speeds using a supine thermal manikin.

Table 1. Predicted tolerance time (min) during patient occupation of all CPPW test configurations in sun and shade conditions at 48.9°C and 20% RH.

CPPW	Mid-day sun	Complete shade
Current-Issue No Ventilation Capability	66	178
Prototype, Non-Laminated, Fan Off	64	177
Prototype, Non-Laminated, Fan On	68	223
Prototype, Laminated, Fan Off	62	164
Prototype, Laminated, Fan On	68	220

## CONCLUSIONS

The results from this study show that any of these CPPW, utilizing low-permeability materials intended to block chemical agent ingress, would impose a high restriction on evaporative cooling of an encapsulated patient. The  $i_{m}/c_{lo}$  values are comparatively low and suggest that minimal evaporative exchange with the environment would occur. The use of a positive-pressure ventilating fan reduced thermal resistance around the TM, while increasing the sweat evaporation potential as well as the predicted tolerance time of a simulated battlefield patient in a shaded desert environment. Combat medical personnel should be trained to place an occupied CPPW in complete shade whenever possible. Individual CPPW should also be clearly marked with this instruction as well as a warning of the potential for heat injury if patients are encapsulated for an extended period of time.

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## REFERENCES

1. Hersh, S.M. 1968. Chemical and Biological Warfare: America's Hidden Arsenal. The Bobbs-Merrill Company, Inc., Indianapolis, IN
2. [http://encyclopedia.fablis.com/index.php/Iran-Iraq\\_War](http://encyclopedia.fablis.com/index.php/Iran-Iraq_War)
3. Cadarette, B.S., Speckman, K.L., and Stephenson, L.A.. Physiological assessments of chemical threat protective patient wraps in three environments. Mil Med, 153, 4:166-170, 1988.

4. Stephenson, L.A., Cadarette, B.S., Endrusick, T.L., Quigley, M.D., and Rock, P.B. Biophysical and Physiological evaluation of the individual chemical threat agent protective patient wrap. USARIEM Technical Report T6-91, March 1991, Natick, MA: U.S. Army Research Institute of Environmental Medicine.
5. Kraning, K., and Gonzalez, R. A mechanistic computer simulation of human work in heat that accounts for physical and physiological effects of clothing, aerobic fitness, and progressive dehydration. *J of Therm Bio*, 22:331-342, 1997.
6. Sawka, M., Latzka, W., Montain, S., et al. Physiological tolerance to uncompensable heat: intermittent exercise, field vs. laboratory. *Med Sci Sports Exerc* 33:422-430, 2000.