AD-A110 875 ARMY RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA F/G 6/19
THERMAL STRESS INSIDE THE XM-1 TANK DDRING OPERATIONS IN AN NBC--ETC(U)
MAY 81 M M TONER, R E WHITE, R F GOLDMAN
UNCLASSIFIED USARIEM-T-4/81 NL

1 of 1
AD
A110875

END
DATE
FILMED
3 82
DTIC

LEVEL II

AD________________

12

REPORT NO T 4/81

THERMAL STRESS INSIDE THE XM-1 TANK DURING OPERATIONS IN AN NBC ENVIRONMENT AND ITS POTENTIAL ALLEVIATION BY AUXILIARY COOLING

AD A110875

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
Natick, Massachusetts

20 May 1981

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

82 02 11 0

UNCLAS

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered).

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: T 4/81 — 2. GOVT ACCESSION NO.: AD-A110 875	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Thermal Stress Inside the XM-1 Tank During Operations In An NBC Environment And Its Potential Alleviation By Auxiliary Cooling	5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Michael M. Toner, Robert E. White, Ralph F. Goldman	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Research Institute of Environmental Medicine, Natick MA 01760	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 3E162777A878
11. CONTROLLING OFFICE NAME AND ADDRESS: Same as 9, above	12. REPORT DATE: 20 May 1981 13. NUMBER OF PAGES: 59
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLAS 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

heat stress, NBC protective clothing, fighting vehicle, water cooled undergarment, dehydration, heart rate, rectal temperature, skin temperature, heat casualty

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thermal stress inside an XM-1 tank parked in the desert was evaluated on heat-acclimated crewmen dressed in the standard Combat Vehicle Crewman (CVC) uniform plus various configurations of chemical protective clothing (i.e. Mission-Oriented Protective Postures [MOPP] I-IV). In addition, an auxiliary water-cooled vest (WVC) was tested for its potential in alleviating heat stress imposed on the active crewmen in a closed hatch, unventilated tank. Two tank crews (4 crewmen each) alternated exposures during the six days of testing. Days 1-3 (MOPP I, III, and IV) presented moderate heat stress to the crews,

whereas on Days 4 and 6, the tank's environmental conditions with hatches closed and ventilator off were intolerable in MOPP IV. Exposure times on Day 4 and Day 6 were 80 and 124 min, respectively, with termination due to crew distress accompanied by high heart rates (HR) and/or convergence of mean weighted skin temperature (MWST) and deep body temperature (T_{re}). The WCV on Day 5 appreciably reduced the heat stress by preventing convergence of MWST on T_{re}; HR and T_{re} responses were substantially lower with WCV as opposed to Days 4 and 6 when the vest was not worn.

AD_______________

TECHNICAL REPORT

NO. T 4/81

THERMAL STRESS INSIDE THE XM-1 TANK DURING OPERATIONS IN AN NBC ENVIRONMENT AND ITS POTENTIAL ALLEVIATION BY AUXILIARY COOLING

by

Michael M. Toner, Robert E. White and Ralph F. Goldman

Project Reference: 3E162777A878

20 May 1981

Series: ME

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
Natick, Massachusetts 01760

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

Thermal stress inside an XM-1 tank parked in the desert was evaluated on heat-acclimated crewmen dressed in the standard Combat Vehicle Crewman (CVC) uniform plus various configurations of chemical protective clothing (i.e. Mission-Oriented Protective Postures I-IV). In addition, an auxiliary water-cooled vest (WCV) was tested for its potential in alleviating heat stress imposed on the active crewmen in a closed hatch, unventilated tank. Two tank crews (4 crewmen each) alternated exposures during six days of testing which included: Day 1 - Mission-Oriented Protective Posture (MOPP) I, open hatch; Day 2 -MOPP III, open hatch; Day 3 -MOPP IV, open hatch; Day 4 - MOPP IV, closed hatch, no ventilation; Day 5 -MOPP IV, closed hatch, no ventilation but with auxiliary cooling; Day 6 - MOPP IV, closed hatch, no ventilation. Mean wet bulb globe temperature (WBGT) index measured outside the tank varied between 25.7^{o}C and 31.9^{o}C while the inside range was 26.8^{o}C to 35.0^{o}C throughout the six days of testing. Days 1-3 presented moderate heat stress to the crews, whereas on Days 4 and 6 the tank's environmental conditions with hatches closed and ventilator off (i.e. a "silent watch" condition) were intolerable. Exposure times on Day 4 and Day 6 were 80 and 124 min, respectively, with termination due to crew distress accompanied by high heart rates (HR) and/or convergence of mean weighted skin temperature (MWST) and deep body temperature (T_{re}). Water loss for the active crewmen on Day 4 and Day 6 averaged 2.05 $l \cdot hr^{-1}$ and 1.69 $l \cdot hr^{-1}$, respectively, whereas on Days 1-3 water loss averaged 0.64, 0.30, and 0.99 $l \cdot hr^{-1}$, respectively. HR on the active crewmen was substantially elevated with average final values of 162 $b \cdot min^{-1}$ on Day 4 and 147 $b \cdot min^{-1}$ on Day 6. In contrast, HR averaged 92 $b \cdot min^{-1}$ on Day 1, 76 on Day 2 and 114 on Day 3. The WCV appreciably reduced the heat stress, not only preventing convergence of MWST on T_{re}, but in fact, increasing the T_{re} to MWST gradient

for the crew to 7.5°C. Final physiological parameters for the crew after 208 min with WCV were HR 113 $b \cdot min^{-1}$, T_{re} 38.1°C, water loss 0.63 $l \cdot hr^{-1}$. In conclusion, an intolerable condition exists when tank crewmen are exposed to a hot, desert environment while wearing full chemical protective clothing in a closed hatched, unventilated tank. A water-cooled vest worn under clothing substantially reduces the heat stress.

INTRODUCTION

With the potential for introduction of Nuclear, Biological and/or Chemical Warfare (NBCW) to the modern battlefield, a major concern has been to evaluate the performance capability of the soldier when he must be protected against such environments. Safety measures have been devised to protect the soldier from chemical agents if and when these are employed; additionally, situations have been considered where chemicals are not yet employed but where there is the potential risk. These risks have been identified and their resultant impact on the soldier and his mission have been organized into a set of multi-level Mission-Oriented Protective Postures (MOPP); these are described in AR 385-63 and FM 21-40 but are also, it appears, currently being redefined by some tacticians.

Protection against Chemical Warfare (CW) agents requires that the soldier be placed in an encapsulating micro-environment. While this provides protection from external contamination, it also may confound the body's ability to eliminate heat and thus result in heat stress on soldiers who are in hot-dry or hot-wet climates. This is inevitable since any CW clothing adds insulation, while also reducing evaporative cooling by interposing a vapor barrier between the skin surface and the ambient environment.

Physiological responses of the soldier to heat have been thoroughly investigated. However, few studies have been concerned with the clothed man and even fewer with the heat stress imposed by the combined CW and desert environments. This Institute has been involved in most of these studies for the past 20 years, as shown in Table 1. Earlier work by Goldman (4) clearly demonstrated the intolerance of heat acclimatized individuals exercising in a hot-wet environment while wearing CW protective clothing. Additional corroborating information was gathered by Joy and Goldman (7) on troops performing a variety of tactical exercises while being exposed to a hot climate and wearing a CW protective ensemble. Tolerance times were substantially reduced when exercise and heat were combined with the added clothing.

Table 1

TIME CHART OF
NBC STUDIES

YEAR	STUDY/EVENT/TITLE	BY
1915	First use of Gas -Germans	
1918	AEF#1433 Defense Against Gas "Troops need practice wearing respirator for longer periods...6 to 8 hours of weartime may be necessary"..."thorough training and drill...in use by troops of protective equipment..."	
1959	Camp Pickett, VA	FT Knox/EPRD*
1960	Copper Man Studies of NBC Clothing	USARIEM
1961	Climatic Chamber Studies	USARIEM
1962	FT Lee Field Studies	USARIEM
1963	Road Operations in a Toxic Environment (Panama)	USARIEM
1964	Road Operations in a Toxic Environment	FT Ord/CDEC*
1965	IPR CB Protective Overgarment	NARADCOM
1966	Mandrake Root (Computer Study)	MUCOM/OPREGG*
1967	Mandrake Root Addendum Study	US/USSR*
1966-68	Effectiveness In a Toxic Environment	CDC/CAG*
1969	US Amphibious Assault 69-10	NMFRL*
1969	Doctrinal Guidance for NBC Wear	USARIEM
1970	Copper Man Evaluations	USARIEM
1971	Reducing heat stress in NBC ensembles	TTCP/Edgewood*
1975	Grand Plot III	CDCEC/IDF*
1975	US/CDA/UK Companion Study	Dugway*
1978	Wetted cover to reduce heat stress in NBC	USARIEM
1979-80	Reducing heat stress in a CB Environment	TRADOC/FM21-40*
1980	Heat stress for XM-1 CVC in CW protection	USARIEM
1980	Potential heat stress in USN Carrier flight operations	USARIEM

*USARIEM INVOLVEMENT

Givoni and Goldman (3) have developed a theoretical model that predicts deep body temperature (T_{re}) and heart rate (HR) over time; it includes inputs for exercise intensity, clothing, degree of heat acclimatization and the environmental conditions. From this model it was predicted that there would be a substantial heat stress on active crewmen, clothed in CW protective clothing, while inside the XM-1 main battle tank in a desert environment. The model was developed from years of environmental chamber and field research studies, including some in which heat stress had been produced under similar circumstances. As a result of this expertise, the Military Ergonomics Division of the US Army Research Institute of Environmental Medicine (USARIEM) was tasked by the principal Deputy Undersecretary of Defense for Research and Engineering to run a study: 1) to demonstrate whether or not there was significant heat stress potential during operations of the XM-1 in a CW environment and 2) if so, to demonstrate that some form of auxiliary cooling could alleviate the stress.

METHODS AND PROCEDURES

Subjects

Eight experienced tank crewmen (2 crews) from the US Marine Corps, Air Ground Combat Center at 29 Palms, California volunteered to participate in this study to evaluate the heat stress imposed by a variety of chemical protective postures in a desert climate while inside the XM-1 main battle tank. The Marine volunteers were superbly fit, extremely well-trained M-60 tank crews (demonstrated 95% first round hit/kill probability), thoroughly heat-acclimated (having just participated in field maneuvers in the desert) and extremely well-motivated. In addition, superb leadership and additional motivation was provided by the Chief Warrant Officer who served as OIC for the subject group; he had particular interest in the study because he was assigned to the 3rd Tank Battalion at 29 Palms as their CW Officer/Expert.

The XM-1 Tank

The XM-1 main battle tank has been designed to replace the current M-60 series vehicle as the Army's primary tank. The XM-1 features a new concept in armor to improve survivability, a turbine engine coupled with a redesigned suspension which allows for very high cross-country speed, and a laser fire control system which increases the percentage of first round hits. The turret ammunition storage area is protected by ballistic doors and by special blast blowout panels to minimize injury to the crew in the event of a direct hit. Much attention has been paid to simplifying various crew controls. The turret has a small ventilator, and the vehicle is equipped with a gas particulate filter system similar to that in the M-60 series main battle tank.

The tank conditions tested both open hatch with the turret ventilator on, and closed hatch with ventilator off. In the latter condition, an investigator was stationed in the tank to observe the crewmen's status. The particulate filter blower which supplied filtered air to the M-25 gas mask remained on during this condition. A plastic cover replaced the driver's hatch during the closed hatch condition because it was felt that an incapacitated driver could not be easily removed through the turret in this study. The tank was parked in the sun by the side of an air-conditioned building, where all the data collection equipment was located.

Experimental Protocol

All testing was performed in September 1980 at the US Army Yuma Proving Grounds, Yuma, Arizona during the hottest hours of each day (i.e. between 1330-1700 hrs). The experimental conditions and schedule are presented in Table 2. The first two days were categorized as training days, to acquaint the crew and investigators with the procedures. Days 2-6 employed the use of a variety of clothing combinations. On Day 2, the Marines wore their own two-piece CW liner undergarment and their CVC uniform. The clothing on Day 3 included the Marines' CVC uniform plus the standard two-piece overgarment with M-25 gas mask, hood, gloves and boots; on Days 4-6 the same clothing ensemble was worn as on Day 3 except that the one-piece CVC uniform supplied by NLABS was substituted for the Marines' CVC uniform. No body armor was used by the crew during any exposure.

Table 2

Test Schedule and Experimental Conditions

Day	Clothing Ensemble	Tank Condition
1	Combat Vehicle Crewman (CVC) only	OH, VT
2	CVC plus NBC suit opened (MOPP III)	OH, VT
3	CVC plus NBC suit closed (MOPP IV)	OH, VT
4	CVC plus MOPP IV	CH, UV
5	CVC plus MOPP IV with Auxiliary Cooling	CH, UV
6	REPEAT of DAY 4	

OH - open hatch; VT - ventilated; CH - closed hatch; UV - unventilated

Auxiliary cooling. Auxiliary cooling was supplied through a water-cooled vest (WCV) which, based on heated copper manikin work completed at USARIEM (2), had an adequate cooling potential. Figure 1 presents the cooling capability of some five different water-cooled garments or clothing items, as a function of the cooling water temperature. The system used in the present study to cool the water was an external, prototype cooler; work is continuing at NLABS and MERADCOM to refine the cooling system.

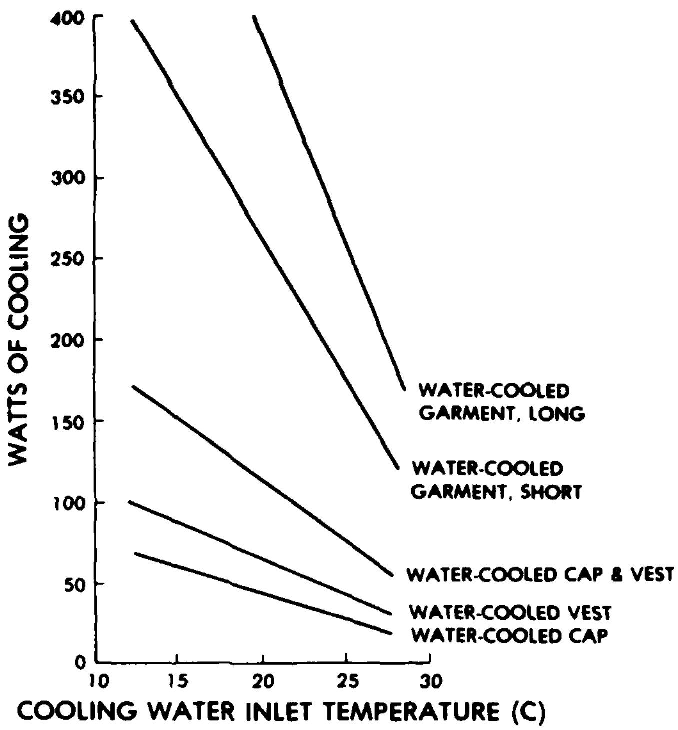


Figure 1. Cooling power of two water-cooled garments, and a water cooled vest and/or cap as a function of inlet water temperature (Fonseca, 1981).

Environmental measurements. Comprehensive meteorological data were acquired both inside and outside the tank. Wet Bulb Globe Temperature (WBGT) index was measured and considered to be the best indicator of the physiological effects of environmental conditions. The WBGT index is a compilation of 10% air temperature, 20% 6" Black Globe Temperature (representing the radiant heat load received by a man) and 70% the naturally convected (i.e. non-ventilated or non-psychrometric) Wet Bulb temperature; the latter is more applicable to a soldier, who only has the available air motion to evaporate whatever sweat he produces, than the conventional or Wet Bulb Temperature (WB) which uses a ventilated wet bulb thermometer.

The general guidance for application of the WBGT index to military operations, as specified in TB MED 507 (8), is that when the WBGT index reaches 26°C (78° F) caution should begin to be taken if extremely intense physical exertion is involved; when the WBGT index reaches 28°C (82° F) discretion should be used in planning heavy exercise for unacclimatized personnel; when it reaches 29°C (85° F) strenuous exercise such as marching at cadence should be suspended in unacclimatized troops during their first three weeks of training, and outdoor classes in the sun should be avoided. When the index reaches 31°C (88° F) strenuous exercise should be curtailed for all recruits and other trainees with less than 12 weeks training in hot weather, although hardened personnel, after full acclimatization each season, can carry on limited activity at WBGT of 31°C - 32°C (88° F to 90° F) for periods not exceeding 6 hours a day. Above a WBGT index of 32°C (90° F) physical training and strenuous exercise should be suspended for all personnel (excluding essential operational commitments not for training purposes, where the risk of heat casualties may be warranted). The statement is also included that wearing of NBC warfare protective uniforms in effect adds 6°C (10° F) to the measured WBGT and limits should be adjusted accordingly.

In addition to the WBGT as measured with the standard Weksler kit (FSN#6665-00-159-2218), two Botsball instruments (i.e. a new and simpler WBGT monitoring instrument (9) just now being introduced into the Federal Stock System), exterior and interior air temperatures (DB) and wet bulb temperatures (WB) were obtained. Exterior wind speed was monitored by a cup anemometer while a hot wire anemometer was used to measure interior air motion.

Physiological measurements. The physiological responses of each crewman were monitored to quantify the heat stress imposed on the crew within each condition and also to insure the crew's safety. HR was obtained using a standard three-lead electrocardiograph (ECG) and recorded at appropriate intervals during the exposure. Mean weighted skin temperature (MWST) was measured with temperature sensors placed on the chest, forearm and calf, while deep body temperature (T_{re}) was recorded from a thermistor inserted 10 cm into the rectum.

The meteorological and physiological data were fed directly into a Hewlett-Packard 9825 computer via a network of cables passed into the building, situated close to the tank. The on-line data acquisition system continuously recorded all information on magnetic tapes and instantaneously graphed these data on a Hewlett-Packard Plotter; this insured maximum safety for the crew.

Pre- and post-nude weights, adjusted for water intake, were obtained with each exposure and yielded a value of the total Sweat Production (P); whereas pre- and post-, fully clothed weights were also recorded to determine Sweat Evaporation (E). The ratio of the amount of sweat evaporated per unit of sweat produced (E/P) is an additional index of heat stress in hot climates.

Activity level. The interior temperatures and humidities anticipated in the XM-1 had been used to predict the response of the crew wearing the CVC uniform plus the NBC protective overgarment. This modelling had been carried out at USARIEM prior to the field study so that the design of the study scenario could meet a commitment to avoid conditions which would lead to potential heat stroke, which has a significant associated fatality rate. It was predicted that, if the activity level were limited so that average exercise intensity over an hour would not amount to more than a moderate level (200 kcal • hr^{-1}) only heat exhaustion, an equally limiting but non-fatal form of heat tolerance limit, would be incurred; in MOPP IV, it was projected to be incurred within one to two hours of exposure for the closed hatch conditions. Further, to avoid potential injuries to subjects unskilled and untrained in XM-1 operations (albeit highly trained in M-60 operations), no power modes would be used; manual controls would be used to generate the desired, low to moderate exercise level. Accordingly, it was decided that there would only be one, 3-5 minute fire mission performed every thirty minutes. Specific tasks were designed for each of the four crew members (Appendix B).

Experimental procedures. Similar procedures were followed throughout the six days of testing. Start times were later on Days 1 and 2 as compared to Days 3-6 since both tank crews were unfamiliar with the test protocol. The appropriate crew arrived at the air conditioned control center following lunch. Each crewman was weighed nude, after he emptied his bowel and bladder. Skin and rectal harnesses were fastened in place, and the three leads for the ECG were attached to the skin by the investigators. The crewmen then were aided in donning the appropriate clothing ensemble for the day. Clothed body weights were obtained after complete dressing, followed by the administration to each crewman of 0.2 liters (½ pint) of water. All administered water was measured and recorded for use with the sweat production and evaporation calculations. Water ingestion was strongly encouraged by the investigators throughout each exposure. After completing all baseline measurements, the fully clothed crew walked to the tank.

RESULTS

Environmental Conditions

The environmental conditions varied throughout the six days of testing and differed both inside and outside the tank. It is fortunate that the first two days were set aside as training days. The first day was the hottest, with air

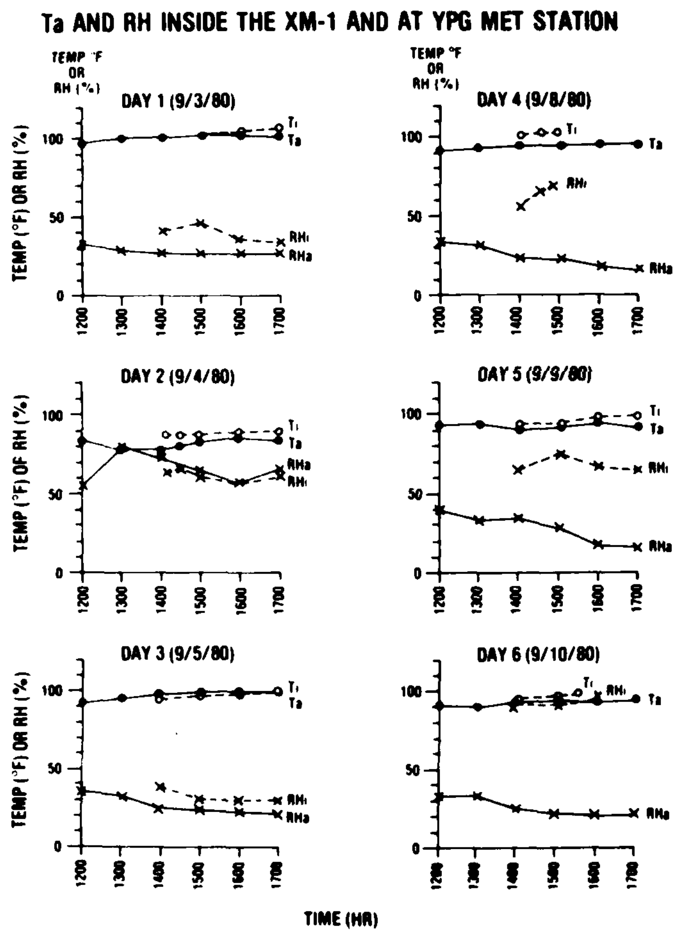


Figure 2. Comparison of the relative humidity and dry-bulb temperature readings inside the tank (RH_i and T_i) with those readings reported at the Yuma Proving Ground Meteorological Station (RH_a and T_a) on Days 1-6.

temperature reaching 102° F at 1500 hr; wearing only the CVC uniform the men experienced substantial discomfort inside the tank. The second day (4 Sept 1980) an unusual thunderstorm occurred which dropped the air temperatures and dramatically raised the humidity.

Conditions were in the desirable range during the four days of actual test operations (5, 8, 9 and 10 Sept). The temperature averaged 95 ± 2° F with 26 ± 2% relative humidity; winds were from 4 to 13 knots and cloud cover was between 13 and 30%. As shown in Figure 2, there was very little buildup of interior air temperature above air temperature reported at Yuma Proving Ground Meteorological Station, even during Days 4, 5 and 6 when the hatches were closed and the ventilators shut off. On Days 1 to 3, when the hatches were open, there was a significant, but small increase (approximately 10%) in interior relative humidity over exterior. However, when the hatches were closed (Days 4, 5 and 6), although there was not much temperature buildup inside the vehicle, the interior relative humidity rose dramatically, to approach 95% RH on Day 6. This contrast in humidity buildup with closed versus opened hatches is depicted graphically in Figure 3; the three dimensional plot emphasizes the difference in relative humidity buildup inside the crew compartment on Day 3, when the hatches were opened, from that on Days 4, 5 and 6 when the hatches were closed.

When one looks at the more relevant WBGT index to describe the environmental stress of the environment, as shown in Figure 4 on Days 1 and 3, the WBGT inside the vehicle was actually lower than outside; this amounted to only a few degrees and was a result of the reduction of the direct radiant load component of the WBGT. However, on Days 4 through 6 there was a substantial and progressive increase in interior WBGT throughout the one to two hour exposure of the subjects inside the vehicle, reflecting the increase in interior humidity as a direct result of the crew's sweat production.

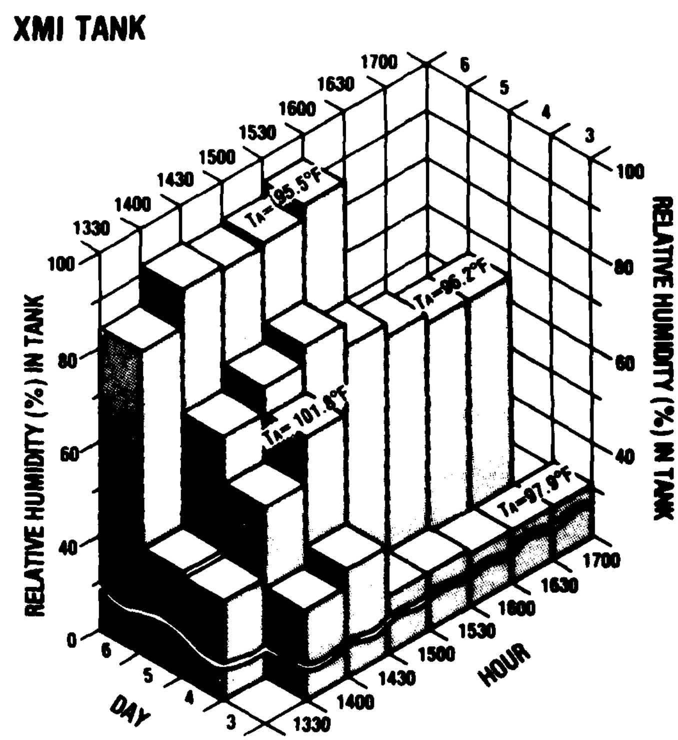


Figure 3. Relative humidity readings inside the XM-1 averaged over each half hour of exposure from Days 3-6.

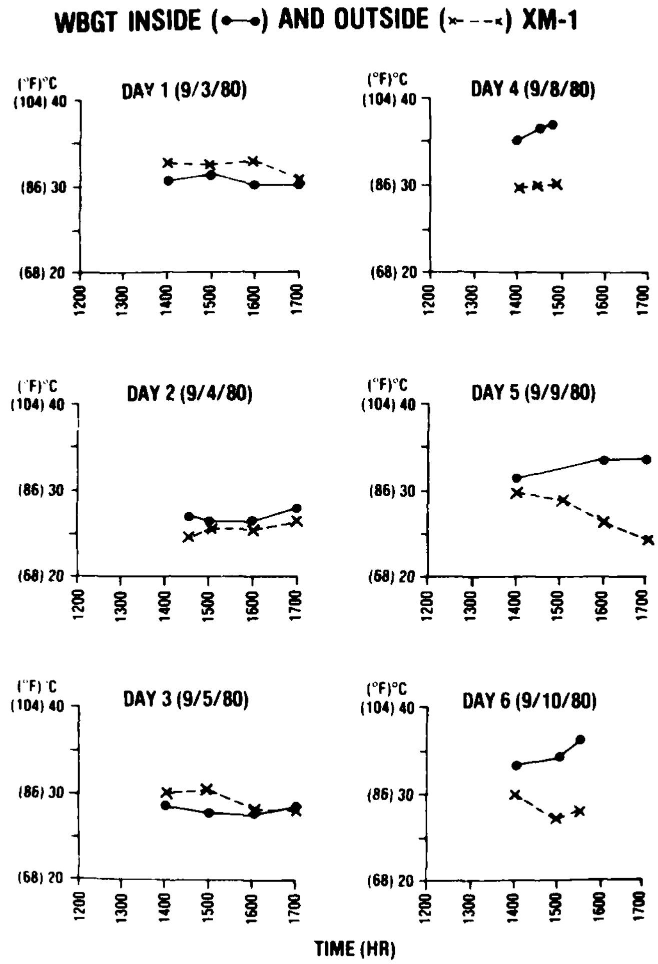


Figure 4. Comparison of WBGT readings inside the XM-1 with outside readings on Days 1-6.

Physiological Responses

Although Day 1 was the hottest day, because the hatches were open, the crew compartment WBGT index averaged only 30.5° C. It can be seen that there was little change in deep body temperature, and skin temperature stayed well below deep body temperature (Fig. 5) for the crew.

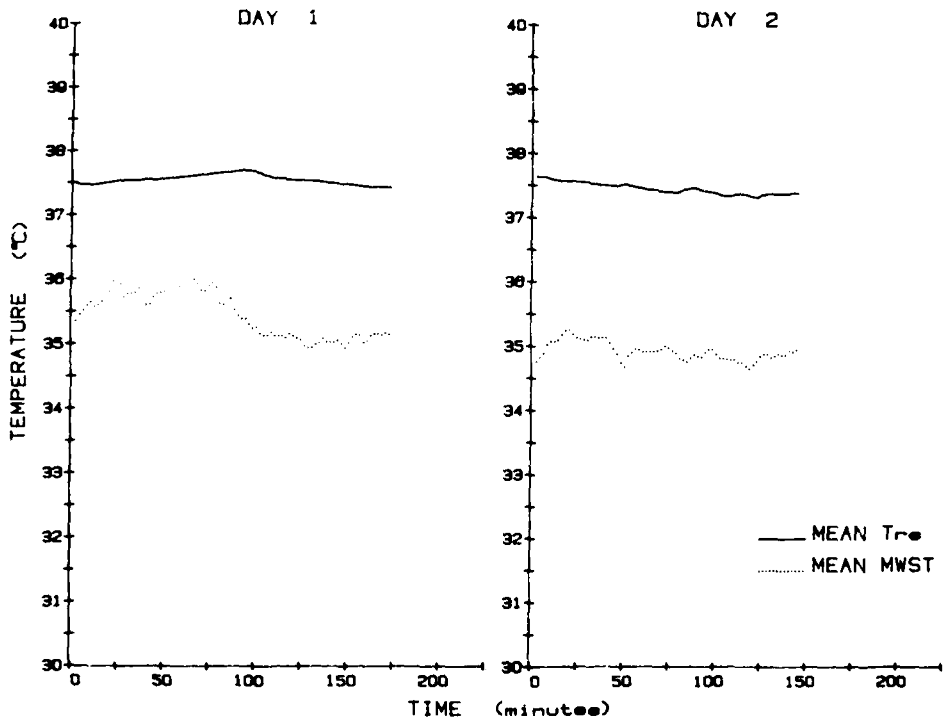


Figure 5. Average deep body temperature (T_{re}) and average mean weighted skin temperature (MWST) of the crew on Days 1 and 2.

Day 2 (4 Sept) was highlighted by an unusual thunderstorm which produced a cool (26.8^{O} C) interior WBGT and an unusually high relative humidity. The men were quite comfortable even though they were wearing their own chemical protective liner undergarments under the CVC uniforms. The difference between skin and deep body temperature is greater than on the first day (Fig. 5). The only changes in skin and deep body temperature during the exposure are associated with the 5 minute fire mission every half hour.

On Day 3 the men did wear the chemical protective overgarment in MOPP IV configuration but, because the hatches were open, again deep body temperature stays quite flat. It can be seen that skin temperatures are much closer to the deep body temperature on Day 3 (Fig. 6), but the men had no difficulty in completing the exposure to the scheduled 1700 hr termination time.

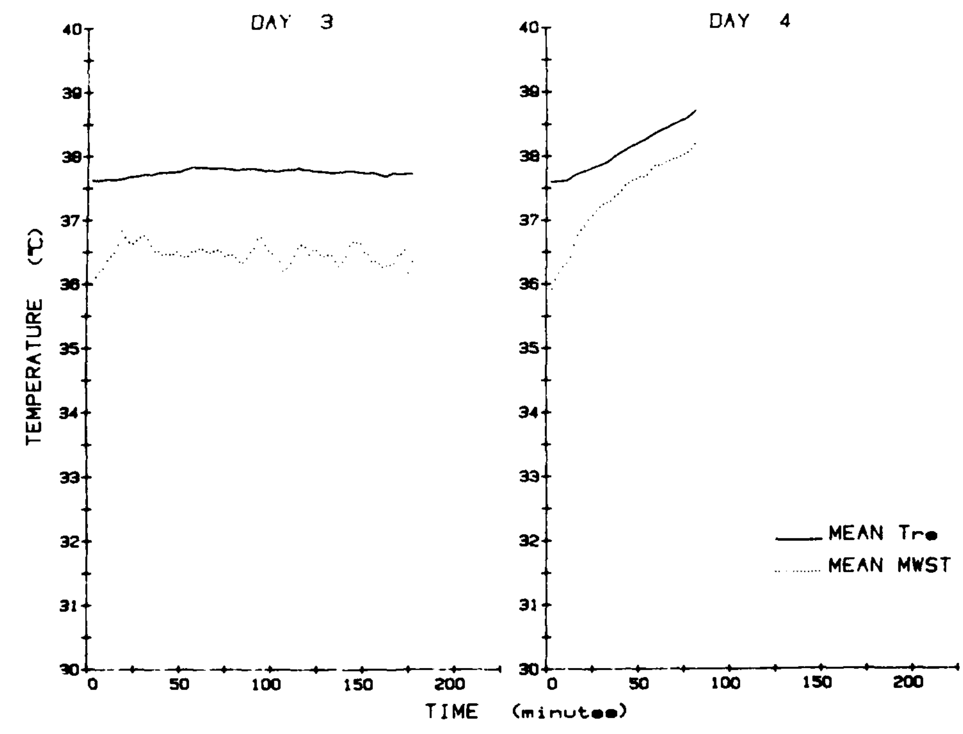


Figure 6. Average T_{re} and MWST of the crew on Days 3 and 4.

On Day 4, however, when the hatches were closed, a very different pattern emerged. Although a relatively constant difference was maintained between the interior and exterior dry bulb temperature (Fig. 2), the interior WBGT rose approximately 6° C (~11° F) within 45 minutes and presented a steeply rising heat stress to the crew. The effects of this stress are immediately notable in the steeply increasing skin temperatures, and in the more slowly responding but nevertheless increasing deep body temperatures of the crew (Fig. 6). Errors were detected in the Commander's directions for the fire mission within 30 minutes of the start of the exposure and within the first hour he, himself, noted he was "making dumb mistakes". Water intake was strongly encouraged and some of the crewmen ingested up to 3 canteens an hour. Despite these unusual attempts to maintain hydration, the superb physical condition of the men, their superb motivation and acclimatization and a high degree of leadership exhibited by the Tank Commander, after 80 minutes the Gunner slumped back in his seat, tore off his gas mask and indicated that he could not continue. The Commander and Gunner had voiced complaints for some time previously that they "felt chilled" and "were a little dizzy", but they had not reached any of the established physiological criteria for removal from the exposure. The crewmen had been encouraged to continue and had voluntarily done so despite their increasing discomfort. Although he had not reached the criteria for investigator termination of his exposure, this voluntary discontinuance by the Gunner was not capricious; his final heart rate was 178 $b \cdot min^{-1}$.

Essentially similar exposure conditions prevailed on Day 5, but the men wore a vest supplied with cooled water; this removed heat at a rate of about 75 watts from each man since the inlet water temperature was about 17.7° C (cf. Fig. 1). Although the interior environmental humidity buildup did occur (Fig. 3), there was little or no rise in deep body temperatures (Fig. 7); skin

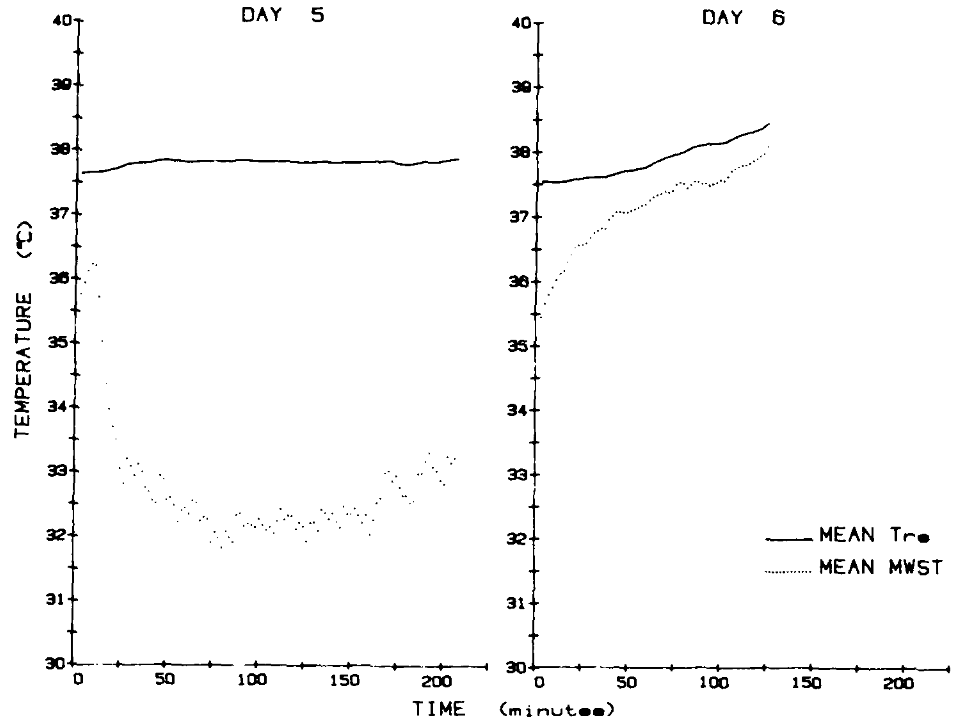


Figure 7. Average T_{re} and MWST of the crew on Days 5 and 6.

temperatures were extremely low. The men completed the full exposure without difficulty, without error and without discomfort other than potential over cooling.

The XM-1 tank used during the first three days of study was removed to be worked on over the weekend. It was returned to the test site with "a dust clip" in place, which substantially reduced the air flow through the particulate filter blower to the gas masks. This had not been detected by the crewmen, who had not noticed any altered ventilation to the mask, nor by the investigators because the clip is located well forward and hidden by the gun barrel. There was therefore some question as to whether or not the early tolerance (at 80 min) experienced on Day 4 might be associated in some readers' minds with a lack of gas mask ventilation. To control for this, the clip had been left in place for the first 80 minutes of exposure on the following day (Day 5), when with the auxiliary cooling system was worn. Although no problem was experienced, and the crewmen did not report any significant difference in their perception of ventilation when the clip was removed at the 80th minute on Day 5, it was decided that the closed hatch, MOPP IV, ventilators off, blowers off condition of Day 4 should be repeated with the particulate filter blower fully functional (i.e. without the clip in place).

Accordingly Day 6, which had been scheduled for photography and as a potential makeup, was utilized to essentially repeat the Day 4 exposure, but with full air flow to the crewmen's masks. The ambient conditions were milder than Day 4 (WBGT was 35^{O} C on Day 4 versus 33.4^{O} C on Day 6) so that it took longer, but the heat intolerance pattern exhibited on Day 4 was clearly repeated (Fig. 7). Again it was the Gunner who, at 124 minutes of exposure, sank back in his seat, removed his mask and declared that he was unable to continue any longer. On this occasion, his voluntary intolerance occurred at about the same time that his skin temperature equaled his deep body temperature. Again, there was no question of malingering. As on Day 4, there were fire command errors, subjective discomfort and complaints beginning fairly early and increasing throughout the exposure. The investigators believed these men did their best in the attempt to complete the full exposure.

The heart rate responses serve as perhaps the best single expression of the combined effects of work, environment and clothing on the crewmen. Figure 8 presents the average response of all crewmen as a function of exposure time for all six days, while Figures 9 and 10 present the individual heart rates for each day for the Tank Commander, Gunner, Loader and Driver, respectively. Looking at the heart rate responses of the crew as a whole, on Day 1 one sees the heart rate relatively flat throughout the entire exposure; the average rarely exceeds

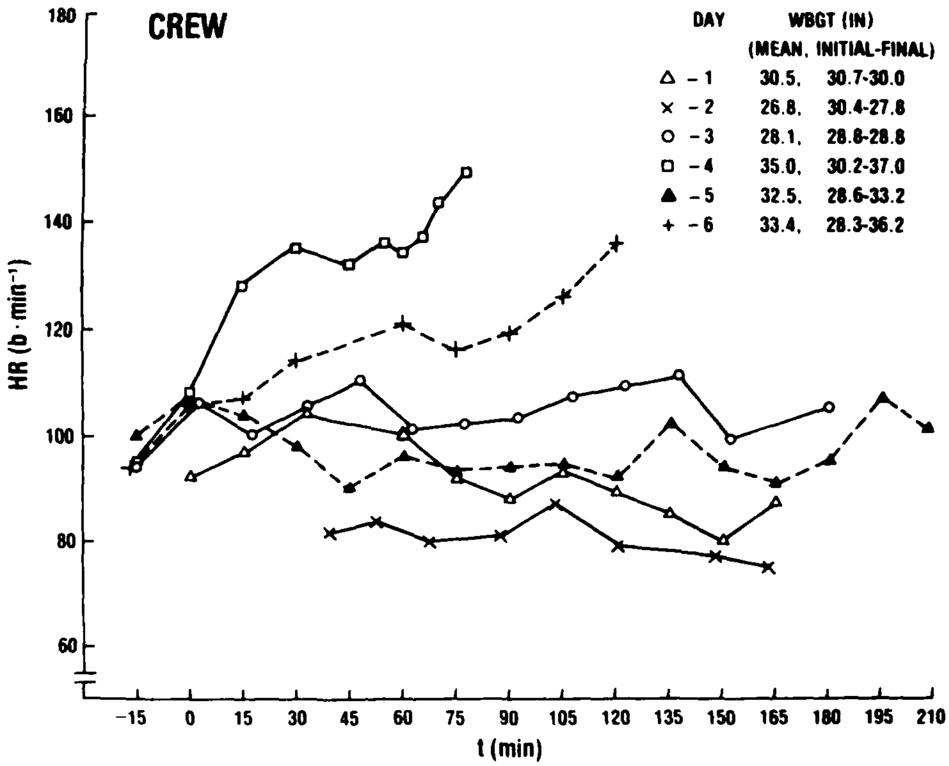
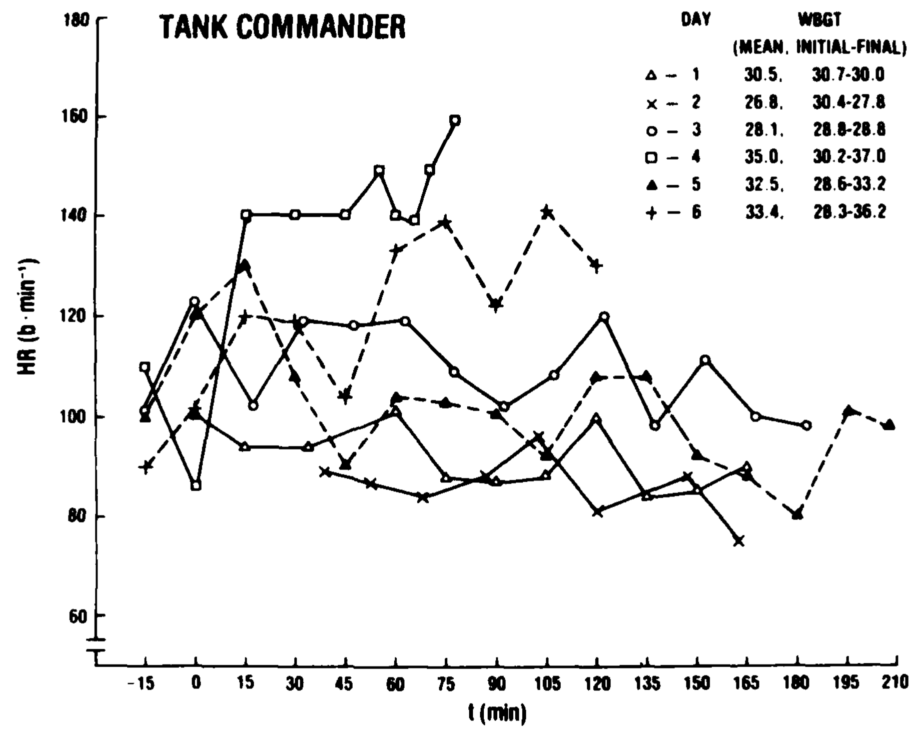


Figure 8. Average heart rate (HR) responses of the crew on Days 1-6.

100 b • min^{-1}. On Day 2, because of the unusually cool conditions accompanying the thundershower, heart rate stayed at about 80 to 85 b • min^{-1} during the entire exposure. On Day 3, with open hatches and ventilators off, heart rate while wearing MOPP IV was still relatively flat but averaged above 100 b • min^{-1}. In contrast, on Days 4 and 6 heart rate rose continually reaching a peak of 150 b • min^{-1} for the average for the four men after 80 min on Day 4 and about 135 b • min^{-1} for the average of the four men at 124 min on Day 6. When auxiliary cooling was provided, the average heart rate of the group was below that observed when the hatches were opened throughout the exposure on Day 3.

The difference in work between the four crew positions is best observed in the individual HR responses shown in Figures 9 and 10; the Tank Commander is clearly not stressed as severely as the Gunner, both are stressed more severely than the Loader and the level of stress on the Driver is minimal, even on Day 4.

The sweat production and sweat evaporation for the crew over the first three days, with hatches open, contrasts with the last three days with hatches closed, as can be clearly seen in Figure 11. The sweat production and evaporation were greater on Day 1, when the men were only wearing CVC garments, than on Day 2 when the men were wearing the CVC garments plus the chemical protective liner; the environmental conditions were substantially hotter on Day 1. On Day 3, with hatches open but with the men in MOPP IV configuration, the sweat evaporation is not substantially different from that on Day 1 but it is achieved at a much greater expense in sweat production. With the hatches closed on Days 4, 5 and 6, the evaporation is stringently limited. As can be seen clearly in Figure 11, there is a substantial conservation of body water with auxiliary cooling. This water conservation is an important benefit. The relative inefficiency of sweat elimination of body heat under these severe heat stress conditions can be clearly seen in the E/P ratio figures shown for Days 4 and 6 (Fig. 11); these are in the 20 $\pm$ 20% range, in contrast to the 31% value with auxiliary cooling on Day 5 or the open hatches of Day 3, and the 60 to 80% of Day 1 when only the CVC uniform was worn.



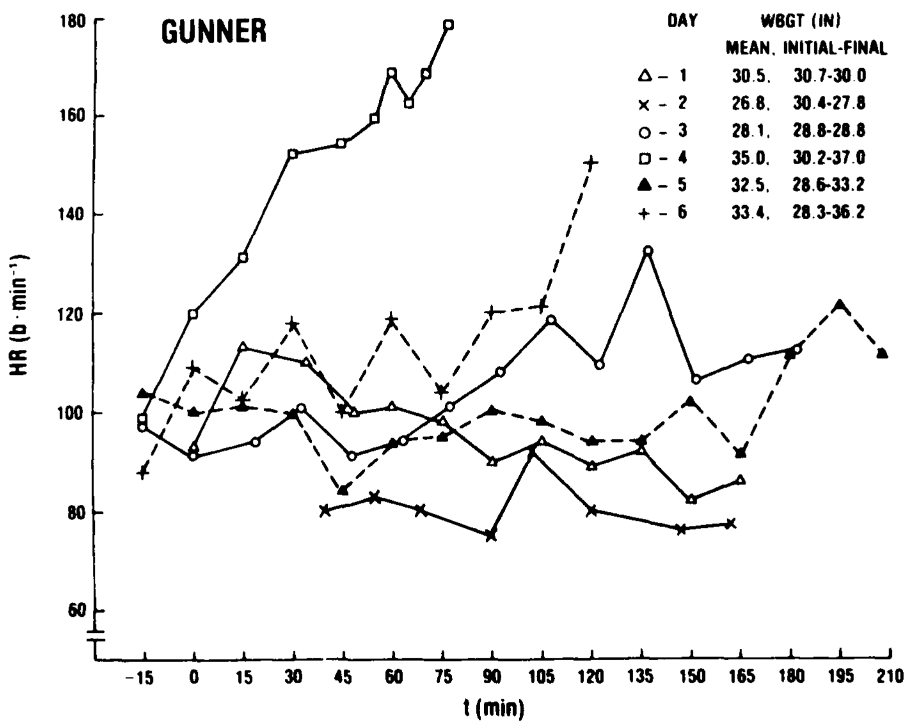
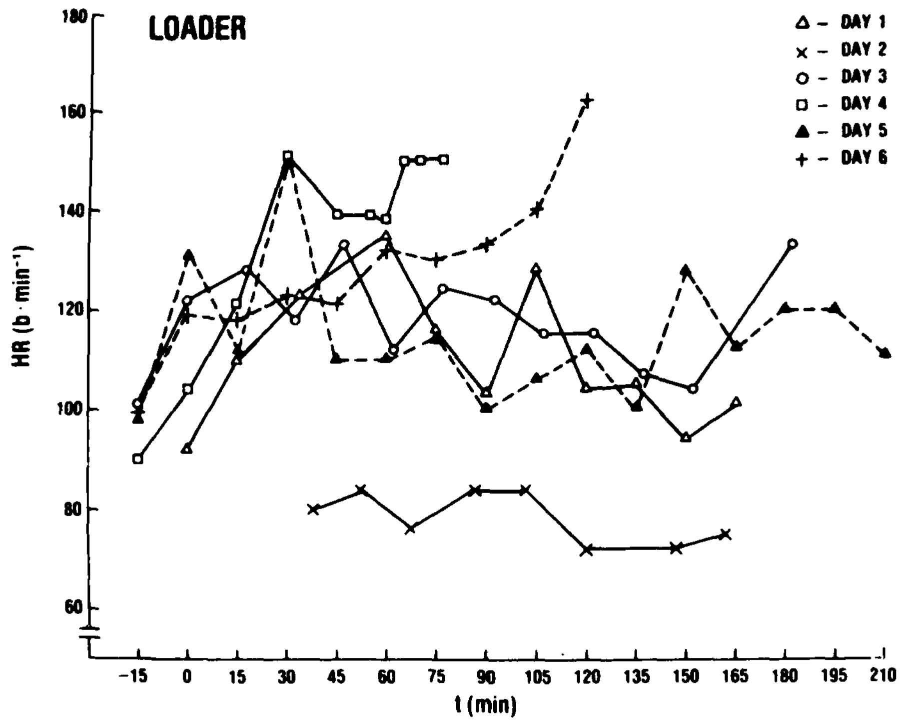


Figure 9. Heart rate (HR) responses of the Tank Commander and Gunner on Days 1-6.



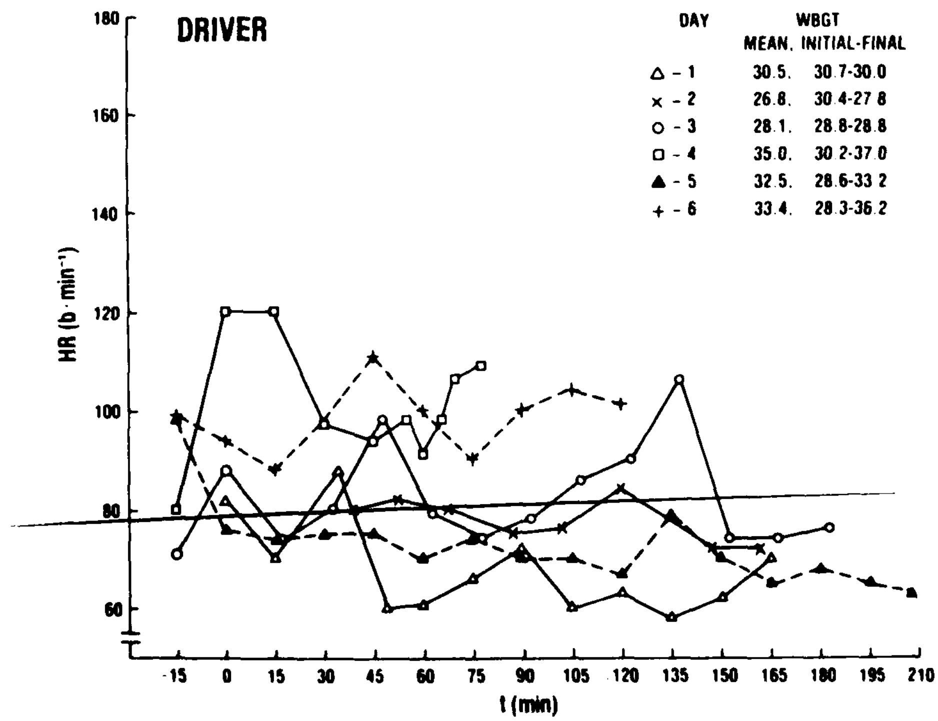


Figure 10. Heart rate (HR) responses of the Loader and Driver on Days 1-6.

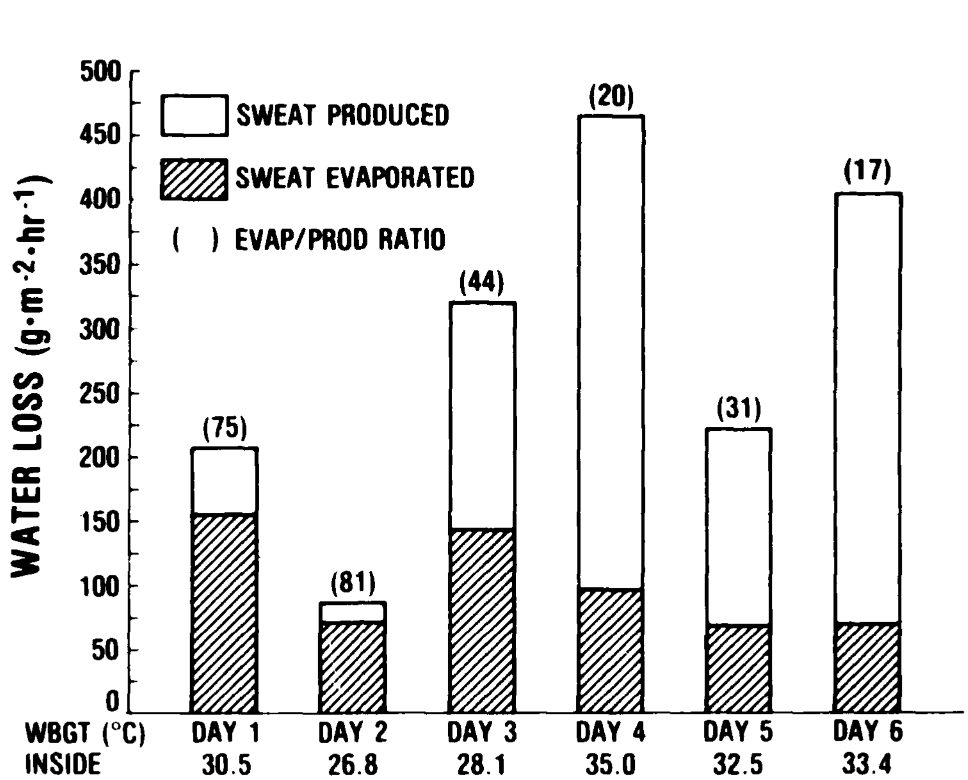


Figure 11. Average sweat production, sweat evaporation and evaporation/production ratio of the crew on Days 1-6.

Individual final MWST, T_{re} and HR for each man, each day, are presented in Table 3. The physiological data fully reflect the relative strains as a result of the exposure in MOPP IV with closed hatches and the consequent inability of the men to continue. The alleviation of heat stress induced by auxiliary cooling is sufficient that the final conditions on Day 5, even though the number of fire missions each half hour was increased, were not terribly dissimilar from those on Day 3 when the CW protective clothing was worn, hatches were open and the ventilators were on; however, these final temperatures on Day 5 were not produced with as little cardiovascular strain (as shown in the heart rates) as on Day 2, when the ambient environmental conditions were cooler.

Table 3

EXPOSURE DURATION AND FINAL SUBJECT STATE

		MWST		T_{re}		HR	DURATION
		°C	°F	°C	°F	b • min⁻¹	(min)
MOPP I open hatch (Day 1)	TC	35.6	(96.1)	37.6	(99.7)	90	172
	L	34.8	(94.6)	37.5	(99.5)	101	
	G	35.7	(96.3)	37.6	(99.7)	86	
	D	34.7	(94.5)	37.1	(98.8)	70	
MOPP III open hatch (Day 2)	TC	35.1	(95.2)	37.8	(100.0)	76	163
	L	34.7	(94.5)	36.9	(98.4)	76	
	G	35.0	(95.0)	37.3	(99.1)	76	
	D	34.9	(94.8)	37.0	(98.6)	72	
MOPP IV open hatch (Day 3)	TC	36.1	(97.0)	38.0	(100.4)	98	177
	L	36.4	(97.5)	37.5	(99.5)	133	
	G	36.9	(98.4)	37.8	(100.0)	112	
	D	36.0	(96.8)	37.5	(99.5)	76	
MOPP IV closed hatch (Day 4)	TC	38.4	(101.1)	39.0	(102.2)	159	80*
	L	38.1	(100.6)	38.8	(101.8)	150	
	G	38.4	(101.1)	38.9	(102.0)	178	
	D	37.9	(100.2)	38.2	(100.8)	109	
MOPP IV closed hatch Auxiliary cooling (Day 5)	TC	29.2	(84.6)	37.8	(100.0)	98	208
	L	35.8	(96.4)	38.3	(100.9)	130	
	G	32.7	(90.9)	38.2	(100.8)	111	
	D	35.3	(95.5)	37.2	(99.0)	63	
MOPP IV closed hatch (Day 6)	TC	38.1	(100.6)	38.7	(101.7)	130	124*
	L	38.1	(100.6)	38.6	(101.5)	162	
	G	38.1	(100.6)	38.3	(100.9)	150	
	D	37.7	(99.9)	38.2	(100.8)	101	

D - Driver; L - Loader; G - Gunner; TC - Tank Commander

*NOTE - EXPOSURE TERMINATED BECAUSE OF INDIVIDUAL DISTRESS

Crew Perceptions

A debriefing was held after each day's run, just after the final clothed and nude weights were obtained. The crewmen were asked to comment on whether or not they felt they could complete the exposure when halfway through the exposure and, at the end, how much longer did they think they could go if asked. They were also asked for their own estimate of their ability to perform at the end of the exposure, in comparison with their normal abilities without any heat stress or encumbrance from CW protective clothing. Their comments are presented in Table 4. The heat stress experienced on Day 1, when only the CVC uniform was worn alone, was such that the men estimated that their ability to perform was only 75% to 85% of what it would be without heat stress. On Day 2, with a cooler 26.8° C (80° F) compartment WBGT, even though they were wearing the chemical protective liner undergarment in a MOPP III configuration the crewmen estimated that they were at a 100% efficiency at the end of the exposure. Going to MOPP IV on Day 3, with a 28° C (83° F) compartment WBGT, produced additional decrements in their estimates of their ability to perform at the end, although they all felt they could complete the study halfway through. However, the Driver had repeated problems with leg cramps because of the small space of his compartment.

With the closed hatch conditions on Day 4, the men knew they were in trouble halfway through, and at the end they felt they could only continue for another 10 or 15 minutes, except for the Driver who obviously was having little or no heat problem, because of his low work rate, but was bothered with leg cramps. Estimated ability to perform was decremented by 25% for the Loader, and by more than 50 to 60% for the Gunner and Tank Commander. With auxiliary cooling on Day 5, although the Loader had a headache (tight mask straps?), the men had no problem completing, and felt they could continue for 3 to 4 hours. The Gunner, who had been in the most difficulty without auxiliary

Table 4

Self-evaluation of Performance

DAY/DATE	COMPARTMENT WBGT + MOPP	CREW POSITION	CAN COMPLETE? -HALFWAY-	HOW MUCH LONGER? -AT END-	ABILITY TO PERFORM -AT END-
1. 9/3/80*	30.5°C	TANK CDR	-*	-	75-85%
"OPEN HATCH"	(87°F)	LOADER	-	-	
	MOPP 1	GUNNER	-	-	
		DRIVER	-	-	
2. 9/4/80*	26.8°C	TC	-*	-	100%
"OPEN HATCH"	(80°F)	L	-	-	
	MOPP 3	G	-	-	
		D	-	-	
3. 9/5/80	28.1°C	TC	✓	NO	60-85%
"OPEN HATCH"	(83°F)	L	✓	2 HRS	70-80%
	MOPP 4	G	✓	4-5 HRS	90%
		D	✓	2 HRS	50-75%
4. 9/8/80	35.0°C	TC	"making mistakes"	10 MIN	40-50%
"CLOSED HATCH"	(95°C)	L	"trouble breathing"	10-15 MIN	75%
	MOPP 4	G	"?another fire mission?"	10-15 MIN	20-40%
		D	✓	1-2 HRS	75%
5. 9/9/80	32.5°C	TC	✓ VERY MUCH	2-4 HRS	100%
"CLOSED HATCH"	(90°C)	L	✓ BUT HEADACHE	3 HRS	75-85%
AUXILIARY COOLING	MOPP 4	G	✓	FOREVER	95%
		D	✓ LEG CRAMPS	4 HRS	60-85%

*CREW TRAINING DAYS

cooling, felt that he could go forever in contrast with his previous experiences. Little problem or decrement in ability to perform was sensed, except for the Loader's headache and Driver's leg cramps.

Overall Findings

The overall study findings are summarized in Table 5, where average values for skin and deep body temperatures, heart rates and sweat rates have been calculated for just the Tank Commander, Gunner and Loader (i.e. without the Driver's, quite different values included). Note that sweat rate on Day 4 averaged 2.05 $1 \cdot hr^{-1}$ (4.5 $lbs \cdot hr^{-1}$) for these three men and the sweat rate for the Loader and Tank Commander exceeded 2.9 liters (6.5 lbs) during the 80 min of exposure. These sweat losses can be contrasted with the average 0.63 $1 \cdot hr^{-1}$ (1.4 $lbs \cdot hr^{-1}$) of sweat produced when auxiliary cooling was available, as shown in Table 5. Clearly there is a reduction in drinking water requirement of between 2 and 3 pints an hour with auxiliary cooling and, in addition, the mission can be accomplished with auxiliary cooling but can not be accomplished without it, when the hatches are closed and the ventilating system is off.

Other Problems

The men were asked each day to comment on specific problems that they identified. It must be emphasized that these are only the subjective opinions of between 1 and 3 crewmen, and may reflect differences in expectations and/or equipment between the standard M-60 vehicle, with which the men were thoroughly familiar, and the new XM-1. A number of the problems that they identified also may have been addressed during design and may be the result of trade-offs; nevertheless, they are included here since they are observations made during the study. The ones that seemed most critical are: the engine and turret ventilator noise, which we monitored at an excess of 100 db near the Loader's ears; the lack of ability to drink water while wearing the gas mask; major

Table 5

XM-1 HEAT STRESS AT YPG

SEPTEMBER 1980

DAY	MOPP/ HATCH	$\bar{T}_a$ o	$\bar{T}_a$ i	$\overline{RH}$ o	$\overline{RH}$ i	$\overline{WBGT}$ o	$\overline{WBGT}$ i	TOLERANCE min	$\bar{T}_{sk}$	$\bar{T}_{re}$	HEART RATE b/min	SWEAT RATE ℓ/hr	COMMENTS
1	I/OPEN	38.7°C	39.1°C	39%	31%	31.9°C	30.5°C	>172	35.4°C	37.6°C	92	0.64	TRAIN #1
2	III/OPEN	28.6	31.4	66	60	25.7	26.8	>163	34.9	37.3	76	0.30	TRAIN #2 (cw under)
3	IV/OPEN	37.6	36.6	29	33	30.0	28.1	>177	36.5	37.8	114	0.99	
4	IV/CLOSED	36.0	38.8	30	57	29.9	35.0	(80)	38.3	38.9	162	2.05	T.C. ERRORS < 60'
5	IV/CLOSED (w/cooling)	36.1	35.7	25	66	27.4	32.5	>208	32.6	38.1	113	0.63	DOUBLE DRILLS
6	IV/CLOSED	34.4	35.3	29	91	28.9	33.4	(124)	38.1	38.5	147	1.69	T.C. ERRORS ~ 60'

problems with the length, and placement of connections of the gas mask hoses; the wetting, shriveling up and sensitivity of the hands following continued wear of the CW protective gloves, even though the men wore white cotton gloves underneath the totally impermeable gloves in an attempt to absorb some of the excess moisture. The Driver's concern was that there was no escape hatch for him. Finally, we note that the radio appears to have been relocated from its position in the M-60 tank to one, in the XM-1, where the Loader will be required to operate the radio controls since it is inaccessible to the Tank Commander; this suggests that it may be the least trained man in the crew who will be responsible for radio operations.

DISCUSSION AND CONCLUSIONS

The delay of the study until the first weeks of September was beneficial; it avoided the extremes of heat stress that would have been experienced during July and August. The ~ 95^{O}F, 25% relative humidity experienced in September did not represent an extreme heat stress condition; such air temperatures occur in the summer in Southern Europe about 1% of the time, with much higher humidities. Indeed, the 5% design condition for air conditioning installations for Rome, Italy is an 89^{O}F air temperature with about 50% relative humidity. The September conditions did not impose a severe heat stress for the crew dressed in full chemical protective clothing on Day 3. However, during the "silent watch" condition of closed hatches and ventilators off, the buildup of interior humidity created by the sweating men, combined with the CW protective clothing, was substantially limiting; such environmental conditions would pose problems even without the chemical protective clothing, if extended exposures (> 3 to 5 hours) were required.

The intolerance of the crewmen on Days 4 and 6 was clearly illustrated from physiological information and individual perceptions. The established criteria for stopping any exposure were convergence of the MWST and T_{re}, HR above 180 $b \cdot min^{-1}$, or a voluntary statement of exhaustion. Earlier work by Pandolf and Goldman (10) indicated that convergence and equating of MWST and T_{re} seemed to be the most appropriate physiological criterion for termination of a heat exposure when semipermeable clothing ensembles were worn by exercising men. As MWST approaches T_{re}, the thermal gradient allowing for heat transfer from the body's core to the skin is progressively reduced; therefore, the heat that is produced during metabolism must be stored in the core. The rising core temperatures on Days 4 and 6 are following the elevated skin temperature (cf. Figs. 6 and 7) and also reflect the accumulation of the heat generated by the fire missions. MWST equaled T_{re} for the Gunner on Day 6. This was the only physiological criterion for exhaustion to be reached during this study and it happened precisely when the Gunner himself felt he could not continue.

The elevated core and skin temperatures increased circulation to the skin; the HR responses on Days 4 and 6 reflect this increased circulatory demand. Rowell (11) pointed out that exposure to high dry bulb and high wet bulb temperatures increases cardiac output in resting subjects. The initial increase in HR and cardiac output is required to maintain the central circulation and to support the added demand for cutaneous perfusion. The subsequently slower upward drift of HR may result from a decrease in central blood volume and a reduced venous filling pressure of the heart, produced by the loss of body fluids to sweat production. This cardiac drift tends to be associated with the rate of sweat loss to the environment (cf. Figs. 8 and 11); Days 4 and 6 showed the highest water loss and the greatest rise in HR, whereas Days 1, 3, and 5 all showed moderate water loss and moderate upward drift in HR. Although water intake was strongly encouraged, the high sweat rates were not matched by intake and subsequent water deficits were recorded following the short exposures of Days 4 and 6.

The sweat production was quite high on Days 4 and 6. Goldman et al. (5) presented data on resting, unclothed individuals exposed to hot-wet environments which compared to the environment experienced by the crewman in the present study. Matching the WBGT on Day 4 with these (earlier) data, one can see the effects of the clothing system combined with the light workloads. With a WBGT of 35.1^{o}C, the same as Day 4, Goldman's subjects (5) averaged 0.5 l • hr^{-1} for sweat production, in contrast to the 1.8 l • hr^{-1} of sweat production in the present study. This production equates to the values obtained in the Goldman study at rest in a WBGT range of 41-45^{o}C (105.6-112.5^{o}F). Therefore the chemical protective clothing plus the light workloads used in the present study produced an effect comparable to adding approximately 6-10^{o}C (10-18^{o}F) on the WBGT index. This supports in a limited sense the TB Med 507 statement of the addition of 6^{o}C (10^{o}F) to the WBGT index to evaluate the potential incremental heat stress induced just by wearing the CW protective clothing.

Studying clothed individuals, one can easily look at both sweat production and sweat evaporation. The E/P ratio (cf. Fig. 11) can be used by itself as an index of the heat strain imposed on the individual by the combination of work, clothing and environment. On Days 1 and 2, the E/P ratios were very high, which indicated an efficient evaporative cooling system. Most of the sweat that was produced at the skin and absorbed into the clothing was evaporated. However, on Day 3 the efficiency was drastically reduced. Since T_{re} did not rise unreasonably on this day, then the sweat evaporation must have been sufficient to maintain thermal balance which was met at the expense of greater water loss. On Days 4 and 6, with higher humidities, the sweat evaporations were less than

Day 3. This reduced evaporation resulted in the elevated T_{re} and the associated decreased tolerance; the E/P ratios were quite depressed. The small improvement from the 17-20% found on Days 4 and 6, to the 31% on Day 5 in the E/P ratio is the result of the reduction in sweat production. The water-cooled vest (WCV) provided an alternative means for heat dissipation which in turn depressed the drive for sweating. T_{re} increased only slightly.

At the inlet water temperature of 17.7°C the WCV provides approximately 75W of heat removal as defined in reference to the copper manikin evaluation of the WCV (Fig. 1); 75W is the difference between the heat input demanded by the heated manikin to maintain a constant skin temperature while 17.7°C water is flowing through the vest at $22.7\ l \cdot hr^{-1}$, minus the heat input required with no water flowing (2). This system was certainly more than adequate, especially in the case of the Driver who complained of overcooling in the area in contact with the vest. No provision was made for the automatic or for self-regulation of flow to the individual man in the present study so this mismatch between heat production and cooling power can be understood; supplying each vest with the same cooling power, one could not accommodate the variations in the heat production of the crew, which ranged from approximately 80W for the Driver to as high as 200W for the Gunner. This mismatch presented only a minor problem expressed by some complaints of discomfort but appeared to have no adverse effects on performance. However, provision for individual control of cooling must be made when wider ranges of heat production are prevalent. Overall, the WCV performed extremely well in attenuating the effects of an intolerable heat stress environment. In addition, it substituted in part for the need to obtain sweat evaporative cooling and thereby contributed to the conservation of body fluids. The associated reduced need for drinking water is a secondary though important feature of auxiliary cooling.

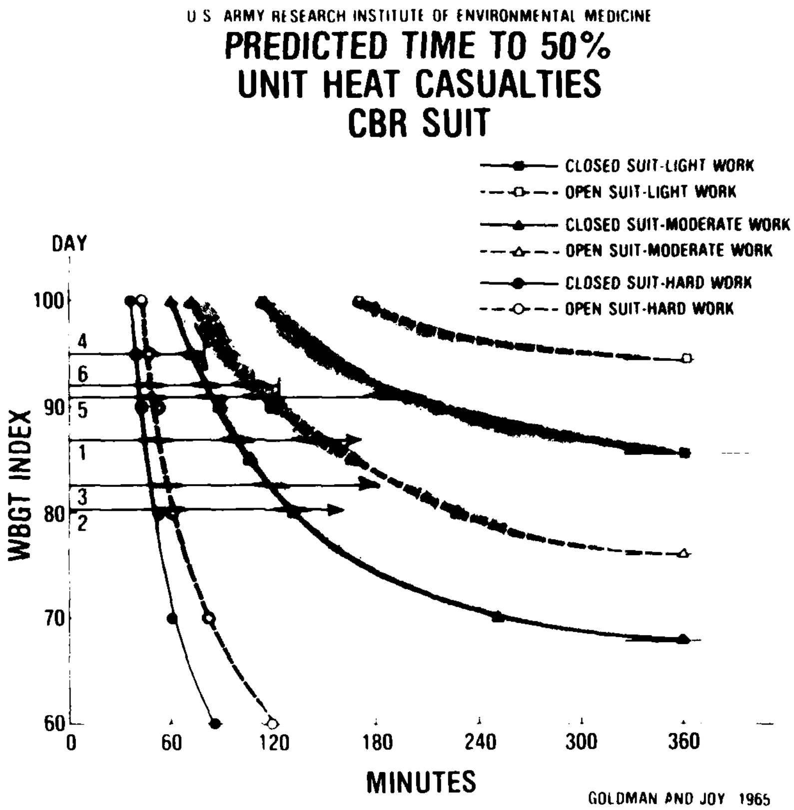


Figure 12. Predicted time to 50% unit heat casualties clothed in a chemical protective suit as a function of exercise intensity and WBGT index.

The results of the study were not at all surprising. In Figure 12, a chart, prepared in 1965 (6), illustrating the "predicted time to 50% unit heat casualties" when wearing the CW protective suit either open (MOPP III) or closed (MOPP IV), is presented; the actual exposure times observed each day of the present study are drawn directly onto this chart of the predicted times. The task for the Gunner was something approaching 200W (i.e. moderate work) and the observed tolerance time on Day 4 in closed suit (MOPP IV) indicated by a vertical line in Fig. 12 is almost identical to the predicted value for this work level; the differences between predicted and observed responses on Day 6 are

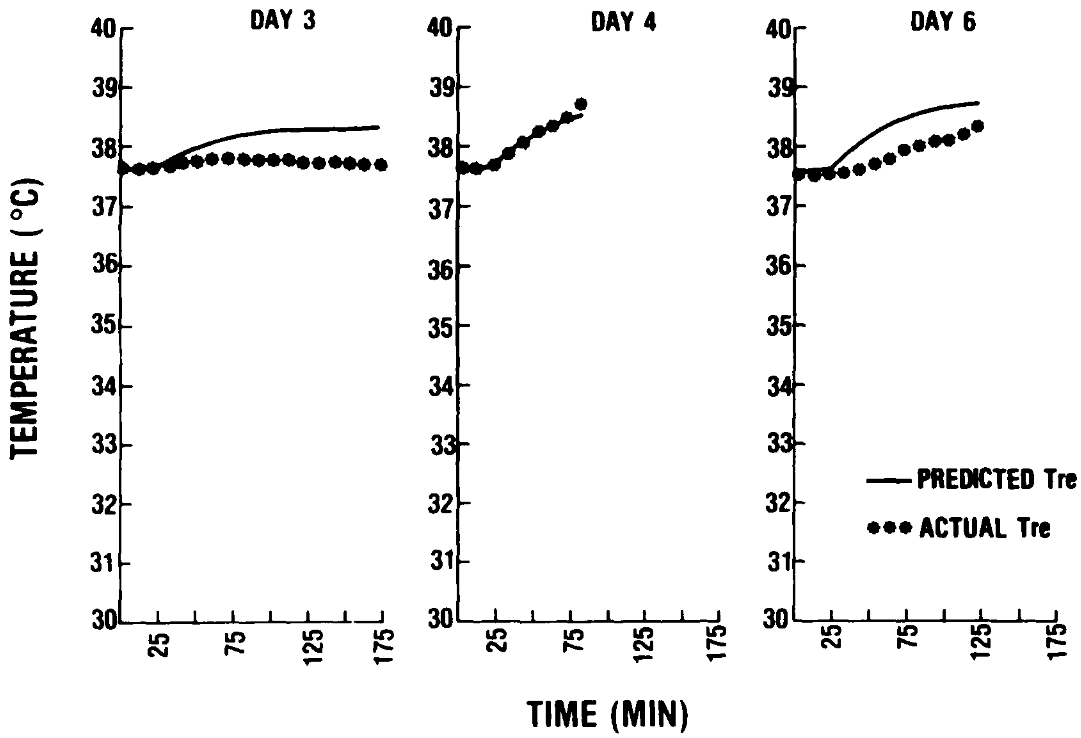


Figure 13. Comparison of the predicted and actual T_{re} for the crew on Days 3, 4 and 6.

also not very great. On the remaining days, no tolerance limitations were experienced; the endpoints, indicated by the arrowheads, were generated by the planned exposure times rather than by any intolerance.

A more appropriate and encompassing approach to the prediction of the soldiers' heat tolerance in CW environments is the use of theoretical and biophysical models which include inputs for climate, degree of heat acclimatization, work intensities and clothing ensembles. Figure 13 compares the actual, deep body temperature of the entire crew and the predicted responses by the USARIEM Heat Casualty Assessment (HECAS) prediction model

(1) for Days 3, 4, and 6. Day 5 was excluded because of inadequate information of the auxiliary cooling system (i.e. flow rates to individual vests). The climate used as the input to the model was the average WBGT to which the crew was exposed. The input for heat production had to be estimated. The driver was essentially at rest, with almost no work; his estimated heat production was between 80 and 100 watts (i.e. under 90 kcal per hour). The Loader was doing less work than either the Commander or the Gunner; the latter, who had the most sustained and heaviest work during the 3 -5 minute fire mission each half hour, [illegible] estimated to have had an hourly heat production of, at most, 225 watts (approximately 200 kcal per hour). Therefore, the average metabolic heat production for the crew was estimated to be between 130 and 150 watts.

The impact of a particular clothing ensemble, in terms of the potential heat load on the soldier, depends on its physical characteristics in addition to its interaction with the soldier's heat production and the environmental conditions. The heat load attributed to the clothing is inversely proportional to its total thermal resistance (clo) and is proportional to its vapor permeability (i_m). The CVC and the CW protective systems, both in the open and closed configuration, were evaluated at USARIEM on a static wetted copper manikin to determine the clo and i_m coefficients. This information was used as input to the model in order to predict the responses of the crew.

The value of such an approach is certainly not in its post hoc analysis, but in its potential for scenario evaluation and modification. In the initial planning for this study, given the clothing ensembles to be worn and estimates of climatic conditions, an upper limit of work rate was established using the model. This upper work rate limit was selected to keep the crewman within limits of physiological safety, which was our basic tasking for this study; other limits could have been selected (e.g. 50% heat casualties) or other clothing or missions could have been used. To achieve this goal in the present study, work rate was modified since the clothing and environmental conditions were fixed. The agreement between the predicted and actual rectal temperatures, particularly for the severe heat stress of Day 4, provides evidence for use of such a predictive modelling approach; the model was designed for constant environmental conditions and appears to have had more difficulty using an average tank environment over time for the milder heat stress conditions of Days 3 and 6. The agreement between the predicted and actual body temperature under the severe heat stress of Day 4 illustrates the potential of such a modelling approach.

In conclusion, when one identifies a mismatch between human capabilities and the demands of the mission, there are generally only three classes of solution: modify the man; modify the clothing or equipment; and/or modify the mission. In the present study everything possible had been done to improve the tolerance of crewmen; the men were fully heat acclimated, had good training in use of and practice in wearing chemical protection, were of excellent physical fitness, had superb motivation and leadership, and were encouraged to take in as much water as possible to compensate for sweat losses of up to 2 and 1/2 canteens an hour. This leaves only the latter two classes of solution to deal with the problem. First of all, it should be possible to redesign the tank ventilation system to avoid the interior humidity (and potential temperature) buildup when the hatches are closed, by arranging to supply filtered, "clean" ambient air, and to use a quiet ventilation system. This will not solve the heat stress problem across the entire environmental range, especially not in hot-humid environments, but it will reduce the environmental range across which heat stress will be a problem. A suitable and, in some ways, a more functional approach is to provide some form of auxiliary cooling directly to the crewmen. A properly designed system will reduce heat stress, conserve large amounts of drinking water which will otherwise be required, and allow unimpaired performance across any climatic range; an auxiliary system can even accommodate the extreme cold conditions in the Arctic if provision for heating the fluid is provided. The only other simple solution is to revise the tactics to minimize any closed hatch, ventilators off operations, limiting duration of such conditions to not more than 30 minutes; as with a revision of the tank ventilation system, this approach will not solve the heat stress problem globally, but it will reduce the range of environments in which it will be experienced.

ACKNOWLEDGEMENTS

The study could not have been done without the cooperation of a great many people; the help of Mr. Tom Nolan of the XM-1 Project Office and of the Marines who volunteered was essential for the study's completion. The superb cooperation of the Yuma Proving Ground personnel, especially Mr. Ernest Horton, Mr. Dave Twomey, and the medical support provided by the Yuma Proving Ground MEDAC was also essential to the completion of the study. The continuing collaboration with the Advance Projects Office at Natick Laboratories, headed by Mr. Vincent Iacono (Mr. Joseph Cohen and Mr. Michael Kupcinskas), and the outstanding support provided by USARIEM personnel and in particular the Military Ergonomics Division personnel (Dr. Barbara Avellini, Mr. Leander Stroschein and Mr. Clement Levell at Yuma; Mr. Gerald Newcomb, Miss Claire Kimbrough, Miss Ella Munro and Miss Marie Stephens at the Institute) were also significant factors in carrying out this study.

REFERENCES

1. Berlin, H. M., L. Stroschein and R. F. Goldman. A computer program to predict energy cost, rectal temperature, and heart rate response to work, clothing, and environment. Special Publication, #ED-SP-75011, Edgewood Arsenal, Aberdeen Proving Ground, MD, 1975.

2. Fonseca, G. T. Effectiveness of five water-cooled undergarments in reducing heat stress of vehicle crewman operating in a hot wet or hot dry environment. Technical Report NO. T 2/81, US Army Research Institute of Environmental Medicine, Natick, MA, 1981.

3. Givoni, B. and R.F. Goldman. Predicting rectal temperature response to work, environment and clothing. J. Appl. Physiol. 32:812-822, 1972.

4. Goldman, R. F. Tolerance time for work in the heat when wearing CBR protective clothing. Military Med. 128:776-786, 1963.

5. Goldman, R. F., E. B. Green and P. F. Iampietro. Tolerance of hot, wet environments by resting men. J. Appl. Physiol. 20:271-277, 1965.

6. Goldman, R. F. and R. J. T. Joy. Prevention of heat casualties in men wearing chemical-biological protective clothing. Technical Report, US Army Research Institute of Environmental Medicine, Natick, MA, October, 1965.

7. Joy, R. J. T. and R. F. Goldman. A method of relating physiology and military performance: A study of some effects of vapor barrier clothing in a hot climate. Military Med. 133:458-470, 1968.

8. Occupational and environmental health: prevention, treatment and control of heat injury. TB Med 507, Department of the Army, Washington DC, 1980.

9. Onkaram, B., L. A. Stroschein and R. F. Goldman. A comparison of four instruments for measuring WBGT index correlations of Botsball with WBGT. Technical Report T4/78, US Army Research Institute of Environmental Medicine, Natick, MA, 1978.

10. Pandolf, K. B. and R. F. Goldman. Convergence of skin and rectal temperatures as criterion for heat tolerance. Aviat. Space Environ. Med. 49:1095-1101, 1978.

11. Rowell, L.B. Human cardiovascular adjustments to exercise and thermal stress. Physiol. Rev. 54:75-159, 1974.

APPENDIX A

YUMA METEOROLOGICAL STATION READINGS

Time	T_a	RH	WIND	Cloud Cover	Time	T_a	RH	WIND	Cloud Cover
			3 Sep 80 - Day 1		Max T_a = 105°; Min T_a = 75°				
1200	98°	33%	5 knots	0%	1500	102°	27%	8 knots	30%
1300	100	29	8	0	1600	101	27	6	20
1400	100	27	4	10	1700	100	27	8	10
			($\bar{x}$ 100.2° 28.7% 6.5 knots 11.7%)						
			4 Sep 80 - Day 2		Max T_a = 86°; Min T_a = 71°				
1200	84	53	5	100*	1500	83	65	6	90
1300	78	79	5	100*	1600	85	57	3	90
1400	78	73	7	100*	1700	84	65	4	90
			($\bar{x}$ 82.0° 65.3% 5.0 knots 95.0%)						
			5 Sep 80 - Day 3		Max T_a = 102°; Min T_a = 71°				
1200	92	37	6	30	1500	99	24	3	30
1300	95	33	5	30	1600	99	23	3	20
1400	98	26	4	30	1700	99	22	0	30
			($\bar{x}$ 97.0° 27.5% 3.5 knots 28.3%)						
			8 Sep 80 - Day 4		Max T_a = 98°; Min T_a = 73°				
1200	91	33	8	30	1500	95	24	8	20
1300	93	31	7	20	1600	96	19	10	20
1400	95	24	8	20	1700	96	17	11	10
			($\bar{x}$ 94.3° 24.7% 8.7 knots 20.0%)						
			9 Sep 80 - Day 5		Max T_a = 98°; Min T_a = 73°				
1200	93	40	10	50	1500	93	29	12	20
1300	94	34	13	50	1600	96	18	14	10
1400	91	35	14	30	1700	93	17	15	20
			($\bar{x}$ 93.3° 28.8% 13.0 knots 30.0%)						
			10 Sep 80 - Day 6		Max T_a = 97°; Min T_a = 70°				
1200	91	33	6	30	1500	95	23	3	10
1300	90	34	3	30	1600	94	22	3	0
1400	93	26	5	10	1700	95	22	4	0
			($\bar{x}$ 93.0° 26.7% 4.0 knots 13.3%)						

* Thunderstorm in progress

APPENDIX B

Exercise Tasks of the Crew

COMMANDER

1. When Driver gives "Driver ready" traverse weapon's station to building on left.
2. Give a fire command for an APC using HEP ammo and range of 1,600 meters: Gunner, HEP, APC, 1,600 meters, 45° left
3. After gunner gives "on the way" rotate weapon's station back to 0°.
4. Give Mission Completed to crew.

Other:
Remain in intercom contact with Driver and insure that he is within the tank when the main gun is rotated or elevated/depressed.

LOADER

1. When Commander gives fire command, load one round into gun from ready rack (place the round into breech so that it protrudes only slightly over the breech block; do not chamber round).
2. Give "up".
3. When Gunner gives "on the way" remove the round and restow in ready rack.
4. Remove round from floor rack and restow in ready rack.

Other:
Do not use any power switches and leave the breech guard in place throughout mission.

GUNNER

1. Lay on the target which is the right corner of the building at 45° left.
2. Use only manual controls.
3. Using Gunner's telescope as the sight, note building at the 1,600 meter range line on the HEP reticle.
4. Elevate tube to 5° or when building appears in the 2,800 meter range line.
5. Give "on the way".
6. Manually lower gun tube to original position and traverse turret back to original position.

Other:
Do not use turret power, and do not use any fire control components.

DRIVER

1. Lower seat and adjust headrest and release parking brake.
2. Close Driver's hatch.
3. Open Driver's hatch unless told not to do so by CONTROLLER WHITE.
4. Leave seat in depressed position until fire mission is over and Commander gives "mission completed". Say "Driver ready" after this point.
5. Raise seat.
6. Set parking brake.

Other:
Before starting engine, make sure that parking brake is set and voltage meter reads 25-29 volts. Reading should stay in green during operation.

Every 15 minutes (unless fire mission inprogress) do the following on record sheet:
write down: engine RPM, turn tank selector to all 4 positions and write down reading, write down reading of gauge marked Electrical System, write down any lights on maintenance monitor panel which come on.

APPENDIX C

XMI HEAT STRESS DEBRIEFING SHEET   DATE__________ TIME__________

CREW POSITION__________________   DEBRIEFER__________________

1. Rate your ability to perform normal crew functions on a scale of 0-100% at this time.

____

____

____

2. Are you able to perform crew functions with NBC uniform? ______________

a. Identify the area of non-performance.

____

____

____

b. Will any components of the NBC uniform affect your ability to carry out your combat mission?

____

____

____

3. At the halfway point of the test, did you feel that you could complete the mission?

____

____

4. At the end of the test, did you feel that you could have gone longer, and if so, how much longer in minutes?

____

5. Are there any systems within the tank which hamper your ability to complete the mission?

____

____

____

6. OTHER COMMENTS:

____

____

____

____

APPENDIX D

YUMA PACKING LIST

Box #1	25x25x16 inches	44.51 Kg (97.9 lbs.)
Quantity	Item	
1	Hewlett Packard (H.P.) digital multi meter	
1	H. P. 60 channel scanner	

Box #2	29x25x16	44.25 Kg (97.4 lbs.)
Quantity	Item	
1	H.P. 60 channel scanner (backup)	
1	H.P. IB interface cable (2 meters)	
1	H.P. real time clock interface	
1	Pkg. 4x4 gauze	

Box #3	28x24x13	40.53 Kg (89.2 lbs.)
Quantity	Item	
1	H.P. 9872 plotter	
1	Box plotter paper	
1	H.P. IB cable	
1	WBGT kit without harness	
2	WBGT kit with harness	
8	loop couple skin harnesses	
2	straight couple skin harnesses	
10	rectal probes	
2	13 ft. conductor cables	

Box #4	23x21x16	33.13 Kg (72.9 lbs.)
Quantity	Item	
1	H.P. 9866 printer	
1	H.P. 9866 cable #6	
2	Botsballs without harness	
2	Botsballs with harness	
1	ECG simulator	
1	sound meter	
1	parachute cord 100 ft.	
	asstorted colored tape	
	spare thermocouples, straight and looped	
2	sponges	
1	plastic bottle (for rectal sterilization)	

Box #5	28x24x14	43.70 Kg (96.1 lbs.)
Quantity	Item	
1	Alnor hot wire anemometer with sensor	
1	Chino wet bulb/dry bulb sensor with stand	
2	Yellow Springs rectal boxes	
1	wind speed transmitter with cups	
1	H.P. 5300 B counter (for wind speed)	
2	boxes assorted Hi-tape (for skin couples)	
10	rolls ECG paper	
6	rolls H.P. printer paper for 9825	
3	box alcohol pads	
1	H.P. timing generator	
5	ECG cables	
5	ECG harnesses	
1	yellow multi box	

Box #6	29x24x9	39.95 Kg (87.9 lbs.)
Quantity	Item	
1	heart rate monitor	
-	H.P. scanner cables	
1	Chino wet bulb/dry bulb sensor with wicks	
5	H.P. certified data cartridges	
1	YSI rectal box	
1	box (30) non-allergenic electrodes	
2	tubes K-Y jelly	
2	box magnets	
10	disposable razors	
3	pr. sunglasses	
1	bottle rectal disenfectant	
6	plastic beakers	
7	skin harness extension cables	
10	rectal harnesses with belts	

Box #7	27x22x12	26.08 Kg (57.4 lbs.)
Quantity	Item	
1	H.P. timing generator	
1	H.P. clock	
2	rolls H.P. printer paper	
2	pkg. 4x4 gauze	
5	canteens	

200	ECG electrodes
	plastic bags
	clip boards
	10x13 envelopes

Box #8 Footlocker 39.29 Kg (86.4 lbs.)

Quantity	Item
1	digital electronic scale
2	base plates with clamps
1	rechargable soldering iron
	assorted plastic ties (flat and ribbon)
1	roll hook up wire
1	pkg. cotton applicators
2	pkg. H.P. plotter pens (4 colors)
1	BCD cable (binary convert digital)
2	D cell batteries
3	bottle insect repellent
2	250 ml. graduated cylinders
1	skin fold calipers
	assorted office supplies
	assorted supplies-elastics for harnesses, RTV sealant, skin lotion, 4x4 gauze, plastic bags, disposable wipes

Box #9 Footlocker 39.29 Kg (86.4 lbs.)

Quantity	Item
6	15 ft. yellow extension cables
2	60 ft. yellow extension cables
3	rectal junction boxes
2	Botsball extensions
1	wind speed power supply, extension cable, BCD cord
11	H.P. power cords
3	rechargable pulsimeters
1	WBGT (Weksler) without harness
4	H.P. cables
4	15' rectal extension cables
1	first aid kit
1	USARIEM emblem

Box #10	26x26x19	29.99 Kg (66.0 lbs.)
	Item	
	Green junction box for skin and rectal connections to scanners	
Box #11	Briefcase	
	assorted tools	
Box #12	Vinyl case	
	9825 calculator	
	program tapes #406 to 409	
	printer paper, power cords	
Box #13	Briefcase	
	3 walkie talkies with chargers	
	1 Nikon 35 mm camera	
	1 flash attachment (for camera)	
	film	
	1 power supply for flash	

DISTRIBUTION LIST

5 copies to:

US Army Medical Research and Development Command
Fort Detrick
Frederick, MD 21701

12 copies to:

Defense Technical Information Center
ATTN: DTIC-DDA
Alexandria, VA 22314

1 copy to:

Commandant
Academy of Health Sciences, US Army
ATTN: AHS-CDM
Fort Sam Houston, TX 78234

1 copy to:

Dir of Biol & Med Sciences Div
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

1 copy to:

CO, Naval Medical R&D Command
National Naval Medical Center
Bethesda, MD 20014

1 copy to:

HQ AFMSC/SGPA
Brooks AFB, TX 78235

1 copy to:

Director of Defense Research and Engineering
ATTN: Assistant Director (Environmental and Life Sciences)
Washington, DC 20301

DA

FILM