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SYSTEMS NOTE 56

COLD WATER SURVIVAL SUITS FOR AIRCREW

by

G. R. WHITE

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SUMMARY

Laboratory and sea trials were used to evaluate the effectiveness of three aircrew cold water survival garments: the British Mark 10 suit, the United States CWU 21/P suit, and the Canadian 'UVIC Thermofloat' jacket. It was concluded that the three alternatives provided similar thermal protection but with regard to several other important features, the UVIC Thermofloat jacket was superior. Consequently, in this evaluation the UVIC Thermofloat jacket was shown to provide the most effective form of aircrew protection.

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ACKNOWLEDGMENTS

Squadron Leader N. Roth of the RAAF Institute of Aviation Medicine was a co-worker in this evaluation and contributed to every aspect of it. The CSIRO Division of Chemical Engineering made available the tank and cooling unit.

The Royal Australian Navy provided a patrol boat and its crew for one week to enable the sea trials to be carried out.

The RAAF Aircraft Research and Development Unit and RAAF Support Command were responsible for the organisation of the trials at RAAF Laverton.

1. THE PROBLEM

Pilots of the Royal Australian Air Force will soon be required to wear cold water survival suits during flights over cold water. Information obtained from the Australian Weather Bureau (Figure 1) indicates that during winter the mean temperature of the water off the south of Tasmania falls to 10 C. If a pilot wearing normal flying clothing were forced down over water at this temperature, his chances of surviving would be very poor. Rapid progress into hypothermia would be accompanied by loss of consciousness and finally drowning even if adequate bouyancy were provided by a life preserver. Keatinge[1] has described incidents in which victims of aircraft ditchings or ship sinkings have been found dead, though supported by a life preserver with their heads well out of the water. Clearly it is not enough to provide adequate flotation for such emergencies: steps must also be taken to keep the survivor warm. However, one difficulty is to devise, for survival in cold water, an anti-exposure suit which provides the wearer with adequate insulation when immersed, but does not induce a state of heat stress during normal flying in bright sunlight.

The purpose of these trials was to compare and evaluate three anti-exposure garments for possible use by the RAAF. These comprised the British Mark 10 and the United States CWU 21/P dry suits, and the UVIC Thermofloat jacket which was recently developed at the University of Victoria, British Columbia. The design of this latter garment is based on the "wet suit" principle.

Heat is lost from the body at a considerably reduced rate if the survivor is able to use a life raft. Life rafts, however, are not included in the survival equipment of many aircraft. Consequently for this evaluation it was assumed that the wearer would be almost totally immersed in the water throughout the exposure.

Initially the purpose of the study was to compare the three anti-exposure garments with respect to their thermal insulation and operational effectiveness and also to estimate survival times with and without this equipment.

The evaluation comprised two parts: laboratory trials, and sea trials. In both, the fall in deep body temperature was used as the most important criterion. Laboratory trials enabled a comparison of the suits to be made under similar and well controlled conditions whereas sea trials permitted the assessment to be extended to more realistic conditions. Subjects, wearing in turn each of the three suits, were required to sit in a tank of cold water while rectal and skin temperatures were measured. Four of these subjects then participated in the sea trials which were carried out in Port Phillip Bay.

Estimates of survival times should only be made with reference to the relevant physiological, biochemical and psychological variables. A brief account of some of these is provided after a description of the garments.

2. DESCRIPTION OF THE SUITS

The British Mark 10 suit is a coverall made of a ventile fabric which is permeable to perspiration vapours. Soft rubber seals are provided at the neck and wrists to prevent the ingress of water and waterproof boots are attached to the bottoms of the legs. A urination tube is fitted under a horizontal slide fastener just above the level of the crotch. Running horizontally across the back of the suit is a gusset slide fastener which allows the back to extend for ease of donning. To don the suit, the gusset slide fastener is opened and legs and arms are inserted through a waterproof slide fastener which runs from the right shoulder to the left hip. The head is then passed under the top of the suit while both hands are used to draw the rubber neck seal over the head. The gusset slide fastener is then closed and a seal which is intended to be waterproof is obtained by closing the front diagonal slide fastener. Size 5 (medium) of the suit has a mass of 2·5 kg.

1. Keatinge, W. R. *Survival in cold water*. Blackwell Scientific Publications: London, 1969.

The United States CWU 21/P coverall is similar in design. It is, however, somewhat lighter and easier to don. The main waterproof slide fastener at the front runs from one shoulder to the other and the greater flexibility of the fabric enables the wearer to don the suit more quickly. Soft rubber neck and wrist seals are provided in this suit also.

Special undergarments are worn under both of these in order to provide an insulating layer of air between the fabric and the skin. Long mesh underwear is worn under the British suit whereas a special undergarment is worn under the CWU 21/P suit. This undergarment consists of a liner having coarse mesh on one side and woven nylon on the side worn next to the skin. A vertical slide fastener at the front extends from the neck to the crotch.

The U.VIC jacket has a woven outer covering and a foamed neoprene lining. An extra flap of neoprene is tucked up inside the suit for normal wearing but when necessary it can be drawn around under the crotch and fastened to clips which are attached to the inside front pockets. This provides some protection for the groins which are known to be high heat loss areas. Furthermore a lightly coloured hood can be deployed from the collar of the jacket. A long vertical slide fastener at the front, when closed, draws the neoprene firmly around the trunk. Photographs of each of these garments are shown in Figure 2.

3. PHYSIOLOGICAL RESPONSE TO COLD STRESS

Immersion in cold water initially excites the thermoreceptors and via the hypothalamus causes intense stimulation of the sympathetic nervous system. The result is generalized peripheral vasoconstriction. This effect is assisted by:

(*a*) the slowing in metabolic rate of the skin with a reduction in the concentration of metabolites being produced, and

(*b*) an increase in blood viscosity.

The blood flow to the extremities is least at regional temperatures of 10–15°C. Skin temperatures below 10°C cause a sensation of pain and a protective phenomenon known as cold vasodilatation is induced.[1] Thus when the skin is exposed to extreme cold, that is, regional temperatures below about 10°C, cyclic variations can occur in the level of vasoconstriction. Intense vasoconstriction is followed by a period in which the arterioles open momentarily allowing a greater bloodflow. This has been called the Lewis Hunting Reaction and its effect on normal performance has been thoroughly investigated by Bensel and Lockhart.[2] Although this reaction is useful in preventing local tissue injury in conditions of extreme cold, it can increase the rate of heat loss from the body. Heat is conserved during exposure to cold environments by a countercurrent method of heat exchange. In the deeper tissues the arteries and veins lie side by side so that cold blood returning to the heart is warmed by blood flowing towards the extremities.

Large individual variations have been observed in the ability of men to tolerate cold stress. This ability has been associated with, amongst other things, body size and shape, and skinfold thickness.[3] For example, in one experiment Keatinge found that a subject with a mean skinfold thickness of 26·8 mm was able to stabilize his deep body temperature in water at 5°C whereas the most lean subject (skinfold thickness 6·5 mm) could only do so at temperatures greater than 20°C.

Keatinge also investigated the survival potential of exercising in cold water. Exercising increases the amount of heat produced by shivering but also raises tissue thermal conductivity as the blood supply to the muscles correspondingly increases. In Keatinge's experiment each unclothed subject was immersed in water at a temperature at which previous exposures had shown that he could just stabilize his deep body temperature. He was then told to exercise as hard as possible. In this way, exercise was always found to increase the rate at which deep body temperature fell. Consequently it would seem that exercising is hazardous when done in water at temperatures likely to threaten life. The main differences in responses between fat and thin men in this experiment were in the water temperatures at which deep body temperature could be stabilized. Subcutaneous fat acts as a passive insulator and the insulating air layer provided by

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1. Folkow, B., and Neil, E. *Circulation*. O.U.P.: London, 1971.
2. Bensel, Carolyn K., and Lockhart, J. M. Cold induced vasodilatation onset and manual performance in the cold. *Ergonomics* **17**, 717–30, 1974.
3. Keatinge, W. R. *Survival in cold water*. Blackwell Scientific Publications: London, 1969.

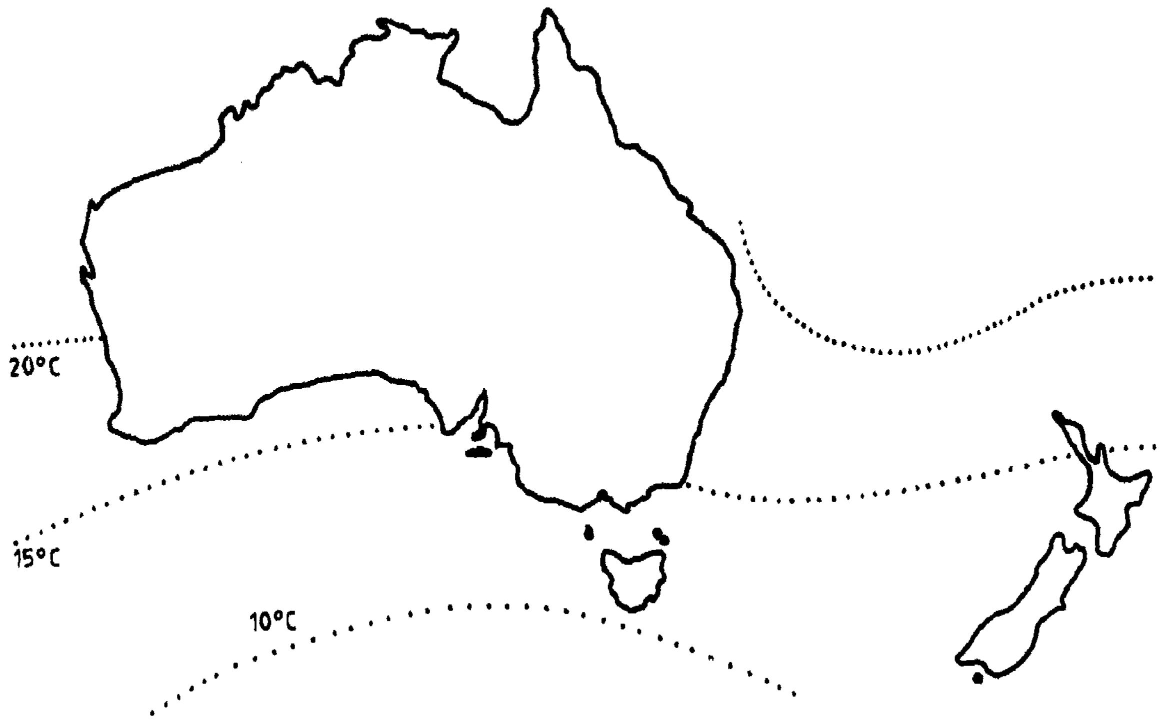
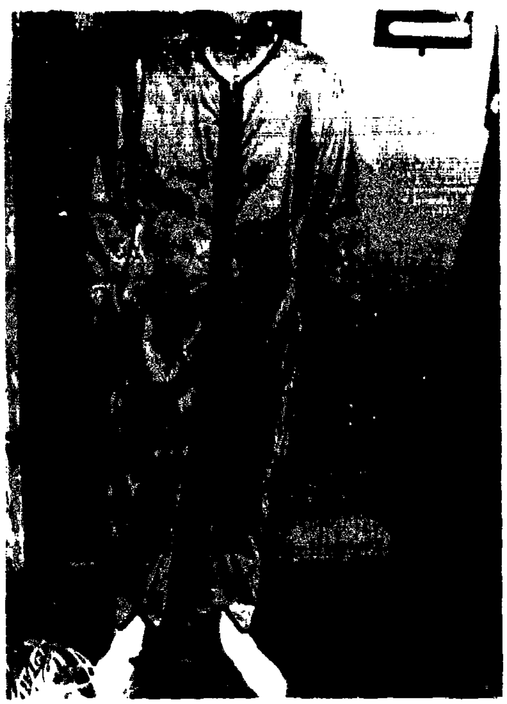


FIG.1. MEAN SEA SURFACE TEMPERATURES DURING WINTER MONTHS

a. British Mark 10 suit

b. United States CWU 21/P suit



c. United States suit undergarment

d. U. VIC thermofloat jacket

FIG. 2. THE THREE ANTI-EXPOSURE GARMENTS WHICH WERE EVALUATED AND ALSO THE UNDERGARMENT FOR THE CWU 21/P SUIT.

dry suits may be expected to act similarly. Consequently if the deep body temperature of an inactive subject does not stabilize while wearing the anti exposure suit, exercising will decrease his chances of survival.

Keatinge's conclusions are in marked contrast to those of Glaser[1] who asserted that exercising in cold water would be beneficial in maintaining body temperature. More recent work reported by Hayward *et al.*,[2] however, confirms Keatinge's claims. Hayward found that treading water significantly increased the rate of progress into hypothermia.

Infra-red thermography carried out on subjects who had been immersed in cold water showed that the areas of highest heat loss include the groins and lateral thorax.[3] Consequently it would be expected that one's chances of survival could be improved by adopting a posture in which the knees are pulled up into a foetal-like position and the upper arms are held firmly against the trunk. Hayward found that for subjects adopting such a posture, rectal temperature cooling rate decreased to 66% of its magnitude in the control.

The effect of the exposure to cold on the urine excretion rate is relevant in assessing the potential effectiveness of anti-exposure suits. The combined effects of peripheral vasoconstriction and hydrostatic pressure results in a redistribution of blood to the body core. This activates certain physiological mechanisms which are sensitive to fluid volume, causing greater fluid excretion. In addition, raised blood cortisol levels cause an increase in glomerular filtration rate while a lowering in blood temperature decreases the metabolic rate of the renal tubule cells and lowers the rate of reabsorption of the filtrate. Blair[4] has reported that lowering the renal temperature to 33°C causes the urine excretion rate to double from 1 to 2 ml/min. de Forest and Beckman[5] showed experimentally that a dramatic increase in urine excretion occurs even when subjects are immersed in water at 25°C. This led Beckman *et al.*[6] to state that immersion in water up to neck level produces a "profound and continuing diuresis of such urgency as to rapidly convert the so-called drysuit to a very wet one".

The effectiveness of the dry-suits depends on a layer of insulating air trapped between the skin and outer coverall. As water has about twenty times the thermal conductivity of air, a wet liner would greatly diminish the suit's insulating properties. Furthermore, other evaluations have shown these suits to be susceptible to leakage.

In 1974 the Royal Air Force evaluated several immersion coveralls including the standard Mark 10.[7] During trials lasting twenty-three minutes three of the suits allowed a water ingress of between 250 and 630 grams. Five hundred grams was the stated allowance and this was considered reasonable provided the wearer has access to a life raft. Leakage was found to occur mainly at the seams but it is apparent that leakage at the neck and wrist seals, aging porosity of the fabric, and of course the presence of any tears would add to the problem.

Performance evaluation[8] carried out on the Mark 10 suit by the Royal New Zealand Air Force also showed that the suits leaked — in this case from the relief tube. Furthermore the neck seals were found to be quite uncomfortable. A light summer flying suit was worn under the coverall in these trials and the rectal temperature of the subject was observed to fall by 0·5°C during one hour of the immersion. Only one subject was used and no information about his

1. Glaser, E. M. Immersion and survival in cold water. *Nature* **166**, 1068, 1950.
2. Hayward, J. S., Eckerson, J. D., and Collis, M. L. Effect of behavioural variables on cooling rate of man in cold water. *Journal of Applied Physiology* **38**, 1073–77, 1975.
3. Hayward, J. S., Collis, M., and Eckerson, J. D. Thermographic evaluation of relative heat loss areas of man during cold water immersion. *Aerospace Medicine* **44**, 708–11, 1973.
4. Blair, E. *Clinical hypothermia.* McGraw Hill: New York, 1964.
5. de Forest, R., and Beckman, E. L. Some contraindications to use of life jacket for survival. *Arch. of Env. Health* **58**, 56–64, 1962.
6. Beckman, E. L., Reeves, E., and Goldman, R. F. Current concepts and practices applicable to the control of body heat loss in aircrew subjected to water immersion. *Aerospace Medicine* **37**, 348–57, 1966.
7. Vere, R. P. Experimental immersion coveralls. Royal Air Force School of Combat Survival and Rescue — Trials Report No. SCS 18/74. November 1974.
8. Aviation Medicine Unit Clarke House Royal New Zealand Air Force Base Auckland. Test Report on MK 10 immersion suits TPA 623/51. November 1971.

skinfold thickness, height or mass was provided. As persons vary greatly from one to another in their tolerance to cold stress these results are of little value as reported.

Trials carried out in a cold water tank at the Royal Naval Medical School[1] in 1975 were to compare two dry suits and two wet suits including the U.VIC Thermofloat jacket. The temperature of the water was 10°C and the assessment was based on the comparison of body temperature and metabolic rates of five volunteer subjects four of whom were immersed once while wearing one of the suits. The fifth subject wore normal Naval working clothes as a control condition. The U.VIC jacket was rated third in order of acceptability. Unfortunately not much reliance can be placed on the conclusions that were drawn from this experiment. The percentage of body fat varied from 12·4 for the subject who wore the U.VIC jacket to 23·1 for the subject who acted as the control. This effect should have been counterbalanced by so designing the trials that each subject was used as his own control. However, it is interesting that by the end of one of these trials, one of the so-called dry suits contained approximately one litre of water in each leg. Furthermore this was the suit that was given the best performance rating.

Survival time for immersion in cold water has been defined by Hayward[14] as the time taken for the rectal temperature to reach 30°C. At this temperature loss of consciousness occurs and even if an optimum flotation posture is maintained—head clear of the water and inclined slightly backwards—enough water would quickly be taken in to cause drowning.

Previous studies have indicated that after a period of 15–30 minutes rectal temperature follows a linear cooling rate.[2,3,4] From these results Hayward[2] has derived an expression which predicts survival time as a function of water temperature.

Thus $t_s = 15 + \frac{7 \cdot 2}{0 \cdot 0785 - 0 \cdot 00347 T_W}$ where t_s is the survival time in minutes and T_W is the water temperature in degrees Celsius ($< 23°C$). This, however, involves extrapolating (by about 5°C) a cooling rate obtained over a drop in rectal temperature of about 2°C. For justification of this Hayward quoted the results of some of the infamous experiments carried out by Germans on concentration camp inmates at Dachau.[4] In these experiments clothed and unclothed subjects were immersed in water at a temperature of about 4·5°C. It was found that after an initial delay, rectal temperature fell at a constant rate to below 30°C. However, no information is provided about the physical condition of these subjects who furthermore had probably given up all hope of survival. These cooling curves are therefore of doubtful value in predicting survival times in cases of accidental immersion.

Survival time probably also depends on the time between the onset of the exposure and the last meal. Although the requirement of the superficial layers for oxygen would be greatly reduced, this is more than compensated by the demands of the muscles involved in shivering. Thus metabolic heat production rises markedly during the exposure. The resulting low blood glucose levels could cause dizziness and syncope. The conservation of liver glycogen for use by the brain would depend amongst other things on the response latency of the metabolic processes to raised blood cortisol levels. Although cortisol secretion would increase minutes after the onset of exposure, its effects on the breakdown of adipose tissue and the utilisation of amino acids for glucose synthesis would probably take two hours to occur. Consequently it would seem that initial low glycogen levels could sometimes result in an earlier loss of consciousness.

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1. Civil Aviation Authority, Airworthiness Division. Survival—the cold facts: Report on hypothermia evaluation of immersion suits carried out in cold water tank at Royal Naval Medical School, Seafield Park. November 1975.

2. Hayward, J. S., Eckerson, J. D., and Collis, M. L. Thermal balance and survival time prediction of man in cold water. *Can. J. Physiol. Pharmacol.* **53**, 21–32, 1975.

3. O'Hanlon, J. F., and Horvath, S. M. Changing physiological relationships in men under acute cold stress. *Can. J. Physiol. Pharmacol.* **48**, 1–10, 1969.

4. Alexander, L. The treatment of shock from prolonged exposure to cold, especially in water. Combined Intelligence Objectives Sub-Committee, Item No. 24, Office of the Publication Board, Department of Commerce, Washington, D.C. Report No. 250, 1946.

In an experiment to assess the long term effects of immersion in cold water reported by Beckman *et al.*[1] some subjects developed blood glucose levels of 50–60 mg per cent and experienced a typical hypoglycaemic episode. Some of the subjects, after being given some coffee and sugar, were able to continue the immersion for another one or two hours. It was concluded that this was the result of an increase in metabolism caused by the "specific dynamic action of food". In this experiment the subjects were nude but the water temperature was 24°C—an important fact to consider when assessing the likely outcome of immersion in water at 7°C.

To summarize: Although at first sight the dry suits appear to provide excellent protection, leakage and cold diuresis may seriously detract from their performance. The U.VIC jacket insulates the high heat loss areas, is less susceptible to damage, and is unaffected by cold diuresis. It does not, however, protect the legs and this may prove important if cold vasodilation occurs or if painful muscle cramps result.

From previous experimental work survival times cannot be predicted accurately enough to be of much value. They depend on many factors besides the type of clothing worn and the temperature of the water. Consequently from the trials reported here only comparative performance assessments were made.

4. LABORATORY TRIALS

4.1 Subjects

Eleven medically fit male volunteer RAAF personnel participated in the evaluation but only eight of them completed all three trials in the tank and four of these also completed four trials at sea. Four of the subjects were trainee pilots, one was an air traffic controller, and the other three were from the Air Force trades. Height, mass, age and skinfold thickness measured at five sites were recorded for each subject and are given in Appendix 1.

4.2 Experimental Equipment

A general layout of the main equipment is shown in Figure 3. A tubular steel framed chair with a canvas seat and roped back was clamped to the inside of a stainless steel tank. The tank was approximately 1·6 m in diameter and 1 m deep. A vertical adjustment was provided for this chair so that the level of immersion could be maintained constant for all of the trials. The tank was filled with water to within about 60 mm of the top rim and a cooling coil situated just behind the chair and about 0·7 m below the surface of the water maintained the water temperature close to 7°C. Continuous circulation of the water around the subject was provided by an electrically driven agitator. The agitator propeller was three bladed, approximately 110 mm in diameter and immersed to a depth of 0·9 m on a vertical shaft which rotated at 133 rev/s. This provided circulation sufficiently turbulent to prevent the development of any stable stagnation points.

The refrigeration unit operated by cooling a water ethanol mixture in a heat exchanger. This fluid was circulated through the cooling coil in the tank. Coarse control of the water temperature was provided by a thermostat which switched the refrigerator on and off when necessary. Furthermore, by monitoring the temperature with a total-immersion glass thermometer and adjusting the amount of cooling fluid circulating accordingly, it proved possible to keep the temperature of the water within ±0·2°C of 7°C.

A Beckman Offner Type S Dynagraph chart recorder with type 481B preamplifiers was used to record the ECG on one channel and EMG on another two. Only the integrated EMG signal was recorded and for this the standard Beckman EMG couplers were used. Silver–silver chloride electrodes were used with Electrogel electrode paste for both the ECG and EMG recordings. Readings from temperature measuring thermistors were obtained by switching them in turn across the arm of a wheatstone bridge and finding the null with a sensitive galvanometer. Details of the bridge and electrode positions are given in Appendix 2.

Two types of thermistors were used: one type, STC M53 has a glass bead on a metal disc

1. Beckman, E. L., Reeves, E., and Goldman, R. F. Current concepts and practices applicable to the control of body heat loss in aircrew subjected to water immersion. *Aerospace Medicine* 37, 348–57, 1966.

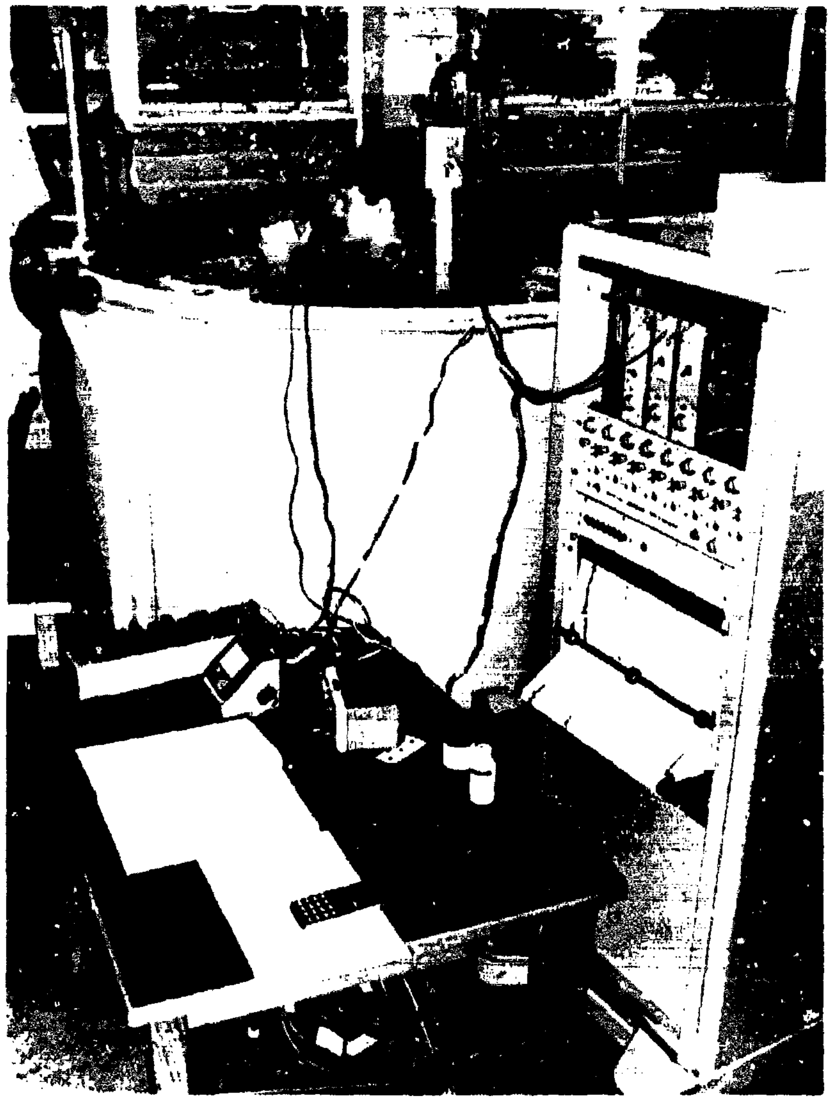

FIG. 3. A VIEW OF THE EQUIPMENT USED FOR THE LABORATORY EVALUATION.

and is suitable for surface temperature measurement; the other, Yellow Springs No. 401 consists of a small round bulb on the end of a long lead and was used for measuring rectal temperature, and the temperature of the water inside the UVIC suit. Calibration curves for all of the five STC thermistors were obtained and from these, two parameters for each thermistor characteristic were derived and used in conjunction with a small programmed calculator to obtain the corresponding temperatures. The Yellow Springs thermistors were well matched to each other and one set of parameters was used as a calibration for all of them.

Details of these are also given in Appendix 2.

4.3 Procedure

For approximately forty-five minutes before the trial, the subject sat, almost naked, in a room maintained at a dry bulb temperature of 20–22°C while electrodes and thermistors were placed in position. He was then assisted in putting on the anti-exposure suit, led into the next room, and asked to sit in a chair next to the tank while the leads were being connected and an initial set of readings recorded. The subject then sat in a tubular steel chair which was positioned near the centre of the tank. Care was taken to ensure that for each trial subjects sat in the same position, that is, with shoulders and neck clear of the water and with the elbows resting on the chair framework in such a way that the hands and part of the forearms were also clear of the water. This approximates the desired flotation level in open water although other aspects of the trials were clearly different from those likely to prevail at sea. While seated in the tank the subject had approximately neutral buoyancy and consequently barely touched the seat base or back. This enabled the water to flow around the entire immersed part of the suit.

Readings of rectal temperature were recorded every five minutes and a complete set of skin and rectal temperatures was recorded at intervals of ten minutes. The ECG (lead II) and EMGs were recorded continuously at a chart paper speed of 1 mm/s except for several seconds directly following each complete set of readings which were recorded at intervals of 10 minutes. At these times the paper speed was set to 10 mm/s so that the wave forms of about 10 complete QRS complexes would be examined. Furthermore, signals from a complete set of ECG leads were taken just before the subject entered the tank and again just before the trial ended.

Each time a rectal temperature was obtained, it was immediately plotted on a graph of rectal temperature versus time and, frequently during the trial, this graph was shown to the subject. As little conscious control can be asserted over autonomic function it was considered that giving the subject knowledge of results would not invalidate the conclusions. The purpose was rather to interest the subject in what was happening and thereby to encourage him to stay in the tank for as long as possible.

At the end of the trial the subject was driven several hundred metres to the Air Force base hospital for rewarming under a hot shower. Each trial was terminated:

(*a*) when the deep body temperature had fallen to 35°C; or

(*b*) on the subject's request; or

(*c*) where, in the opinion of either experimenter, the subject was experiencing an unacceptable level of discomfort

4.4 Experimental Design

Eight subjects wore each of three clothing combinations once. The three combinations comprised:

(*a*) United States CWU 21/P coverall, standard US undergarment, cotton underpants, woollen socks, and service boots;

(*b*) Royal Air Force Mark 10 coverall, standard US undergarment, cotton underpants, woollen socks and service boots;

(*c*) UVIC Thermofloat jacket, cotton flying suit, cotton underpants, woollen socks and service boots.

For logistical reasons it was not possible to begin all of the trials at exactly the same time each day but they all took place during the late morning and early afternoon. This minimised differential effects on deep body temperature caused by the usual diurnal variation. Keele and Neil[1]

1. Keele, C. A., and Neil, E. *Samson Wright's Applied Physiology*. Twelfth Edition. O.U.P. London, 1971.

stated that a diurnal variation in temperature of 1·5 C can occur in any normal person. The deep body temperature may increase by as much as 0·5 C in two hours at certain times of the day. Usually deep body temperature falls to its lowest level in the early hours of the morning and rises to a peak in the evening. These cycles vary slightly in phase from one day to the next and are a source of extraneous uncontrolled variation in experiments which require the monitoring of rectal temperature. Furthermore, as the present trials were conducted during the phase of normal temperature rise, the cooling rates observed would only apply to this time of the day. As the purpose was mainly to obtain data on the comparative rather than the absolute performance of the suits and as the effect was practically the same for all three conditions, the diurnal changes could not invalidate the conclusions.

Unfortunately, it was impracticable to control the food intake of the subject prior to each exposure. However, it is certain that no subject commenced a trial within two hours of the previous meal.

Subjects were interviewed informally about what they had eaten for breakfast and it was found that they tended to be consistent in their eating habits. Some did not eat breakfast at all, whereas others had a light breakfast regularly comprising, for example, toast and coffee. This consistency of eating habits and the fact that each subject was used as his own control, makes it unlikely that variations in blood glucose levels would have introduced any important bias into each subject's cooling rates on the successive exposures. Five thermistors were used to monitor skin temperature and thereby give an indication of the level of vasoconstriction at five sites of particular relevance:

(*a*) on the left lateral neck – on the midpoint of the sterno-mastoid muscle;
(*b*) on the left axilla – at the level of the nipple;
(*c*) on the back – in the midline at the lower limit of the scapulae;
(*d*) on the left knee – over the head of the fibula;
(*e*) on the left forearm – on the body of the brachio-radialis muscle 40–50 mm distal to the biceps tendon.

The neck and axillae are similar in that both are areas of high heat loss: where they differ is in the protection offered by the suits. The former is partly covered by the suits but the latter are well inside. The back was chosen as representative of a protected low heat loss area.

Evidence has been reported[1] to suggest that the degree of vasoconstriction in the unprotected extremities is such that comparatively little heat is lost from these areas. Consequently one would expect temperatures recorded from the leg of a subject wearing the U.VIC jacket to approach the temperature of the water. It follows that if this premise is correct there may be little point in supplementing the body's own defence mechanism with extra unnecessary protection. The knee location was chosen to represent the extremities.

All of the suits provided protection for the arms and since arm muscles are important for the kind of manual dexterity required, for example, to enter a life raft or attach a winch-hook it was considered important to measure skin temperature at the forearm.

In addition, EMGs were recorded from the sternomastoid and biceps muscles. It was considered that the indication of shivering intensity so provided would be useful when trying to rationalise the rates of change of deep body temperature and other experimental results. It has been indicated, for example, that EMGs recorded from the neck correlate well with metabolic rate.[2] In this evaluation three electrodes were used at both sites – two for the differential signal and one to earth a point on the muscle nearby.

4.5 Results

It was apparent that despite efforts to minimize sources of extraneous variation, large variations did occur. Subjects differed in their ability to withstand fatigue induced by shivering and also in their abilities to adapt physiologically to the cold environment. Consequently some subjects needed to be removed from the tank long before their deep body temperature would have reached 35 C whereas others cooled to this temperature very quickly. Figures 4, 5, and 6

1. Hayward, J. S., Collis, M. L., and Eckerson, J. D. Thermographic evaluation of relative heat loss areas of man during cold water immersion. *Aerospace Medicine* **44**, 708–11, 1966.
2. Hayward J. S. Personal communication, 1976.

show the rectal temperature cooling curves corresponding respectively to the British Mark 10 United States CWU 21/P, and the Canadian U.VIC Thermofloat anti-exposure garments.

Each of the three exposures of one subject had to be terminated within 1·2 hours owing to a sudden fall in rectal temperature to 35°C. At the other extreme, another subject on one trial (Figure 6) stayed in the tank for four hours without his core temperature reaching 35°C. After 2·76 hours his temperature had fallen to 35·9°C but then rose to 36·5°C during the next 1·25 hours. The immersion was then terminated at the subject's request.

Thus exposure duration and temperature drop varied from trial to trial and since these are highly interdependent, neither taken separately should be used as a criterion for comparing the suits. Consequently it was necessary to combine these parameters in some reasonable manner. Here this has been done by dividing the decrease in rectal temperature in degrees Celsius for the trial (ΔT_r) by the exposure duration in hours (Δt). However, it is stressed that this overall cooling rate should not be used to predict survival times. It is used here as a criterion because it has some physical significance and can be obtained for each trial. However, the highly non-linear nature of the rectal temperature versus time relationship precludes the interpretation of this as a cooling rate on a minute by minute basis.

The summarised rectal temperature data are given in Table 1. A Friedman 2-way Analysis of Variance by Ranks[1] on the $\Delta T_r/\Delta t$ values (where ΔT_r is the temperature drop in degrees Celsius and Δt is the exposure duration in hours) showed that the differences between the three clothing combinations were not significant ($\chi_r^2 = 1{\cdot}75$, $p < 0{\cdot}53$). Consequently the differences in insulating properties of the three anti-exposure suits were too small to be detected in this experiment using $\Delta T_r/\Delta t$ as the criterion.

In Figure 7 the rectal temperature means are shown for the initial exposure period. These have been translated to begin at 37·0°C. The apparent difference of approximately 0·3°C between the mean for the U.VIC jacket and those of the two dry suits after 20–30 minutes, may be consistent with an initial penalty inherent in the wet-suit design of the jacket. The mean cooling rates for all three suits appear to be similar thereafter.

The increase in heart rate during the exposure was also used for comparing the adequacy of the suits since this, it was considered, would reflect the level of stress experienced by the subject. An initial fall in heart rate at the beginning of a sudden exposure to cold stress is to be expected. Redistribution of blood to the core would increase venous return to the heart and hence cardiac output. This would cause a temporary rise in blood pressure which would be adjusted back to normal by a reduction in heart rate. However, with the onset of violent shivering overall metabolic rate increases and to supply the muscle with its metabolic needs, heart rate could be expected to increase again. Table 2 lists the observed heart rate increases (ΔHR) and the corresponding exposure durations in hours. A comparison of the $\Delta HR/\Delta t$ data for the three clothing combinations showed the differences not to be significant ($\chi_r^2 = 2{\cdot}25$, $p < 0{\cdot}36$). It is interesting and seems anomalous that the subject who was able to stabilize his rectal temperature in the U.VIC trial experienced a drop in heart rate in all three tank trials.

Reference to Figures 4, 5, and 6 shows that in the majority of immersions a three-part core cooling pattern occurred. The first part corresponds to the constancy of deep body temperature which persists for 20–30 minutes after the onset of the exposure. This is followed by a characteristic linear cooling period. The third part in which cooling rate decreases, in some cases quite substantially, has not been reported before. Whether all exposures, if continued, would have progressed into the third phase is unclear. One subject agreed to stay in the tank somewhat longer to investigate this phenomenon. His core temperature fell to below 35°C during a typically linear second phase. At 34·5°C his cooling rate suddenly decreased almost to zero and this temperature was maintained for thirty minutes until the exposure was terminated at the request of the subject.

This three phase cooling pattern was observed in exposures of longer than one hour, and its presence invalidates simple extrapolation of the more rapid second phase of cooling to determine either absolute or relative survival times. It also indicates the importance of using prolonged exposures in this kind of study. Further investigation of this effect would appear to be warranted. The final reduction in cooling rate during exposures under these conditions can be rationalized as follows. When challenged by a potentially threatening situation such as an immersion in

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1. Siegel, S. *Nonparametric statistics for the behavioural sciences.* McGraw Hill: New York, 1956.

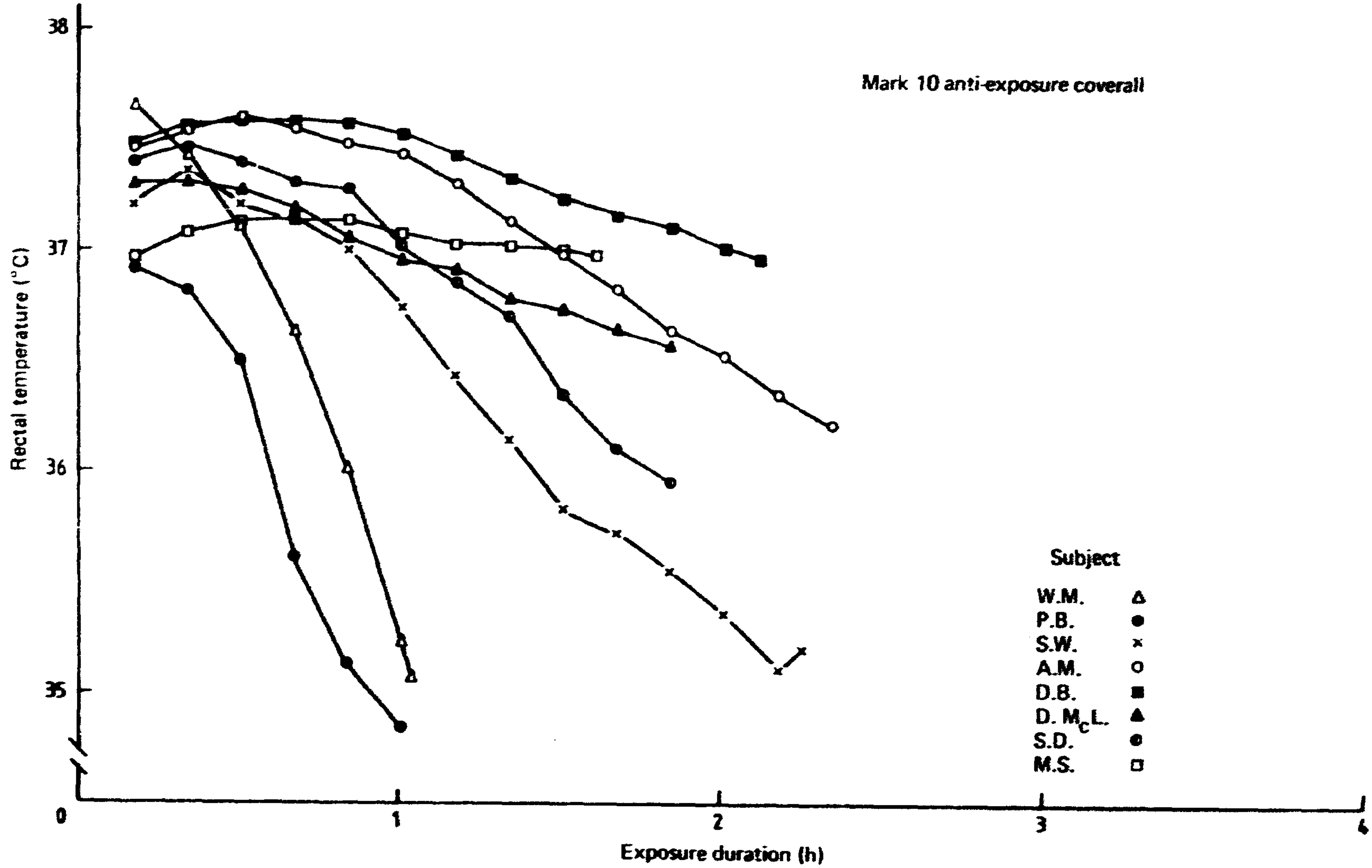


FIG. 4. GRAPHS SHOWING THE FALL IN RECTAL TEMPERATURE FOR EACH OF EIGHT SUBJECTS DURING IMMERSION IN WATER AT 7°C WHILE WEARING THE MARK 10 ANTI-EXPOSURE COVERALL.

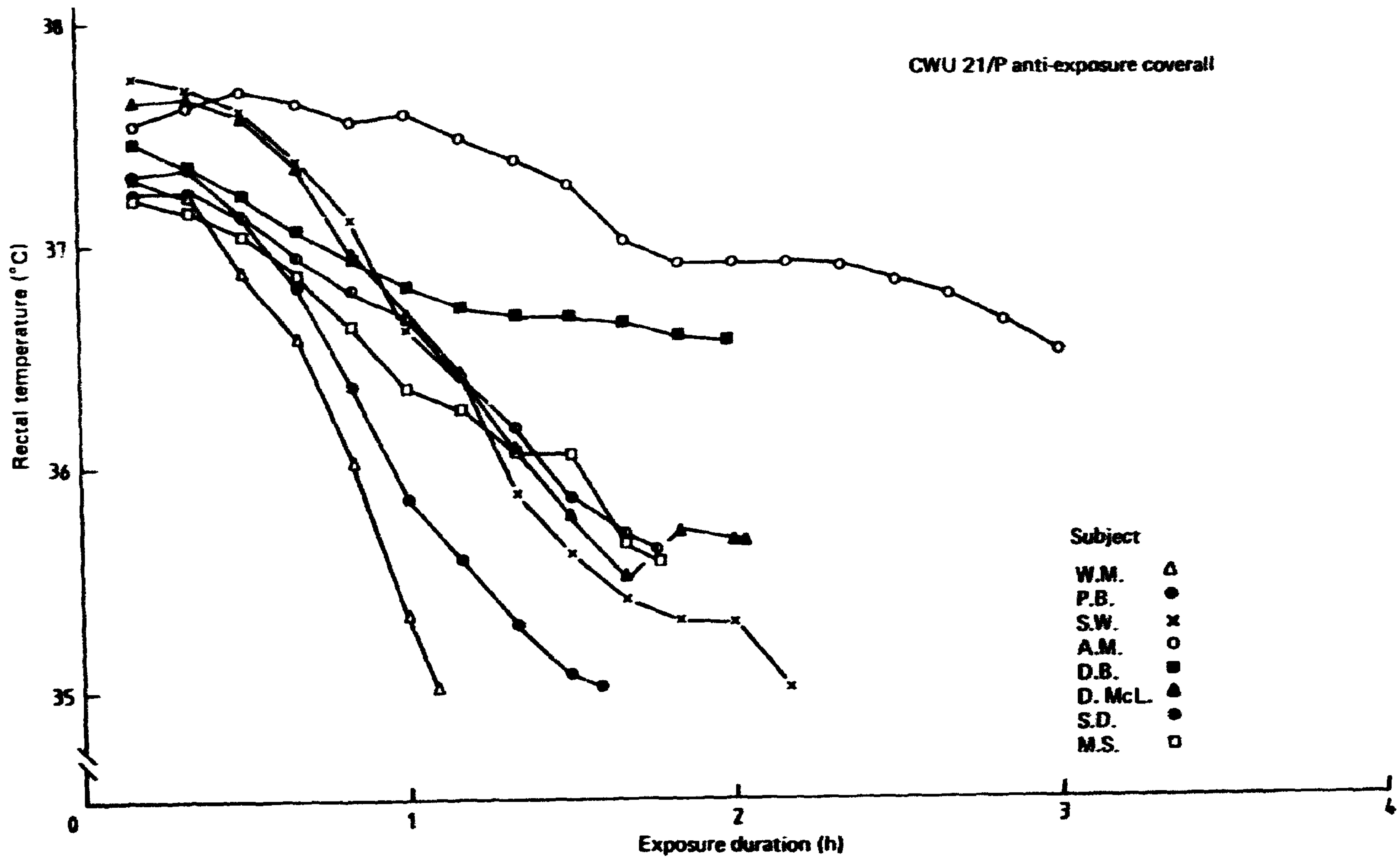


FIG. 5. GRAPHS SHOWING THE FALL IN RECTAL TEMPERATURE FOR EACH OF EIGHT SUBJECTS DURING IMMERSION IN WATER AT 7°C WHILE WEARING THE CWU 21/P ANTI-EXPOSURE COVERALL.

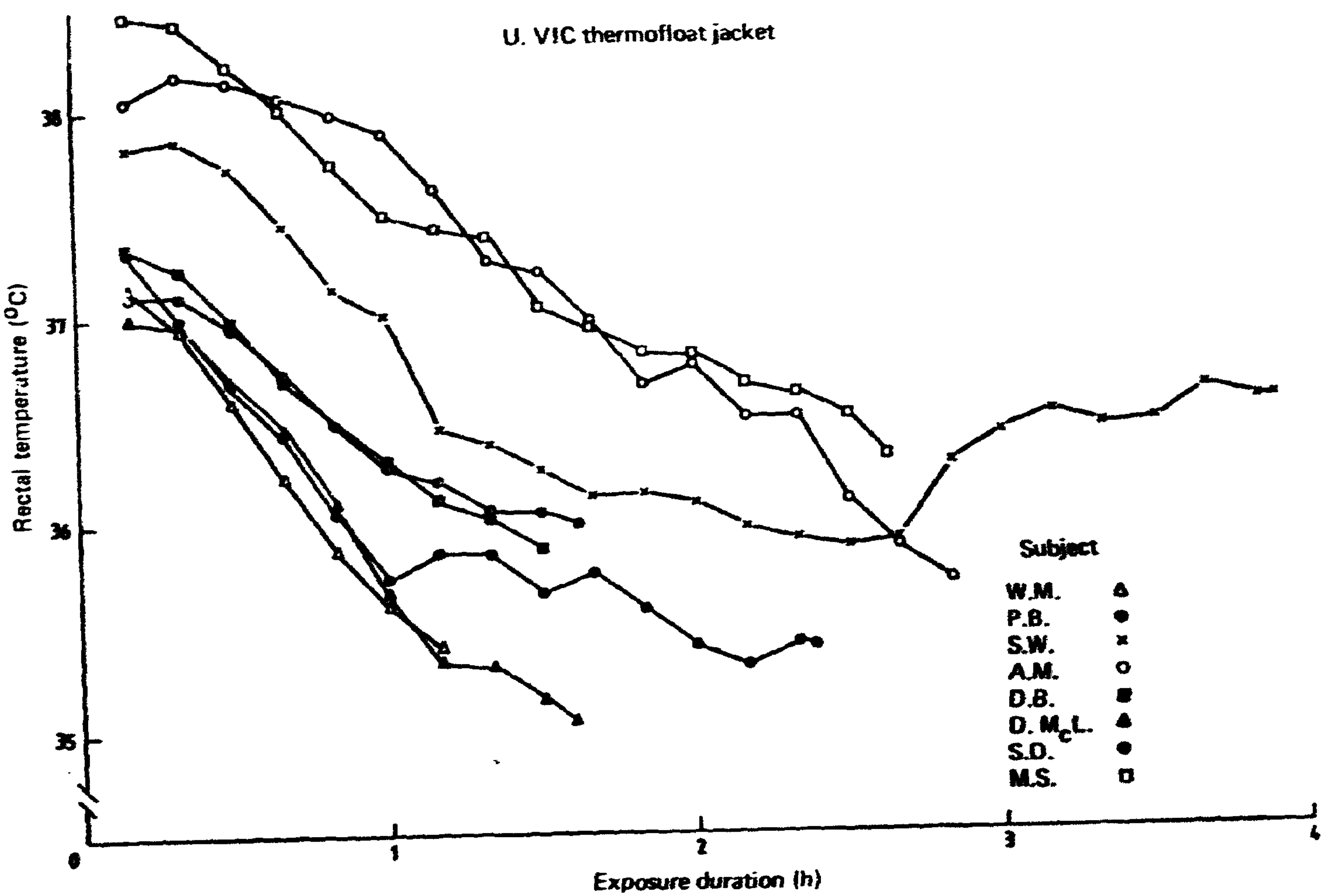


FIG. 6. GRAPHS SHOWING THE FALL IN RECTAL TEMPERATURE FOR EACH OF EIGHT SUBJECTS DURING IMMERSION IN WATER AT 7°C WHILE WEARING THE U. VIC THERMOFLOAT JACKET.

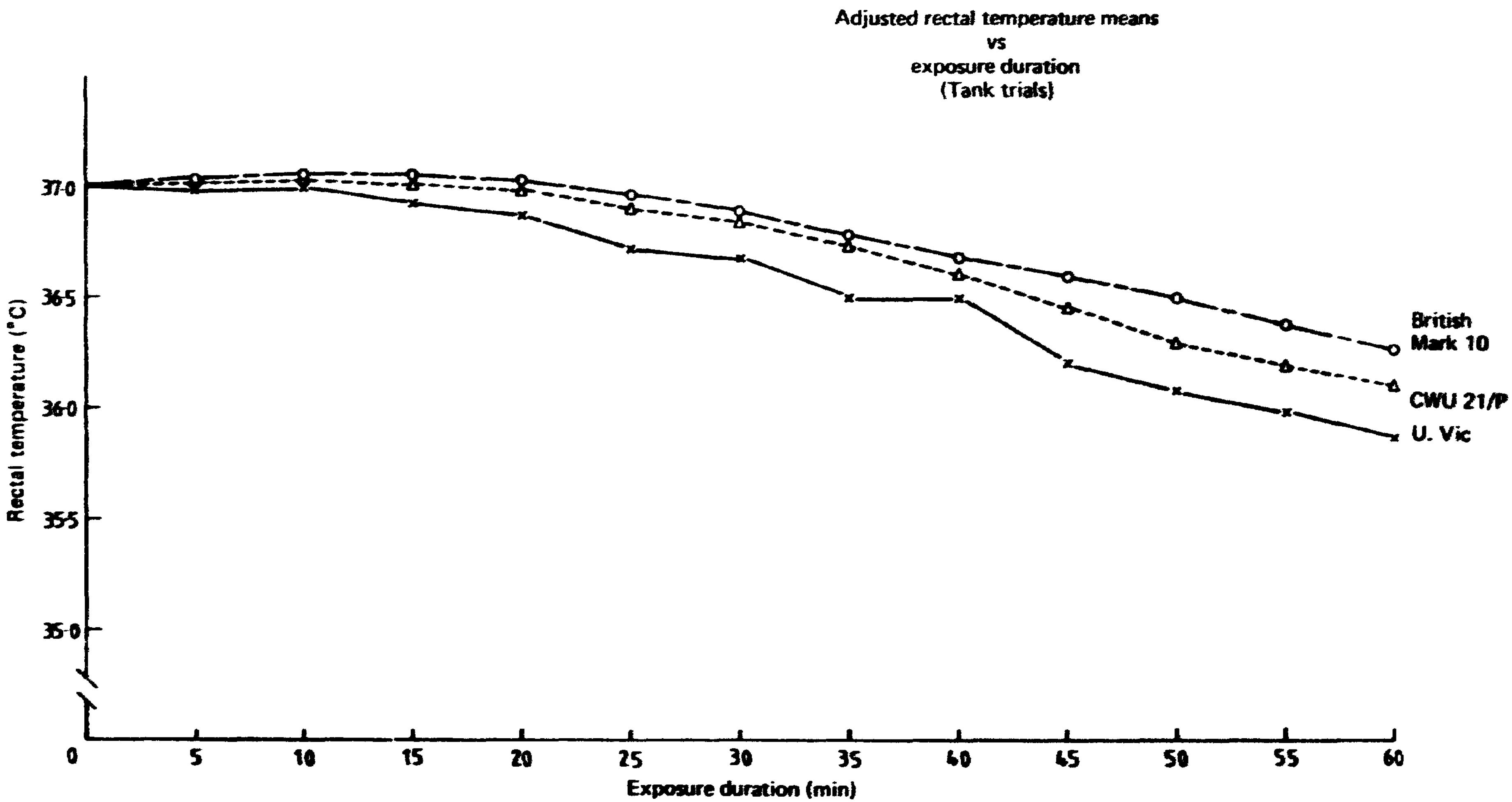


FIG. 7. GRAPHS SHOWING THE RECTAL TEMPERATURE MEANS FOR SUBJECTS WEARING EACH OF THE ANTI-EXPOSURE GARMENTS DURING THE TANK TRIALS. THE GRAPHS WERE SLIGHTLY ADJUSTED VERTICALLY SO AS TO BEGIN AT 37°C.

cold water the body's defences might not be able to maintain the core temperature at its normal level. Cooling then occurs until the hypothalamic inputs are so intense as to result in a metabolic heat production which is high enough to stabilize core temperature at a level which is lower than normal. Whether or not this would occur in individual cases would depend on total insulation, effectiveness of the metabolic heat production, and the temperature difference between the water and body core. At extremely low temperatures, however, active insulation mechanisms may be disrupted by cold vasodilatation.

A similar analysis was carried out on the skin temperature data. Each observation on which the analysis was based was obtained by subtracting the final temperature from that recorded just before the subject entered the tank and dividing by the exposure duration in hours. Only the differences based on back temperature were significant. Table 3 contains these results. The mean $(\Delta T_b/\Delta t)$s corresponding to the U.VIC, US, and UK garments were 2·20, 6·85 and 7·03 respectively. Consequently when the U.VIC suit was worn the temperature drop/unit time for the skin on the subject's back was less than that occurring when either the British Mk 10 or the CWU 21/P suits were worn. A Randomisation test showed this difference to be significant at the $p < 0{\cdot}01$ level. The mean temperature of the water measured inside the front of the U.VIC jacket was 11·33°C, only a little over 4°C above ambient. These temperature means are on trials of eight subjects, two of whom are different from those in all of the preceding analyses.

No cyclic patterns of skin temperature variation were observed for any of the skin thermistors in these trials indicating that the Lewis Hunting Reaction was not detected at the locations and time intervals sampled. Moreover, there was no evidence of cold vasodilatation in any of these trials.

Both the "dry" suits leaked in several of the trials. The leakage was not from the neck and wrists as these were kept out of the water. From the shape of the wet patch on the inner garment it was evident that leakage had occurred at the ends of the slide fasteners despite care on the part of the experimenters to secure them properly. Furthermore, it was found that the soft rubber neck seals and boots were particularly susceptible to tearing. Several repairs had to be made during the experiment.

Most of the exposures were fairly short in duration but as expected, some subjects needed to urinate during the trial. Consequently, after almost every trial, the inside of the dry suit had been wet one way or another.

5. SEA TRIALS

5.1 Introduction

HMAS *Ardent*, a naval patrol boat, was made available as an experimental platform on four successive days. Hot showers were available so that the subjects could be rapidly rewarmed and a small crane on deck was used to winch them back on-board after each exposure. Four of the subjects who participated in the tank trials also took part in these trials. Their masses, skinfold thickness, and heights are given in Appendix 1.

The trials were carried out in Port Phillip Bay and the conditions varied from overcast with some wind and mildly choppy seas to bright sunlight and flat calm water. During the experiment the temperature of the water remained fairly constant at about 10·5°C.

Only rectal temperature and the temperature inside the U.VIC jacket were monitored precisely in this part of the evaluation. A medical officer in a dinghy maintained a close surveillance of the subjects.

5.2 Experimental Design

Four clothing combinations were used and each subject wore a different one of these four on each of the four days of the sea trials. The four clothing combinations comprised the following garments:

(*a*) Royal Air Force Mark 10 suit, US undergarment, cotton underpants, woollen socks and flying boots;

(*b*) United States CWU 21/P coverall, US undergarment, cotton underpants, woollen socks and flying boots;

(c) Canadian UVIC jacket, cotton underpants, long mesh underwear, Australian cotton flying suit, woollen socks and flying boots,

(d) normal flying clothing comprising flying jacket, cotton underpants, RAAF cotton flying suit, long mesh underwear, woollen socks and flying boots.

In each case a life preserver was also worn. The Yellow Springs 401 thermistor leads were lengthened for the sea trials and temperatures were taken every 5 minutes during immersion. As in the tank evaluation, each reading was obtained by switching the thermistor into one arm of a wheatstone bridge which was then balanced by adjusting the settings on a decade box.

5.3 Procedure

On the first day all four subjects were in the water at the same time but it was found too difficult to maintain adequate surveillance of all four simultaneously, so on subsequent days they were tested two at a time.

After dressing in the suits below deck the subjects stood on deck while the life preservers were put on and the thermistors connected to the wheatstone bridge. They then entered the water by climbing down some foot holds at the stern of the boat and floated just sufficiently far from the side to be exposed to the wind and waves.

The criteria used for ending the trials were the same as those used for the tank trials. At the end of the trial the subject was hoisted back on-board and immediately given a hot shower.

5.4 Results

Difficulties with equipment on the first day prevented a complete set of data from being obtained. However, by interpolating between points it was possible to plot graphs of rectal temperature versus time for each subject.

Graphs of the mean rectal temperature versus time characteristic are given in Figure 8. Each point is the mean of four observations adjusted so that each graph starts at 37°C. It can be seen that the overall cooling rates corresponding to the three anti-exposure suits appear to be similar to one another but substantially lower than those of the control conditions, that is, the condition in which flying gear only was worn. These differences, when considered alone, are not statistically significant (see Table 4). But they are in agreement with those of the tank trials in so far as the similarity of protection afforded by the three suits is concerned.

The mean temperature of the water inside the UVIC jacket was 17·64°C—about 7°C above the temperature of the water. It is considered that this improvement in temperature differential across the jacket as compared with the tank trials may result from two causes. First, the sea trials required the wearing of a life preserver, the straps of which probably caused the jacket to wrap more tightly around the trunk. Second, in the sea the subjects tended to adopt a more extended posture. Consequently, with less bending at the waist, there would have been less tendency for the suit to bulge in the front and allow the circulation of water. Important differences were observed between suits in flotation position. The dry suits permitted only a horizontal posture to be maintained whereas the UVIC suit provided buoyancy only above the groin. This enabled the subjects to maintain a more upright posture in the water.

Only the first day of the bay trials provided conditions which were substantially different from those of the tank trials. The sky was overcast, there was some wind and the sea was slightly choppy though calm enough for a small dinghy to be used for surveillance of the subjects. However, a subjective assessment of the subjects' responses made by the investigators and the subjects on this day gives some insight into performance limitations of the survival equipment.

As each small wave passed, the stole of the life preserver rolled up around the side of the subject's head instead of providing the buoyancy necessary to keep the head clear of the water. This meant that the small chop which was superimposed on the waves caused constant splashing of the face—a high heat loss area. Furthermore, windchill accelerated the cooling of the face and hands which were unprotected. All four of the subjects needed to be removed from the water within one hour of entering it and all claimed that the conditions were much more severe than those applying to the tank trials. Within the first 50 minutes the rectal temperatures of two of the subjects—one wearing just normal flying gear and the other wearing the US CWU 21/P suit—had fallen to a point close to 35°C. Furthermore, the subjects were in considerable discomfort when first taken from the water.

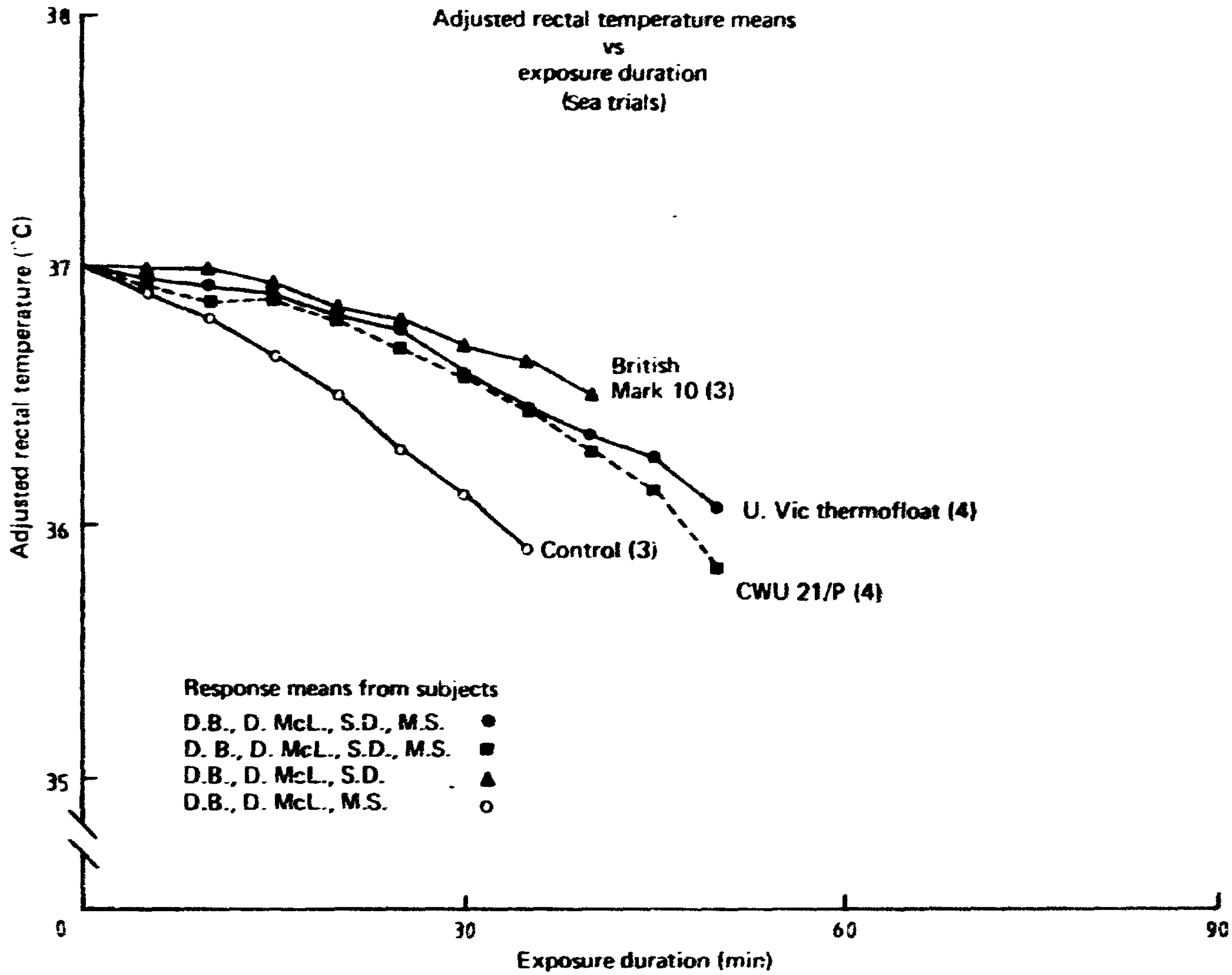


FIG. 8. GRAPHS SHOWING THE RECTAL TEMPERATURE MEANS FOR SUBJECTS WEARING EACH OF THE ANTI-EXPOSURE GARMENTS DURING THE SEA TRIALS. THE GRAPHS WERE SLIGHTLY ADJUSTED VERTICALLY SO AS TO BEGIN AT 37°C.

These observations emphasize that absolute performance (survival times) under operational conditions cannot be estimated from laboratory results or even from those of sea trials in calm conditions. It was also apparent that none of the three suits provide adequate protection in their present form. Protection should be provided for the head and for the hands.

6. CONCLUSIONS

Within the variability of this experiment the thermal insulating properties of the exposure suits were found to be comparable. However, in several other respects the U.VIC jacket was found to be superior to the two dry suits and to have the greatest potential for further development.

(*a*) The insulating properties of the U.VIC jacket are less affected by damage than are those of the two dry suits. Even if the neoprene lining is holed in several places it can still be expected to offer substantial protection provided the lining is fitted firmly around the trunk. However, even a small leak in a dry suit would drastically reduce its effectiveness.

(*b*) Cold stress results in a greater urine excretion rate. The thermal insulation of the U.VIC jacket will be unaffected when the wearer needs to urinate, whereas that of the dry suit would probably be markedly reduced.

(*c*) The design of the dry suits renders them susceptible to damage. During the trials on several occasions it was necessary to repair tears in the soft rubber neck seal and in the boots. No apparent damage was sustained by the U.VIC jacket.

(*d*) A fairly upright flotation position is possible when wearing the U.VIC jacket. Subjects wearing the dry suits float in a horizontal position on their backs and have less control of their movement.

(*e*) The dry suits are more difficult to put on and take off than is the U.VIC jacket.

7. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

The U.VIC jacket provides about 75 N buoyancy whereas the minimum specified in the ASCC standard is 156 N. Consequently a separate life preserver must also be worn. This combined outfit is fairly heavy and bulky regardless of whether the U.VIC jacket or one of the dry suits are used. However, it is possible to enhance the buoyancy of the U.VIC jacket by providing an inflatable bladder in its upper lining. Pockets for flares, transmitter, flashlight and other survival equipment could also be incorporated.

The most serious deficiency in the original design of the jacket was the poor fit around the trunk. This allowed some circulation of the water around high heat loss areas. If the jacket were made tighter at the waist or if straps at the side could be tightened to give the same effect, this deficiency could be easily overcome.

Even in this modified form however, the U.VIC jacket would probably be heavier and more bulky than necessary. If insulation could be provided by means other than neoprene, it may be possible to alleviate these problems. For example, depending on the availability of a suitable material, a jacket could be made similar in shape to the U.VIC jacket but with the neoprene rubber replaced by an inflatable lining divided into several air cells. When inflated, the lining would displace much of the water from around the trunk and provide sufficient buoyancy to preclude the necessity for a separate life preserver. This modified jacket would provide excellent thermal insulation when inflated, but still be lighter and less bulky for normal wear.

TABLE 1

$\Delta T_r/\Delta t$ (rectal temperature drop in °C/interval of time of measurement in hours) for the tank trials

Treatment / Subject	U.VIC jacket			US CWU 21/P Suit			British Mark 10 Suit		
Subject	ΔT_r	Δt	$\Delta T_r/\Delta t$	ΔT_r	Δt	$\Delta T_r/\Delta t$	ΔT_r	Δt	$\Delta T_r/\Delta t$
W.M.	1·80	1·05	1·71	2·90	1·08	2·68	2·87	1·08	2·65
P.B.	2·09	2·30	0·91	2·34	1·75	1·34	2·50	1·58	1·58
A.M.	2·33	2·70	0·86	0·98	3·07	0·32	1·23	2·33	0·53
S.W.	1·17	3·92	0·30	2·74	2·25	1·22	1·99	2·17	0·92
M.S.	2·40	2·67	0·90	1·75	1·83	0·95	−0·04	1·58	−0·03
S.D.	1·03	1·58	0·65	1·65	1·92	0·86	1·29	1·75	0·74
D.McL.	2·11	1·55	1·36	1·99	2·00	1·00	0·76	1·83	0·41
D.B.	1·23	2·33	0·53	0·87	1·92	0·45	0·50	2·17	0·23

TABLE 2

$\Delta HR/\Delta t$ (rise in heart rate in beats per minute/interval of time of measurement in hours) for the tank trials

Treatment / Subject	U.VIC Jacket			US CWU 21/P Suit			British Mark 10 Suit		
Subject	ΔHR	Δt	$\Delta HR/\Delta t$	ΔHR	Δt	$\Delta HR/\Delta t$	ΔHR	Δt	$\Delta HR/\Delta t$
W.M.	13	1·08	12·04	1	1·17	0·85	13	0·95	13·68
P.B.	8	1·55	5·16	6	1·60	3·75	19	1·50	12·67
A.M.	5	2·73	1·83	7	2·95	2·37	16	2·32	6·90
S.W.	21	3·75	5·32	30	1·95	15·38	−16	2·07	−7·73
M.S.	22	2·53	8·70	27	1·73	15·61	3	1·48	2·03
S.D.	42	1·48	28·38	8	1·75	4·57	−7	1·68	−2·96
D.McL.	10	1·47	6·80	18	1·85	9·73	21	1·80	11·67
D.B.	6	1·43	4·20	15	1·85	8·11	10	2·17	4·61

TABLE 3

$\Delta T_b/\Delta t$ (drop in back skin temperature in °C/hours of exposure for the tank trials)

Treatment / Subjects	U.VIC Jacket ΔT_b	U.VIC Jacket Δt	U.VIC Jacket $\Delta T_b/\Delta t$	US CWU 21/P Suit ΔT_b	US CWU 21/P Suit Δt	US CWU 21/P Suit $\Delta T_b/\Delta t$	British Mark 10 Suit ΔT_b	British Mark 10 Suit Δt	British Mark 10 Suit $\Delta T_b/\Delta t$
W.M.	3·20	1·10	2·91	10·62	1·10	9·65	11·30	1·03	10·97
P.B.	4·41	2·38	1·85	20·74	1·67	12·42	13·55	1·58	8·58
A.M.	5·53	2·82	1·96	16·01	3·00	5·34	15·99	2·33	6·86
S.W.	9·49	4·00	2·37	9·33	2·17	4·30	10·41	2·08	5·00
M.S.	9·40	2·67	3·52	11·99	1·68	7·14	15·53	1·50	10·35
S.D.	3·70	1·53	2·42	9·25	1·70	5·44	9·57	1·73	5·33
D.McL.	3·00	1·52	1·97	11·30	2·12	5·33	7·14	1·85	3·86
D.B.	1·85	1·42	1·30	9·86	1·90	5·19	11·14	2·18	5·11

TABLE 4

$\Delta T/\Delta t$ (temperature drop in °C/exposure duration in hours) data for the sea trials

Treatment A / Subjects B	U.VIC jacket	CWU 21/P suit	Mark 10 suit	Flying clothes	
S.D.	0·54	1·02	0·74	3·25	5·55
D.B.	1·19	3·64	1·08	1·95	7·86
D.McL.	2·32	1·06	1·25	1·60	6·23
M.S.	0·69	1·00	1·57	1·83	5·09
	4·74	6·72	4·64	8·63	24·73

Analysis of Variance Table

Source of variation	df	SS	MS	F
A (treatments)	3	2·69	0·897	0·997 n.s.
B (subjects)	3	1·11	0·370	
Error	9	8·09	0·899	
Total	15	11·78		

$F(3, 9) = 0{\cdot}997$, $p < 0{\cdot}25$.

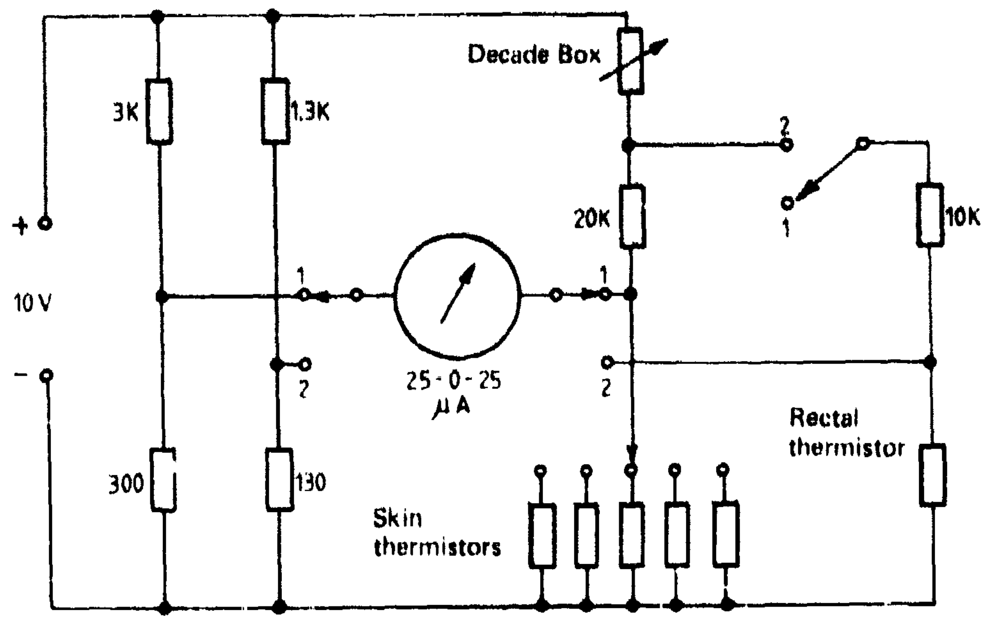
Thus differences in cooling rates between the four clothing conditions are not significant according to this test.

APPENDIX 1

Subjects

Subject	Age (yr)	Height (m)	Mass (kg)	Skinfold thickness (mm)				
				Triceps	Sub-scapular	Biceps	Iliac crest	Costal margin
Tank trials only								
W.M.	22	1·76	73·5	11·6	12·4	4·2	10·5	11·2
P.B.	22	1·87	83·2	3·5	9·5	6·7	10·5	10·5
S.W.	22	1·77	76·9	6·8	11·0	6·5	15·5	19·5
A.M.	28	1·79	81·0	20·0	10·5	9·6	15·5	29·2
Tank and bay trials								
D.B.	27	1·73	60·0	7·2	9·5	4·5	5·8	8·2
D.McL.	26	1·73	67·0	10·6	17·9	5·3	12·6	28·8
S.D.	28	1·79	62·0	7·8	9·7	3·9	8·3	15·9
M.S.	22	1·78	82·0	12·9	17·8	8·7	13·5	23·1

APPENDIX 2



Switch position 1 for skin thermistors measurements
Switch position 2 for rectal thermistor measurements

The thermistor characteristic is $R = R_o e^{b/T}$ where R is the resistance and T the absolute temperature. R_o and b are parameters which depend on the construction of the thermistor

Thermistor type	R_o	b
Yellow Springs 401	·004434	3914·00
STC M53 1	·064770	3311·78
STC M53 2	·079720	3234·25
STC M53 3	·070720	3275·55
STC M53 4	·049565	3371·29
STC M53 5	·073770	3252·07

DOCUMENT CONTROL DATA SHEET

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16. ABSTRACT

Laboratory and sea trials were used to evaluate the effectiveness of three aircrew cold water survival garments: the British Mark 10 suit, the United States CWU 21/P suit, and the Canadian 'U.VIC Thermofloat' jacket. It was concluded that the three alternatives provided similar thermal protection but with regard to several other important features, the U.VIC Thermofloat jacket was superior. Consequently, in this evaluation the U.VIC Thermofloat jacket was shown to provide the most effective form of aircrew protection.

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