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PROBLEMS OF NAVAL WARFARE UNDER CLIMATIC EXTREMES*

BY

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PART II.—LECTURE I (continued)

CLOTHING

The story of naval clothing can be told in four chapters. At first there was little or no control of what was worn, and pressed men came aboard clad in their filthy rags, which were replaced only when eventually disintegrated. This practice naturally favoured the spread of louse-borne disease, and especially the *febris navica*, or typhus. Next came the period of medical reform at the close of the eighteenth century, when Lind, Blane, and Trotter in turn pleaded for a regulation sea-habit. At length, from the weight of medical pressure, it was made compulsory for all new entries to be stripped, scrubbed—their rags destroyed—and then re-clad in clean apparel supplied by Admiralty "slop ships." Since 1789, thanks to Middleton, the comptroller, special ships were set aside to accommodate new entries during the first few weeks of their Service career. The third chapter concerns the regularization of the quantity, cut, and pattern of the clothing issued—the story of naval uniform, in fact. Two factors brought this about: the institution of continuous service in 1852, and the Grog Committee of 1857, checking the practice of men going ashore and bartering their kit for rum. The Uniform Committee of 1858 followed the precedent of the French marine of two years before, and enacted that every seaman should have so many articles of naval dress, of standard quality and appearance. The Uniform Committee of 1890 reopened the subject and made more recommendations along the same lines. This stage of preoccupation with uniform design, badges of rank, buttons, and gold lace lasted until the outbreak of the present war.

Since 1939 we have embarked upon the fourth chapter, which deals with the organized science of clothing as a means of protection against climate, flash, bullets, insects, gas, and other noxious influences. This novel subject of clothing physiology may be considered in greater detail.

Clothing for Cold Climates

In the Royal Navy special expeditions must have always demanded special clothing, and indeed the Service has for long played an important part in advising upon the appropriate dress for polar explorers. Their counsel must have largely been empirical, founded upon the experiences of generations of explorers and the usages of local inhabitants. The need for special cold-weather clothing in the Navy would seem obvious, and yet, judging by the complaints lodged by Blane and others, no adequate routine provision was made in the old days for the exigencies of the climate. Even as late as 1890 evidence was presented to the Uniform Committee that all was not well, for we read: "*It is often quite pitiable to see the men . . . although they have piled on so many articles of clothing under their serge frocks that they can hardly move, crouching under the lee of funnel-casing, etc., shivering and shaking all over. . . . The want of giving due importance to this subject has resulted, there can be no doubt, in our men being old and rheumatic when they ought to be in full vigour. . . . Had pro-*

tective clothing been compulsory and not optional, the spectacle of men spending their leave on a bed of sickness would not have been such a commonplace."

The Arctic operations of this war have focused attention upon this problem and have also led to a vast improvement in the nature of the clothing issued. The Canadian cold-weather-clothing trials held during the winter of 1943-4 form a landmark in this study, and gave an opportunity for a field test of the comparative merits of the Navy, Army, and Air Force clothing used by the British, Canadians, and Americans.

Field tests show that cold-weather clothing must be flexible enough to suit a number of different circumstances. There are problems of dry cold *versus* wet cold; still air as opposed to high-velocity winds; sudden rises of temperature which, though occurring in the lower part of the scale, are as great a contrast as between a spring morning at home and a tropical midday. Lastly, there are the differences between men engaged in heavy work and those who stand inactive on look-out; and an important intermediate group whose exertions are interrupted by short stand-easies in the open.

The role of cold-weather clothing is one of heat regulation: it forms a protective insulation which retards heat exchange. This is brought about in various ways—partly by the thermal properties of the fabric itself, partly by bodily heat production caused by the heavy clothing, but mainly by the garments trapping insulating layers of warm air—the so-called "private climate." When clothes become wet, either from sweating or from outside, the insulatory action suffers enormously, for water has 240 times the thermal conductivity of air and 3,000 times its heat capacity.

A. P. Gagge, A. C. Burton, and H. C. Bazett have made an ingenious attempt to form a scientific vocabulary for discussing the thermo-regulatory function of clothing. They start by assuming that the sensation of environmental comfort depends upon the temperature of the skin, as suggested by the traditional table drawn up by Vincent. It is, of course, open to question whether this is not an over-simplification of the problem, by ignoring cortical mechanisms which participate in the feelings of warmth and of cold. Nevertheless, it may perhaps serve as a working hypothesis. They suggest that the optimal average skin temperature conducive to comfort is 92° F. (33° C.). A person seated at rest and in a state of thermal comfort has a metabolic activity of 50 calories per hour per square metre of the surface area. This unit they call a "*met*." For a man of average size this is about the same thermal output as that of a 100-watt lamp. The same individual when standing has a heat production of 1.5 met (or 75 cal./m.²/hr.), and walking fast on the level, 4 met (or 200 cal./m.²/hr.). The amount of insulation (as afforded by clothing) required to keep such a sitting-resting subject comfortable in a normally ventilated room (air movement 20 ft./min. at a temperature of 70° F. (21° C.) and a humidity less than 50%) constitutes the unit measurement of insulation, which they call a "*clo*." One clo equals the insulating value of everyday clothing, or the value of a heavy top-coat alone. In cold environments the additional clothing needed to maintain comfort may be reckoned in terms of 2 clo, 3 clo, and so on.

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Doriot says that 4 clo is the greatest thickness of clothing in which a soldier can work; and 8 clo is the maximum he can carry as sleeping-gear.

The conception of a clo unit is attractive by its very simplicity. It recalls the traditional Chinese description of cold weather in terms of a "one-coat" or a "two-coat" day. Perhaps it is too simple, and may vary and err like other biological measurements based on subjective sensations translated into speech. The factor of acclimatization is not catered for. For greater accuracy one must resort to the physical laboratory and compute the insulation values of a particular textile from the density, thickness, and thermal conductivity of the fabric.

Among the physical properties of clothing which matter in heat regulation there is the density of the textile, the looseness of the weave, the thermal conductivity, and the hygroscopic value of the fibres. These properties affect the permeability of the cloth to air, to water, and to water vapour, and its power of heat storage. Fabrics which are hygroscopic—e.g., wool, silk, rayon—are thereby minor sources of heat until equilibrium is reached between the garment, the body, and the environment. The age of a garment, its cleanliness, and its reaction to repeated wetting or washing, all affect thermal conductivity. Colour has a bearing upon the heat-absorbing powers. Consequently the value of a particular material as a protection against cold is influenced by a number of factors. For example, Siple has compared blanket cloth (15.1 oz.) with melton overcoating (22.8 oz.): though the former is 30% lighter than the latter it has 1.4 times more insulation value. But as it is 4 times more permeable to air its protection in moving air is low. If, however, a layer of poplin (8.9 oz.) is put outside the blanket the weight now becomes the same as the overcoating. In still air its insulation value is now double that of the overcoat material, while in moving air its resistance is nearly 3.75 times as great.

As a means of protection against cooling by radiation and conduction wool is both efficient and economical. Protection against cooling by moving air calls for a shell of a closely woven, light-weight, water-repellent cotton fabric—e.g., those known eponymously as Wordie, Grenfell, Fison, Byrd, or Shirley cloths.

Fur is the characteristic wear in polar climates. Eskimos use only two garments—the inner one of caribou with the hairs towards the skin, and the outer one with the hairs directed externally. Fur comprises in volume only 2% solid matter and 98% air. Its biophysical effects are analogous to wool and poplin juxtaposed, in that an insulating layer of warm air is imprisoned within the hairs while a wind-impermeable layer is formed by the hide. But for general purposes fur is much too heavy, and its scarcity would in any case preclude its use in the Service.

For those who must do hard physical work in environments of intense cold, and especially if intervals of inactivity recur, the Brynje (or Brun) system of clothing has much in its favour. It is the traditional clothing of the Norwegian ski-troops. The Brynje set of garments consists of a loosely woven string vest, worn beneath a wind-proof jacket with wide sleeves, a zip-fastener opening, and a hood. Sometimes a lining of fine-mesh fishing-net is worn beneath trousers made of the same wind-proof material as the tunic. Mittens and a képi type of cap, also lined with fishing-net, complete the outfit. It is important that this system of clothing be adopted in its entirety, for there is no special virtue in wearing Brynje vests as compared with any other loose-meshed undergarment without the rest of the outfit. So long as the wearer is exerting himself and producing heat the hood is lowered and the zip-fastener undone. When at a standstill the hood should be raised and the tunic fastened tightly to the neck.

The advantages of such a system of clothing might be considerable in the case of naval landing parties and of Royal Marines operating ashore. The Brynje system is not likely to be of much value to personnel afloat, except perhaps the stoke branch.

It is believed that at -40° F. in still air 11 clo of insulation is required to conserve body heat. Watch-keepers in severe Arctic weather will therefore need a different system of clothing. The Navy has adopted and modernized the pattern of the anarak, or the traditional Eskimo garment. This com-

prises a long smock of duffel cloth furnished with a hood and covered with a layer of windproof material—e.g., Grenfell cloth. Long-haired fur—wolverine or musk-rat—edges the hood. Trousers of wind-proof fabric are worn over the ordinary serge trousers. Such a garment is especially useful in conditions of dry intense cold, and perhaps less suitable for the driving wind and wet of a North Atlantic gale. For this latter type of weather a one-piece suit would be desirable. One of the chief difficulties about winter clothing in ships is that bulkiness makes it difficult to clamber through hatchways. The same applies to tank crews operating in severe cold. There is a scope, therefore, for a one- or two-piece padded (or wadded) suit like the winter garments of the Chinese or Russians, but made of modern closely woven fabric, lined with a light-weight heat-insulating flock—e.g., kapok, aerogel, or bubbfil. Most difficulty is found in the choice of protection for the hands and feet. For walking through crisp snow there is much to be said for the Russian "valinki," or high boots of felt. Unfortunately they are unsuitable in the wet even when covered by a rubber galosh; hence their value in the Royal Navy is limited. Ordinary rubber and leather sea-boots are most inadequate in very cold weather. The foot-gear worn by Arctic dwellers is much better—e.g., moccasins, mukluks, finneskos, and kamliks. The last, made of untanned sealskin with the hair close-shorn and sewn with reindeer tendon, are almost ideal, though for ship-board wear they need wooden or leather soles. Kamliks are already in limited use in the Service, and were the supply problem simpler they might now be in general issue. The choice of gloves turns on the question whether the rating is called upon to carry out finger manipulations or not. If so, there is much to recommend a glove made of rayon or silk, worn beneath a fur mitt. According to Doriot, 2 clo is the most that can be worn on the hands and dexterity still be retained. Otherwise a duffel cloth mitt covered by a loosely fitting seal-leather outer one is most suitable. Separate "trigger-finger" compartments are not approved.

Eskimos make considerable use of the insulating properties of dry "senne-grass," which they stuff inside their gloves, boots, and pockets. This practice might be adopted and improved upon by using a more efficient light-weight plastic.

Electrically heated suits, as used in the R.A.F., have been seriously considered for naval wear. Watch-keepers in exposed positions, unable to move about to keep warm and too cramped to wear many layers of clothing, might be made comfortable and more efficient by such means. Director crews in the control tops, and perhaps look-outs upon an open bridge, are in mind. The various technical difficulties are not insurmountable. To the physiologist one of the problems concerns the correct placing of the heating elements within the suit—whether to warm the trunk, the extremities, or both. Overheating must be avoided, lest the wearer become somnolent.

Clothing in the Tropics

Let us now turn from Arctic to tropical clothing. In this connexion nothing is more striking than the contrast between the practice a generation or so ago and that which obtains to-day in ships on tropical service. During Victorian times, and even within the memory of many serving officers, it was usual in the Persian Gulf in the hottest season to wear high-necked uniform, thick underwear, topees, and spine-pads. The ratings' white ducks were heavy, cumbersome, and uncomfortable. Disciplinary action was taken against those who ventured on deck without sun-helmets. "*The best dress in a hot climate, for working, and in boats is a check shirt with collar over a flannel*": so wrote Admiral Commerell in 1889.

Admiralty Fleet Orders, and especially those issued from the East India Station, display the gradually changing opinion about correct tropical wear. In 1871, we read, officers must wear waistcoats if they elect to leave their frock-coats unbuttoned. We find that in 1893 the signal might be made in hot weather, "Off jumpers." In 1912 singlets instead of flannels were permitted on occasion in the Persian Gulf. In 1921 the sennet hat (i.e., the characteristic sailors' straw hat) was abolished. In 1925 shirts were allowed instead of tunics, and, at the discretion of the senior officer, ratings—but not duty men—might be excused jumpers. In 1932 officers' tropical rig comprised tunic, shorts, and black stockings.

To-day ratings afloat in the Tropics wear shorts and sandals, and usually nothing else, even on their heads. Officers may wear the same. In boiler-rooms, of course, light clothing is worn to protect the skin against the intense radiation of heat. Ashore, officers and ratings wear, as "tropical rig," cap, shirt, shorts, white stockings, and shoes. Sun-helmets and dark glasses are virtually never seen, and the spine-pad, which survived as an extra strip of material sewn into the rating's shirt, has gone by the board. Contrary to all prognostications, the health of the Navy has improved since this scanty rig became the custom, especially as regards prickly heat and boils.

What is the reason for such a change from overdress to comparative nudity? In the first place it is largely sociological. Sailors nowadays share with the rest of the community a high standard of living and of personal hygiene. Scanty comfortable wear is now a hall-mark of emancipation, social security, and enlightenment. In part, overdress in the Tropics was bound up with the idea of protection against chill and the "dry belly-ache." The high incidence of fever in the eighteenth-century Navy was at times ascribed to a drop in temperature after sundown, but it is obvious that unrecognized cases of malaria were chiefly at work. To protect against the perils of the miasmata, flannels and woollens were worn in the Tropics, especially by boat crews at night. Traces of this belief linger in the cult of the cholera belt as a protection against tropical infective enteritis.

Some of the blame must be laid on the naval executive, and on Admiral Lord St. Vincent in particular. Like many other high-ranking laymen, he held strong but peculiar views on medical matters. In a Fleet Order of Oct. 13, 1810, we read: "*Confident as the Commander-in-Chief is that many consumptive cases might be prevented and others mitigated by timely application of flannel next the skin in catarrhs, coughs, and common colds, he most seriously exhorts the captains of ships comprising the fleet under his command to inculcate this doctrine in the minds of their surgeons, who, from caprice and passive opposition to every wholesome regulation, grossly neglect this important duty.*" Naval medicine suffered as the result of this lay interference; for the surgeons—startled into acquiescence—fell into line, and for a time actually became the chief exponents of this cult.

Thus, during the Committee stage of the 1890 Commission on Clothing, opinions were sought as to the most suitable rig for the Tropics. The staff surgeon in *H.M.S. Hercules* testified that "*cholera belts made of two thicknesses of best flannel, overlapping in front, and secured by strings, and well quilted, . . . would in my opinion prevent an enormous amount of diarrhoea, enteritis, and even dysentery . . . inboard ship, especially in the Tropics.*" Another offender was the then Medical Director-General, whose *ex-cathedra* recommendations for the Tropics comprised: flannel with sleeves reaching half-way to the wrists, and flannel underpants coming below the knee in order to protect the joints against rheumatism; and a modified sun-helmet on all occasions, to protect the nape of the neck—"a vital part of the nervous system."

The scanty dress worn nowadays at sea appears ideal from physiological and hygienic points of view, but there is a drawback—namely, the risk of severe burns during enemy action. There is a need, therefore, for some sort of garment which will cover all exposed areas of skin, including face and hands; in other words, an action rig which can be quickly donned when needed. This rig should be of the lightest possible weight, so as to impose the least physical load; it can, if necessary, be made of material impregnated against flash. The choice of fabric is a wide one, and there is much in favour of a loose cellular-weave cotton, so long as it is not worn ashore after nightfall. Of greater difficulty is the decision as to the appropriate design, and trials have been made of one-piece garments; shorts which can be lengthened to form trousers; and shirts, gauntlets, and hoods stowed close at hand to the ratings' action stations. Common sense enjoins that a certain risk must be run, for it would be intolerable to wear an action rig all day and every day at sea in the Tropics, whatever its virtues against flash.

But, in addition to this working dress which can be quickly transformed into an action rig, the sailor in the Tropics will need a shore-going uniform which is smart and cool. It might

be required that such a uniform be worn by landing parties and sailors on combined operations. Here the chief consideration is not flash- but mosquito-permeability. The sailor who remains ashore after sundown, or whose ship ties up in a malarious district, requires that his uniform should not expose an undue area of skin, and that the textile should be impervious to mosquitoes. This is a property which can be readily tested in the laboratory. The cool cellular weaves are thereby ruled out. Thick twills are uncomfortably hot. The fabric of choice is therefore one of the tightly woven cottons, such as gaberdine, Byrd cloth, poplin, Shirley cloth, or else nylon or a nylon mixture. Here other but less important factors will decide—e.g., water repellency, ventility, ease of impregnation with anti-gas chemicals or insect repellents, colour, durability, tropic-proofness, and lastly, of course, availability.

With personnel working and fighting ashore, and especially in the jungle, lightness of weight assumes added importance. Jungle clothing, though primarily a military problem, also concerns Royal Marine detachments. Every ounce of unessential equipment, and any undue heaviness in uniform and accoutrement, increases the physiological burden. Considerable attention has therefore been given to the determination of the relative climatic efficiency of fabrics by studying their influence on "the index of physiological effect" (Robinson). Subjects are tested in a hot chamber of standard temperature and humidity, and walk for a specified time upon a treadmill working at a certain speed. The reactions of the subject as shown by pulse rate, skin and rectal temperatures, and rate of sweating are recorded under basic conditions—i.e., while wearing shorts and shoes only. The subjects are then studied while wearing experimental uniforms of different textiles. This affords a delicate measure of a fabric's suitability for tropical wear, and in general terms it can be said that the physiological load of a material varies directly with its weight.

In the case of seamen and mariners working ashore in the Far East it is highly important so to design the working rig that not only mosquitoes but also leeches, ticks, and mites are excluded. Because of their insinuating properties this is not an easy matter, but the control of such a military hazard as scrub typhus is largely bound up with adequate covering of the trunk and extremities, together with the use of repellents.

The colour of the garment is of some importance in the Tropics, especially when the sun's glare is intense. At one time the suggestion was made that the ideal tropical dress would comprise a white outer layer worn over black under-garments. But whites, though cool and smart in appearance, need frequent laundering. They may also render the wearer when ashore conspicuous to hostile aircraft. Hence the advantages of a blue-grey uniform, which is both light enough to be fairly heat-repellent and dark enough for purposes of camouflage.

Brynje vests of wool mixtures have been tested in the Tropics. They should be worn beneath another garment, and hence add to the physiological load of the wearer. These vests have two advantages, however: they keep the outer layers of clothing off the skin, so that clammy garments do not stick to it, while mosquito-bites are also thus avoided. Brynje vests are useful for wear beneath an officer's white tunic.

It is not suggested that physiological tests should be the sole criterion in the choice of fabrics. Suitability depends upon many additional factors. A particular textile might seem ideal for tropical wear, being insect-proof and cool, and yet prove to be uncomfortable, too flat and smooth, clammy and clinging when wet, friable, and subject to deterioration from moulds. Light weight is not the only source of coolness. For instance, a loose fit combined with a certain rigidity may be an advantage in creating a wider air space. The bellows action of a pair of slightly starched shorts may give a cooling effect beyond that due to weight alone. Even the "feel" of a textile is significant. Design is most important, and constriction of the body and limbs must be avoided not only in Arctic wear (to promote free circulation) but also in the Tropics (to avoid prickly heat).

The procedure in choosing an item of Service clothing for the Tropics, jungle, or Arctic should be something as follows: First a report as to the merits and demerits of the items at present in use. Next, the selection of textiles and design which are promising and which are available in bulk. These are made up. Some go to the physiologists for testing as to heat

load, insulation value, flash-proofness, and so on. Next come mock field trials, whereby troops in this country wear the items under conditions which mimic to some extent the terrain or environment which will be encountered abroad. Full reports are made. At the same time samples are dispatched over-seas for testing under genuine Service conditions. Questionnaires are compiled, and reports submitted by observers sent out specifically. Lastly, after a period of, say, six months, the experimental items are returned, and examined as to wear and tear, deterioration, and so on. Such is the modern and common-sense drill which replaces the fortuitous choice of Service uniform of earlier times.

LECTURE II

The Human Problem in Naval Warfare

The first lecture mainly concerned the material side of naval warfare under climatic extremes and those modifications of environment and dress which have been evolved to meet the contingencies. One now turns to the human side of the problem, a consideration often neglected. As the Fleet developed from sail, the personnel changed from simple men engaged upon simple tasks to a community of skilled technicians and specialists. Instruments and equipment became more and more elaborate and sensitive, and mechanical and engineering research was lavished upon their design, their upkeep, and their protection against rough usage. Perhaps attention was focused too narrowly upon the instrument and not enough upon the man, who, after all, may prove to be the weakest link in the chain of efficient function. There is nothing new in this discrepancy, for it has been a perpetual source of contention in the Service. Over 150 years ago Blane was grumbling that "*sailors . . . had not the attention paid to them which would have been due even to inanimate machines of equal utility, for there seemed to be much more anxiety about preserving arms from rusting and cordage from rotting than about maintaining men in an effective state of health.*"

Two questions may be asked: first, How do men fare who have to keep watch while exposed to intense cold or excessive heat?; and, secondly, How do personnel react after prolonged service in polar or tropical climates? The one largely deals with mental and physical efficiency and the other mainly concerns morale.

On the bridge or weather-deck, or in the control top of a ship in the Arctic, a watch-keeper may remain immobilized up to four hours, unable to keep warm by exercise. During this time he is required to keep alert at some responsible, if not vital, task, the temperature being well below zero. Impeded by many layers of clothing, he faces a wind of high velocity with driving sleet or snow. Gradually the bulky clothing proves tiring and burdensome. The high wind makes hearing difficult and handicaps intercommunication. Lacrimation and smarting of the eyes impair visual acuity. The northern twilight and the mist may combine with fatigue to produce visual illusions, so that a look-out may mistake a breaking top for a bow wave or the wake of a periscope. The pain of the intense cold produces a general sensation of distress, which, as it continues, more and more dominates consciousness. In this way attention becomes distracted; the victim becomes slow and inaccurate in perception and performance. A mood of depression may supervene, though irritability is the commonest effect. Finger movements become clumsy, either through numbness from cold or because of the cumbersome Arctic handwear. Lastly, somnolence is common, and may become overwhelming when the rating comes off watch and goes below to his warm mess-deck.

The contrasting picture is that of a rating in the Tropics, trying to maintain vigilance while crouched in some minute compartment, with a dry bulb standing at 95° F. (I have known it to be 110° F.) and a wet bulb at 85° F. There may possibly be some near-by electrical apparatus which itself is generating heat to the figure of some 1 to 1.5 kilowatts, which is almost equivalent to the amount of heat that would be given off by 15 men at rest. He may be naked except for shorts; his body is streaming with sweat, and in addition he is probably covered with the irritating rash of prickly heat, perhaps secondarily infected. Hot nights—precluding regular sound sleep—diarrhoea, toe-rot, otitis externa, and other maladies and discomforts

have perhaps already left their mark, and he has to cope with an exacting, boring, but highly important task.

One may quote the description afforded us by Burdon, the medical officer of a Persian Gulf sloop:

"In addition to monotony and strain, the fierce climate played a major part in producing neuroses. The summers of 1940 and 1941 were very humid and hot, with malaria in addition in 1941. In June, 1941, for example, the forenoon temperature in the sick-bay was about 110° F., although the deck above was wooden and kept wet. Sometimes it was midnight before the thermometer registered less than 100° F. The evening fall of temperature was offset by the relative increase in humidity, so that the only respite from sweating profusely came between midnight and morning. Even so, it was usual to wake up on a mattress sodden with sweat. . . . The wet bulb in the shade on deck showed maximum recordings of just over 100° F. on three occasions. It is usually regarded as impossible to work under these conditions, but work went on for weeks on end until the cooler weather arrived. The usual rig was a pair of shorts and sandals, and these were permanently wet where they touched the body. Sweat dripped from the elbows, fingers, nose, and chin, and ran in a rivulet down the spine. It was a difficult task to write a letter without smudging it. A copious fluid intake was of course a necessity, and everyone suffered from sweat rashes, often with sepsis. A journal referring to this period mentions the 'repeated and powerful mental irritation induced by humidity, heat, and flies.' Such conditions engendered in most subjects an irritable despair, which cannot adequately be described. . . . Nearly everybody lost weight, some as much as a stone. Physical illness was common, and during the worst period as many as 10% of the complement were off duty sick at one time. In the worst quarter 43% of the total complement had an illness lasting on an average 7 to 14 days. The main causes were malaria, septic infections, and heat exhaustion; all were related to the climate. Accident-proneness was also raised during the hot weather. . . . Mood was worst when the climate was worst."

To justify drastic improvement in habitability it is not enough merely to assert that inefficiency occurs; it must be demonstrated, measured, and, if possible, correlated with the thermometer scale. The problem must be put on the very firmest scientific basis. Three approaches are open: (1) a comparison with experiences in industry; (2) field studies—i.e., in ships; and (3) laboratory tests in environments of severe cold or heat.

Habitability: Comparison with Experiences in Industry

Industrial data are to some extent tied up with experimental studies. Comparisons are hindered by the non-uniformity of the environmental standards adopted. (i) Using *dry-bulb* readings, Huntington found the optimum temperature for factory workers to be 60 to 65° F. Bedford found that 15% more work is done at 68° than at 75° F. Cadman said that work in coal-mines was impossible at a saturated temperature of 86° F. McConnell, Houghton, and Taylor asserted that a saturated temperature of 90° was the upper limit for a man at rest, but Dreosti found that fit and acclimatized persons could do light work even at a saturated temperature of 95° F.—though he did not mention how long or how well they worked. (ii) Judging by isolated *wet-bulb* figures, Wyatt noted a falling off in the output of cotton-weavers above 73° F. The Cotton Cloth Factories Regulations (1929) required that artificial humidification must cease when the wet-bulb temperature exceeded 72.5° F., and enacted that all work must stop should the wet-bulb temperature be above 80° F. Caplan found that working efficiency dropped rapidly in gold-mines over 92° F. and that it virtually ceased at 97° F. (iii) Using the terminology of "*effective temperature*" Vernon and Bedford found a decreasing output in coal-mines as the figure exceeded 66° F. According to Yaglou, twice as much work was done at 70 as at 93°, and Liberson and Marques found the work capacity halved in changing from 91 to 97°. At 95° (Yaglou) mechanical efficiency suffered, especially for heavy work. (iv) Employing *dry- and wet-bulb katathermometry*, Orenstein and Ireland noted impaired efficiency in the Rand gold-mines when the cooling power was less than 6 (dry) or 16 (wet). At cooling powers of 1.5 and 5 respectively the production was only 55%. (v) *Air-conditioning* of offices has been noted many times as leading to better performance, but the enhanced efficiency has rarely been measured. Workmen building the Boulder Dam suffered severely from heat during the first year, with 15 deaths from heat-stroke. Next year, when their dormitories were air-conditioned, there was a marked improvement, with no deaths and only 5 cases of cramp. The output of a factory in Manila

was increased by 28% by air-conditioning. (vi) Lastly, *increased air movement* has been shown to give results. In the gold-mines a small fan giving 2,000 cu. ft./min., placed 10 to 20 feet away, increased output by 46% (Orenstein and Ireland). Lee, Reid, and others showed that the physical well-being of tank crews in the Tropics was improved by spot-cooling with ambient air, and more particularly with cooled air; and still further when air—especially cooled air—was introduced beneath the clothing by means of a hose. These industrial studies have the drawbacks of intangibility, the terms "light work" and "heavy work" not being always clearly defined, details of clothing and water consumption not being given, and environmental standards being ill established. The other defect is a paucity of data as to work in cold conditions. Indeed, almost the sole available information relates to an increased accident rate in munition workers in the last war, when their factories were kept at a low temperature. This was ascribed largely to loss of manual dexterity. Moreover, there is very little information as to mental work. Almost the only information comes from Huntington, who found that the scholastic performance of U.S. naval and military cadets was lowest during both the hottest and the coldest seasons, and highest in the spring and autumn. Kuno noted that mental work was especially tiring in very hot atmospheres—an observation which he ascribed to the known inhibitory effect of mental exertion on the sweating produced by high temperatures.

Field Studies (Ships)

That inefficiency occurs at sea in all these foregoing uncomfortable circumstances can scarcely be doubted, though to demonstrate the point may not be easy. It may be that in the excitement of action the shackles of apathy and lassitude are thrown off and performance returns to normal. The same temporary improvement may happen in a laboratory when a subject is given an actual psychometric task.

Wireless sending and receiving would be a good index of efficiency, for any deterioration would soon become obvious. Thus in transmitting messages the speed of sending might drop. More errors and corrupt signals might be expected to creep in, with a tendency to lengthen the dashes and to accentuate the dots. Wireless receivers would perhaps betray their inefficiency by their posture, their untidy penmanship, and a tendency to miss the first few words of the signal.

Engine-room ratings are noticed to be sleepy and lackadaisical in very hot weather, and when off watch they turn in rather than read, write, or play cards. In submarines, before the introduction of coolers, personnel sometimes made silly errors and omissions. Two medical officers taking records in a hot and stuffy shell-handling room found difficulty in making correct arithmetical calculations. The ship surgeon may find it difficult to embark on the writing-up of his quarterly report.

In the gunnery division there may be a premature flattening out, if not a decline, in the learning or working-up curve, which usually ascends steadily after a ship has commissioned. Men engaged in heavy tasks may flag in the heat to the extent of retarding the work of others. It may be necessary to open the hatches periodically while at action stations, and to detail hands to stand by to close them in an emergency. While ammunitioning ship minor accidents are not uncommon, and these occur more often in the Tropics.

The foregoing field observations relate to tropical conditions, but would largely apply also to the Arctic. Extremes of temperature produce psychological effects which are comparable, both being in great part due to the distracting influence of intense discomfort. In the cold the greatest effects would be on personnel who are immobilized and who are on the alert to pick up a chance visual or auditory stimulus (asdic, radar, look-out personnel). Men whose work entails physical exertion—e.g., shell-handers, stokers—will suffer far less than in the Tropics. H. G. Armstrong has described the sequence of events in airmen. Restlessness, discomfort, impaired tactile acuity, numbness, and clumsiness of movement are accompanied by distracted attention, mental distress, loss of morale, indifference, or distaste towards the operational mission, leading to a tendency to panic. Stupor and death would supervene in those extreme circumstances. M. C. Grow describes the mental symptoms of exposure to cold as beginning with disordered

judgment, a distortion of the intellect, leading to incoherence, confusion, and eventually to a fatal coma. The author believes the cerebral symptoms in states of cold are due to anoxia, and not to the release of histamine-like toxins into the blood.

Laboratory Tests

To gather scientific evidence it has been necessary to carry out efficiency tests under laboratory conditions. Within a hot chamber, wherein high levels of temperature can be attained, one studies the physiological reactions of naval ratings upon a treadmill adjusted so that their work reproduces the energy expended in any of their duties afloat. But nowadays most sailors might be classed as sedentary workers, and their jobs are skilled psychomotor and psychosensory activities rather than hard muscular work. Hence one installs in the hot room mock-up instruments which duplicate the principles of ordinary naval tasks in such a way that speed and accuracy can be recorded and inattentiveness and irritability noted. Such experiments are under way in the Department of Experimental Psychology, Cambridge, and will be carried out in a naval establishment in the Tropics; while the U.S. Navy are working along similar lines at Bethesda.

Again it is noteworthy that there is a dearth of experimental psychological study of performance in environments of severe cold.

It is not intended to deal here with the physiological effects of heavy work in hot atmospheres—a subject so thoroughly studied by workers in Boston, Philadelphia, Brisbane, Johannesburg, and the University of Indiana. For the Royal Navy there is the important work under way at the National Hospital, Queen Square, by Carmichael, McArdle, Weiner, and others. My own interests lie more in the researches into psychological efficiency of ratings under various test conditions. Examination first under average temperate environments measures the inefficiency due to fatigue, and determines the effect of correct seating, lighting, instrument display, and the influence of such factors as rest, water, salt, food, and such drugs as benzedrine and pregnenolone. The optimal duration of watches and tricks—a question hitherto treated empirically—can now be answered scientifically. Such experiments are then repeated in hot rooms where the effective temperature can be regulated and maintained as desired. The subjects can be kept continuously in these hot atmospheres, for a week or two if desired.

It is not yet permissible to describe the researches of the Cambridge school. The work of Prof. F. C. Bartlett and of the late Dr. Craik, Mackworth, and Cameron will not be revealed until the war ends, but already important Service applications have emerged. Some interim data may be quoted without indiscretion. Bartlett's study of fatigue accruing from elaborate and highly skilled work can serve as an index of what probably occurs in hot environments. He points out that there may be a progressive and unnoticed raising of the threshold range, an increasing inaccuracy of timed response, a dissociation of performance and of stimulus units. The subject's insight grows more and more defective. He becomes worried, irritable, and obsessed with his physical discomfort. "He is at once more optimistic about his performance and pessimistic about his state."

This unawareness of inefficiency is of extreme importance in naval warfare. Officers and ratings, without realizing it, may be losing efficiency and yet scorn the suggestion. Physiologists will recognize a similar unconscious impairment of performance both in states of anoxaemia and in CO₂ poisoning.

Efficiency in an individual may matter little, but when that person is a vital link in a chain then the small error may become highly significant. True, one can rouse oneself from the apathy engendered by heat to give an ultimate performance which may be adequate. But such a recourse to reserve capital cannot go on indefinitely, and toleration might lead to a dangerous complacency. The personal loss of efficiency during fatigue may be projected, and, as Bartlett showed, the individual may blame the instrument rather than himself. This process of exterojection may ultimately lead to a lack of the man's confidence in his machine, an increasing preoccupation with his physical discomfort, discontent, and eventually an impaired morale.

(These lectures will be concluded in next week's issue, which will contain a list of references.)