I subscribe to the view that every anaesthetist has a mild bee in his bonnet. Mine, for the moment, happens to be the belief that bulky and complicated apparatus is not essential for good results: moreover, it has dangers all its own to which I have not referred in this brief paper.

Summary

Bulky anaesthetic apparatus whose function depends on cylinders of gases is not essential for good anaesthesia. In wartime cumbersome apparatus can be a liability, and the transport of cylinders may present difficulties. Even now there are countries where the price of nitrous oxide makes its routine use impossible.

Simple equipment is described which does not rely on cylinders. It is adequate for any operation and is easily transportable. If respiration is paralysed oxygenation is ensured by use of the hand bellows component, which inflates the lungs with air.

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THE ATMOSPHERIC ENVIRONMENT BETWEEN DECKS IN THE ROYAL NAVY*

BY

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It is not necessary to dip deeply into the archives to discover that the environment between decks has been a challenge to naval hygienists and naval architects ever since decks were fitted to ships. Even in the time of Queen Elizabeth I, nearly three centuries before heat generated by machinery and stringent black-out and damage-control precautions complicated the issue, Sir Walter Raleigh commented, "Cabins are but sluttish dens that breed sickness" (Shaw, 1929). The problem is essentially one of accommodation and of maintaining effective standards of air hygiene. Much careful thought has been devoted to both aspects, and in particular by two Admiralty Ventilation Committees which reported in 1914 and 1937. These committees were fortunate to be able to call in turn on the services of Professor J. S. Haldane and Sir Leonard Hill, and the modern methods for warship ventilation have evolved largely from their deliberations.

The main findings have been summarized elsewhere (Ellis, 1948a); certain salient points will be reiterated later, but I would like to draw attention to one important difference now. The 1914 Committee accepted the standard, conventional for those days, that systems should be designed to keep the level of carbon dioxide in the atmosphere below 0.07%, by ventilation which provided 50 cubic feet (1.4 cubic metres) of fresh air per man per minute on the mess decks. The 1937 Committee considered that the designer's aim should

be to carry away the heat generated within ships rather than the carbon dioxide, but the information available was inadequate to indicate how this might be done to the best advantage. In effect, a reduction in the fresh air requirements to 33 cubic feet (0.9 cubic metre) per man per minute was accepted, and it was left to those who had to contend with these problems during the second world war to work out the details. Air-conditioning was not considered to be essential.

In 1944 the transfer of a large part of the Fleet to the Tropics forced an urgent review of the situation. The Medical Research Council's Royal Naval Personnel Research Committee was invited by the Admiralty to appoint a subcommittee to advise on problems of the environment between decks and in particular to define thermal standards for ventilating warships in the Tropics. After 11 years the first phase of this committee's deliberations is nearing completion.

In the meantime, developments in thermonuclear, biological, chemical, and aerial warfare have re-emphasized the need for warships to be closed down effectively and quickly when necessary and have called for a knowledge of the acceptable minimum as well as the optimum requirements for fresh air. In the submarine world the post-war introduction of the British version of the German and Dutch schnorkel, a hollow mast which permits the continuous ventilation and diesel-propulsion of a submerged submarine, and the launching of the first nuclear-powered submarine in America last year, with a reputed underwater endurance which exceeds that of earlier types, are providing environmental hygienists with new and intriguing questions to answer.

Accommodation

Sir Sheldon Dudley (1946) has summarized the accommodation problem thus: "What is the ratio of the space allocated to the human element to the space allotted to the mechanical element of the total fighting ship (ship plus ship's company) which will make the most efficient engine of war?" The priorities are weighted so heavily in favour of materiel that in practice this amounts to "what is the minimum space which can be allotted to the ship's company without imposing serious limitations on their health or efficiency?"

At the time when the 1937 Committee was sitting an average space of only 120 cubic feet (3.4 cubic metres) per man was available on the messdecks in the Fleet. This was later found to be inadequate for swollen war complements, and towards the end of the 1939-45 hostilities ships were being designed to provide each man with a space of approximately 160 cubic feet (4.5 cubic metres), or 20 square feet (1.9 square metres) of floor space if there was 8 feet (2.4 metres) between the decks (Sims, 1945). Experience had shown that this was the minimum which would accommodate a man and his equipment so that he could live reasonably for long periods during global operations. In the Tropics up to 70% or more slept on the upper deck on camp beds whenever they were allowed to do so, which might not be permissible in another major war. Even to-day, with the most careful planning, the complexity and diversity of a modern warship's equipment, and the numbers of men required to operate and care for it, permits only 20 square feet (1.9 square metres) of floor space to be allocated for junior ratings and 25 square feet (2.3 square metres) for those more senior, calculated for the full war complement. When this is compared with the wartime minimum for naval barracks of not less than 45 square feet (4.2 square metres) per man, or 30 square feet (2.8 square metres) if double-tiered bunks were used (Dudley, 1943), it is obvious that here is a situation on which to keep a watchful eye.

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In submarines the average cubic space per man varies from rather below to rather above 100 cubic feet (2.8 cubic metres) in the compact living and sleeping quarters; but, as a submarine is a single compartment for ventilation purposes, the available volume of "breathable air" varies from 300 to 500 cubic feet (8.5 to 14.2 cubic metres) for each man in the different classes.

Thus the space allowances per man between decks tends to depend on the amount of space which remains to be divided up between ships' companies when provision has been made for the installation of weapons, equipment, machinery, and stores rather than on basic hygienic principles which at present escape precise definition.

Thermal Environment

The climate between decks is probably next in importance to the space available. The American effective temperature scales (Houghten and Yaglou, 1923, 1924; Yaglou and Miller, 1925) are used for describing the thermal environment in British warships nowadays. These scales enable an observer to relate the thermal comfort sensations of persons engaged in sedentary or light occupations, wearing light clothing or stripped to the waist, and exposed to varying combinations of air temperature, humidity, and turbulence, to the temperatures of still and saturated air in which they would experience the same sensations of thermal comfort. A correction, proposed by Bedford (1946), is used to allow for radiant heat when necessary by substituting the globe thermometer temperature for the dry-bulb temperature when the effective temperature is determined, to give a "corrected effective temperature." This theoretical compromise is open to criticism; and several alternatives to effective temperature as an index of physiological effect are under trial in England and the United States.

A notable post-war concept, suggested by McArdle and his co-workers in 1947 to the Royal Naval Personnel Research Committee, was to use the predicted four-hour sweat rate (or sweat loss), which could be determined for different conditions of climate, work, and clothing from an empirical nomogram based on the data of their experiments in London. Their system probably provides us with the most useful basis for a stress index which has been thought of since effective temperature, and it offers certain advantages over the latter, particularly when the sweat output is profuse, one gain being that an adjustment is made for differences in work rate as well as climate (Smith, 1955; *Lancet*, 1955). It is, however, more difficult to use: by definition, it can be employed only in the temperature range in which people sweat; the data available were perhaps rather scanty for the construction of such a comprehensive nomogram; and at present it has been tested insufficiently for it to be considered more than a research tool which should be kept in the hands of those who know how to use it. Meanwhile the current value of effective temperature will be enhanced if ship ventilation trials support the use of an ingenious method, devised by Gray and Smith (1952) from a study of data collected by the former in the British Pacific Fleet and by Surgeon Lieutenant-Commander H. E. Holling, R.N.V.R., Mr. E. A. Brokensha, of the Royal Corps of Naval Constructors, and myself in the Eastern Fleet, for predicting effective temperatures in the Tropics from measurements made on the mess-decks in temperate waters.

A considerable amount of work was done in Singapore at the Royal Naval Tropical Research Unit between 1948 and 1953 to show whether the effects of short-term exposures to high temperatures, such as men would experience during a four-hour watch, are the same for acclimatized young men living in hot climates as they are for young men who are trained to work at high temperatures but live in temperate climates. This issue is vital to the interpretation in the Tropics of much of the earlier experimental work in temperate climates. The answer so far appears to be that to all intents and purposes the effects are probably much the same, provided both groups are similar and are equally

trained to do the same sort of work and wear the same clothing (Ellis, 1953a). This confirms the finding of wartime studies that trained naval hot-room subjects in London were able to compete more effectively with the heavy work of handling ammunition than less well trained gun crews in the Tropics (Benson *et al.*, 1945; Ellis, 1947). Training is probably at least of equal significance to being merely exposed to a warm atmosphere for those with strenuous duties. The experiments in Singapore showed that long-wavelength heat radiations such as may be experienced in modern warships are not usually a major factor limiting a man's ability to work, and physiological support was provided for the use for the time being of Bedford's correction to the effective temperature scale (Macpherson, 1953). The detailed results have still to be published by the Medical Research Council.

There is convincing evidence that ships' companies were affected adversely by wartime conditions in the Tropics. Macdonald Critchley (1945) has drawn a vivid picture of the way they lived. The average effective temperatures in different types of compartment in the Eastern Fleet in 1944 were found by Holling, Brokensha, and myself to vary between 83 and 90° F. (28.3 and 32.2° C.), but more severe warmth was encountered frequently (Ellis, 1953a). Work took longer to do and was not done so well as in more temperate waters. Laboratory studies by Mackworth (1950) and Pepler (1953) in temperate and in tropical climates confirm that deterioration occurs in the performance of tasks of even short duration when the effective temperature is in the lower eighties. When the average upper-deck dry-bulb temperature at noon exceeds 80° F. (26.7° C.), which corresponds approximately to average mess-deck effective temperatures of the same order (80° F.), minor sickness, particularly skin disease, is more common (Ellis, Smith, and Underwood, 1953). The reported overall sickness incidence was between 50 and 100% greater in ships than on shore in the Eastern and British Pacific Fleets in 1944 and 1945 (Ellis, 1948b); and when ships went to the Tropics from temperate waters the sickness incidence and working days lost were doubled or trebled (Roberts, 1948; Ellis, 1952a). Furthermore, most people, whether on shore or in ships, feel uncomfortably warm when the effective temperature is above 80° F. (26.7° C.) for more than a short time, their skin is moist with sweat, sleep is disturbed, and hot-climate fatigue is encountered more frequently as service afloat is prolonged (Ellis, 1952a, 1952b, 1953b, 1953c, 1954). The coincidence of an increase in discomfort and in minor ill-health and a decrease in efficiency at these levels of warmth is undeniable.

A provisional wartime recommendation that whenever practicable in spaces where men live or work in ships in warm climates the effective temperature (or corrected effective temperature) should be kept below 80° F. (26.7° C.) (Bedford, 1946) is supported by the research work of the last 11 years, except that 78° F. (25.6° C.) should be the upper desirable limit rather than 80° F. (26.7° C.) (Sims, 1945; Ellis, 1953b). This is in agreement with American views (Pace *et al.*, 1943, 1945; Behnke, 1945; Kellogg, 1946). Fortunately much of the criticism which has been aimed at effective temperature does not apply when prescribing conditions for mess-decks, workshops, or offices. When the thermal stress is more severe, as in certain machinery spaces, or when hard work has to be done it is probably wiser to be guided by the wet-bulb temperature alone. If the dry-bulb temperature is in the region of 100–110° F. (37.8–43.3° C.) a wet-bulb temperature in excess of 92° F. (33.3° C.) is likely to prove intolerable within a few hours for many trained and acclimatized lightly clad men engaged in moderate activity even when radiant heat is not an important factor and the air is circulating briskly. Anything above 88–89° F. (31.1–31.7° C.) wet-bulb temperature may cause incapacitation with a dry-bulb temperature of 120–130° F. (48.9–54.4° C.) (Ellis *et al.*, 1954.)

If warships which are not air-conditioned are closed down in tropical waters, to protect against the hazards of flash

burns, flooding, or air contaminated with harmful chemical, biological, or radioactive particles or droplets, a rise in wet-bulb temperature of anything from 5 to 14° F. (2.8 to 7.8° C.) or more will occur in a few hours, and varies with the number and activities of the occupants and the size of the compartment. When the starting wet-bulb temperature is already well into the eighties an intolerable state of affairs is thus likely to force the evacuation of some spaces before very long. The value of air-conditioning for British ships in the Persian Gulf was recognized by Forbes Guild as long ago as 1940, and its success in submarines later in the war provides an outstanding example of effective control of the thermal environment in confined spaces (Logan, 1944). When air-conditioning is not available under very warm conditions the adverse effect of "still" air, and the benefit derived under most circumstances from creating turbulent air currents with high-velocity ventilation terminals, ceiling or table fans, or by natural means, cannot be stated too strongly. In certain severe closed-down situations, however, this may be of little avail or may even add to the stress. There should always be facilities for men who work in very hot spaces to recuperate in a cool space where cool drinking-water and a palatable salt preparation are available (Ellis, 1955).

At the other end of the temperature scale recent experience supports the opinion of the 1937 Committee that in northerly or southerly waters air temperatures between 60 and 65° F. (15.6 and 18.3° C.) are preferred by most men living and working between decks and wearing conventional clothing, and are usually attainable. Thus attention now is focused more on the design of clothing and equipment which will keep a man warm and dry on the upper deck without impairing his working efficiency.

Oxygen and Carbon Dioxide

When crowded compartments are closed down for prolonged periods the atmospheric oxygen is used up and the carbon dioxide level rises. These changes also vary with the

Carbon dioxide and oxygen content of the air in a sparsely occupied non-air-conditioned living space and in a crowded air-conditioned working space of a ship closed down.

carbon dioxide, unless the alternative of restoring the air supply and filtering it of potentially harmful agents was acceptable. In submarines carbon dioxide levels will be in the region of 3% of one atmosphere, and mild anoxia is unavoidable at the end of a long day's dive if no corrective measures are applied. An accurate knowledge of the composition of the atmosphere and of the acceptable limits

will become of increasing importance as the underwater endurance of these craft is increased, and is essential to our understanding of life in enclosed spaces.

Barometric Pressure

Changes in barometric pressure were not usually an important feature of the shipboard environment until the advent of the schnorkel, when they were investigated during the first prolonged underwater cruise completed by a British submarine (Ellis, 1949). The air-supply inlet at the upper end of the schnorkel mast is fitted with a float valve which closes off the air duct when the air inlet dips beneath the surface, as it may in a choppy sea, or if the men controlling the hydroplanes make a mistake in depth-keeping. The suction of the engines and the resistance of the narrow air duct cause a negative pressure within the craft which increases with the speed under water and the related demands of the engines. Novel features included (1) reduced barometric pressure; (2) concurrent mild anoxia equivalent to flying at between 4,000 and 5,000 feet (1,220 and 1,520 metres); (3) pressures fluctuating every few minutes between values equivalent to those encountered at altitudes of 4,000 to 8,000 feet (1,220 to 2,440 metres); (4) more violent pressure fluctuations, when the depth control was faulty, which gave rise to otitic, sinus, or dental barotrauma; and (5) traces of carbon monoxide from the schnorkel exhaust gases with a following wind or from unexpected submergence under diesel propulsion. These were reduced to a minimum by modifications in the equipment and operating procedures, by training and selection of crews, and by eliminating the unfit.

Bacterial Content of the Air

Repeated wartime epidemics of respiratory tract infections in ships also prompted an investigation of the bacterial content of the air in a newly built cruiser and a submarine in 1945 (Ellis and Raymond, 1948). Previous investigations on shore had suggested that counts of bacteria-carrying particles exceeding 50 per cubic foot (1,760 per cubic metre) of air were undesirable. In most of the working compartments of the cruiser this level was not usually exceeded, but it was on the mess-decks, particularly when there was much activity, in the bathrooms in the morning, and in the sick bay when cots were made up. Dust-laying precautions and the correct use of handkerchiefs were advised during epidemics. The relative importance of the control of dust and infected airborne particles and of direct contact in cross-infection is, however, still debatable (Seal, 1953); and when overcrowding is unavoidable the aim should be to control infectious material at its source by measures such as mass radiography, mass immunization, as effective and otherwise acceptable vaccines become available, or mass chemoprophylaxis during epidemics (Seal, 1955). The air in the submarine was remarkably free of bacteria whether it was submerged or on the surface. This may have been because about 365 cubic feet (10.3 cubic metres) of "breathable" air was available for each man or because bacteria-carrying particles adhered to oily machinery as the air was recirculated through the engine-room and other machinery compartments.

Preliminary tests in an air-conditioned space in the cruiser and in a climate-controlled laboratory in London indicate that a build-up of bacteria-carrying particles in the air does not occur even when the air is completely recirculated for a few hours; but this aspect, and particularly the effect of prolonged recirculation, merits further investigation.

Fresh Air Supplies

The minimal supplies of fresh air which will permit men to live a comfortable, healthy, and efficient existence in an enclosed space are thus influenced by a variety of factors. Unrestricted heavy tobacco smoking causes malaise, headaches, and upper respiratory tract irritation. Consolazio and Pecora (1946) have concluded that, with air cooling, 5 cubic feet (0.15 cubic metres) of air per man per minute suffices

to keep body and tobacco odours at acceptable levels. When they used activated carbon filters with air cooling even 1 cubic foot (0.03 cubic metre) per man per minute was found to be adequate, and carbon dioxide, carbon monoxide, bacteria, and dust did not reach "noxious or objectionable levels." In the United States Navy a fresh air supply of 5 cubic feet (0.15 cubic metres) per man per minute is the minimum required by design for air-cooled compartments, although, for other reasons, this amount is usually exceeded in practice. In the Royal Navy at least 10 cubic feet (0.3 cubic metre) per man per minute is supplied in air-cooled compartments when the cooling is in operation. For compartments with normal ventilation an allowance of 10 cubic feet (0.3 cubic metre) per man per minute is added to the amount which is calculated to be necessary to get rid of the heat within the compartment. The total quantity must be equivalent to at least 30 cubic feet (0.9 cubic metre) per man per minute.

Little is known about the effects of prolonged or repeated residence in a totally enclosed space. There is no obvious reason why serious adverse effects, other perhaps than those of a psychological nature, should occur if the equipment for controlling the temperature and composition of the air is efficient and is used correctly. However, ill effects due to the contamination of air by harmful chemicals were not very uncommon in the Navy in wartime, particularly when ventilation was restricted (Weiner and Thomson, 1947; Ellis, 1952c). The possibility should not be forgotten that in an unventilated or poorly ventilated space small amounts of contaminants, such as the breakdown products of fuels, lubricants, paints, or similar chemical substances, which are innocuous in a ventilated compartment, may affect men adversely if exposure is prolonged or repeated.

Conclusion

The environmental health of a community contributes to what Richmond (1947) has termed its "positive health." Serious defects in the environment may not be reflected by obvious "negative health." It is thus advisable to supplement the bald records of sickness in the Navy by measuring the environmental factors and relating these measurements to established criteria of what is or is not desirable. New instruments and techniques are helping to close many of the gaps which hampered this work in the past; and, largely as a result of the stimulus of the Royal Naval Personnel Research Committee, firm answers are being obtained to many questions which were formerly controversial. The requirements of the men must be appreciated against a complex background of material needs and tactical situations, and this is the task of various working groups and panels, which include not only leading scientists and naval medical officers but representatives of the Naval Staff, the Admiralty Materiel Departments, and the Naval Scientific Service. This arrangement provides a powerful but flexible instrument with which to tackle the many problems of the ever-changing naval environment, to only a few of which I have referred here.

This account is published by the kind permission of Surgeon Vice-Admiral Sir Alexander Ingleby-Mackenzie, the Medical Director-General of the Navy. The data in the Chart are abstracted from an unpublished report to the Royal Naval Personnel Research Committee by Surgeon Lieutenant-Commander R. T. John, Royal Navy, Dr. R. K. Macpherson, Mr. P. S. B. Newling, and myself.

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POST-TRAUMATIC INOCULATION TUBERCULOSIS

WITH A REPORT OF A CASE OF TUBERCULOUS INFECTION IN A SCALP WOUND

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Tuberculous infection in a skin wound is a rare but well-known condition. Of 2,114 cases of primary tuberculosis reported by various investigators, Ghon and Kudlich (1930) found 3 (0.14%) to be primary tuberculosis of the skin. Sallick (1939), reporting a case of probable primary inoculation tuberculosis of the skin, stated that a recognized example of this condition had never been seen before at the Mount Sinai Hospital, New York. The commonest sites for this condition are the fingers and the dorsum of the hand, and one of the earliest cases reported, by Tscherning in 1888, was that of a servant who contracted tuberculous infection in a finger, with subsequent lymphatic involvement, after wounding the finger on a sputum cup used by a tuberculous master. The local lesion is given several names—post-mortem wart, dissection tubercle, anatomical tubercle, pathologist's wart, and verruca necrogenica