ATMOSPHERE CONTROL IN NUCLEAR SUBMARINES

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Nuclear submarines are required to stay submerged for periods of up to 75 days continuously without access to the outside atmosphere. During this time, the atmosphere enclosed within the submarine from the moment of diving must be controlled so that the complement of 100 or more are able to carry out their duties efficiently and so that their long-term health is not hazarded.

The Philosophy of Respiration

To remain alive, human beings need a continuous supply of energy. This is provided by burning certain constituents of food bio-chemically with oxygen. The waste products of combustion include carbon dioxide and water. Oxygen from the inhaled air passes through the lung membrane to the blood stream which carries it to the various parts of the body. In exchange the blood carries the carbon dioxide back to the lungs for expiration.

For prolonged submergence in an enclosed atmosphere it is necessary to provide an adequate supply of oxygen and to maintain levels of other gases within acceptable limits. The biologically significant quantity of any gas is expressed by its partial pressure in the presence of other constituents since this rather than its percentage volume determines its effect on the body. So it is necessary to maintain the partial pressures of oxygen and carbon dioxide within set limits as ambient pressure varies.

The composition of air at the standard total pressure of 760 mm of mercury is 79 per cent. nitrogen, 20·9 per cent. oxygen and 0·04 per cent. carbon dioxide. Thus the oxygen exhibits a partial pressure of 20·9 per cent. of 760 mm which is 159 mm of mercury.

Physiological effects from oxygen deprivation can arise from a reduction in the partial pressure, the first functions to be affected being night vision and reliability of judgement. The accepted minimum oxygen level for proper alertness is 137 mm mercury. This is equivalent to an 18 per cent. concentration by volume at standard pressure or a pressure of 654 mm mercury for the standard concentration of 20·9 per cent.

An oxygen-rich atmosphere supports combustion and so fire risk dictates that the oxygen partial pressure should not exceed 167 mm mercury which is equivalent to 22 per cent. concentration at standard pressure.

For nuclear submarines the aim is to keep the oxygen concentration at normal pressure between 20 per cent. and 21 per cent., that is between 152 mm and 160 mm mercury partial pressure. This also avoids combination effects with contaminants in the air.

The effects of carbon dioxide as its partial pressure increases are progressively slight fatigue, severe headaches accompanied by difficulty in breathing and eventually unconsciousness and death at very high levels. The effects are aggravated by smoking, presence of carbon monoxide or reduced oxygen level. For long term exposure, a maximum level of 1 per cent. concentration is set to avoid the metabolic changes which occur at higher concentrations.

Acceptable Levels of Atmospheric Contaminants

Although pollution is an emotive word these days, industry and the submarine world have been concerned with it for many years. Threshold limit values—known as TLVs—for very many substances, have been determined on the basis of exposure for an 8-hour day, 5-day week, and are applied throughout industry. The submariner, however, is on board for 24 hours a day and 7 days a week and so he is exposed to any contamination for about four times as long without the chance to cleanse his lungs and blood stream in the outside atmosphere. It is obvious that rather lower limits than TLVs are necessary in nuclear submarines. At the start of the nuclear submarine programme the TLVs were extrapolated to levels safe for continuously submerged periods of 90 days. The term applied to these levels is Maximum Permissible Concentrations—known as MPCs. These are under continual review as knowledge is gained and MPCs are also assessed for the by-products of new materials as they become available.

MPCs are most frequently expressed in parts per million (ppm), that is the number of parts of the particular component in one million parts of air. For particulate matter, such as occurs in smoke or aerosols, it is usual to express the MPC as a weight per volume ratio, the common unit being milligrams per cubic metre. For example, the MPC for carbon monoxide can be expressed either as 25 ppm or 27·5 mg/m^3.

Atmospheric Contaminants

The chief abnormal constituent of submarine air is *carbon monoxide*. This combines with the haemoglobin in the blood to form a relatively stable compound which blocks the carriage of oxygen by the blood-stream. Since the affinity of CO for haemoglobin is about 200 times that of oxygen, only small amounts of it present in the air will cause toxic effects. The main source of CO is smoking and indeed the level of CO saturation of the blood depends on the smoking habits of the individual as well as on atmospheric concentration. Some impairment of judgement may occur at blood levels above 10 per cent. saturation. This level may be reached in a 20 cigarettes/day smoker in an atmospheric level of 25 ppm of CO which is set as the MPC to allow unrestricted smoking on board. If the MPC is exceeded then smoking must either be restricted or prohibited. Other sources of CO include cooking and overheating of electrical equipment or oil soaked lagging.

Hydrogen is evolved from lead acid batteries and may leak from high pressure systems. Whilst not a risk to health, a level of 4 per cent. provides a potentially explosive mixture and an MPC of 2 per cent. is accordingly set for safety.

The various *freons* used as refrigerants are biologically nearly inert and have a mild narcotic effect at high concentrations. The vapours are heavy and can cause a reduction in oxygen levels in bilges following spillage. However, the main problem with refrigerant vapours is that when heated they break down into respiratory irritants some of which are also corrosive to hardware—such as hydrogen fluoride and hydrogen chloride. Breakdown can occur at the tips of lighted cigarettes and points of electrical arcing. The MPC for freon 12, used in the submarines, is set at 500 ppm and, if this level is reached because of the danger of direct inhalation of the breakdown products, smoking must cease.

Many other air-borne constituents have been identified in the submarine atmosphere which can have harmful effects if the MPCs are exceeded. The overall approach for dealing with the problem is to avoid the source where possible, to circulate the air through suitable eliminators and to monitor continuously the state of the atmosphere.

Many materials release vapours into the atmosphere—for example, paints and adhesives, cleaning agents, insulants and lubricants. Some materials, while themselves acceptable, are associated with a material which is not; for instance, aerosol spray cans are usually operated by freon under pressure. Many materials produce toxic gases when heated. It would be virtually impossible to build a nuclear submarine if all of these were ruled out and so all materials which it is proposed to use are investigated. From this, a Materials Toxicity Guide has been prepared in which are listed all banned materials and others to which constraints are applied. For instance, the use of certain paints must be discontinued not later than 5 days before a submarine dives and the filters used to absorb the vapours released must be replaced immediately before diving.

Air Purification Equipment

The traditional method of providing oxygen which is still used for patrol submarines and for escape purposes in all submarines is to burn oxygen candles. The candle is placed in an oxygen generator which has a heating element to start the reaction and produces about 66 ft^3 of oxygen.

For nuclear submarines with large crews which stay submerged for long periods, the space and weight required for sufficient oxygen candles or for sufficient bottled oxygen is excessive. An electrolyser is used instead to provide oxygen by the electrolysis of water.

Demineralised water, to which an electrolyte has been added, is contained in a pressure vessel. A high current at low voltage is applied between an anode and cathode to split the water into its oxygen and hydrogen ions. Molecules of the gases can then be removed from the liquid, the oxygen being bled into the submarine atmosphere and the hydrogen being discharged overboard.

Carbon dioxide is removed from the atmosphere of patrol submarines by passing the air through canisters of soda lime and this method is used for escape purposes in all submarines.

A CO_2 scrubber has been developed for this duty in nuclear submarines. It uses an organic chemical called monoethanolamine—more commonly referred to as MEA or amine. The atmosphere containing CO_2 is forced through a bed of amine foam which removes the CO_2. On heating, the CO_2 is released, the clean air is vented back into the submarine atmosphere and the CO_2 is compressed and discharged overboard.

No special measures are necessary to remove carbon monoxide if smoking is prohibited or if the atmosphere can be purged—such as by snorting—at regular intervals. Since nuclear submarines are required to stay completely submerged for long periods and because of the effect on morale if smoking

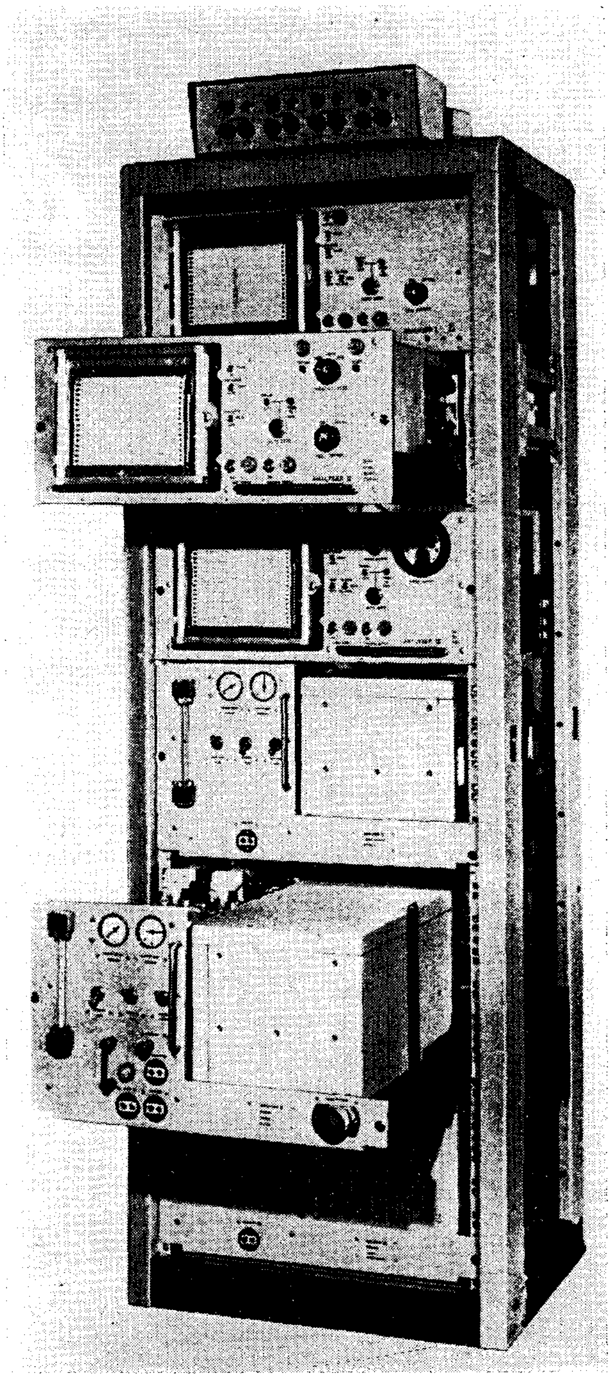

FIG. 1—PYE ATMOSPHERE ANALYSER

was not allowed at all, a catalytic burner has been developed. This removes hydrogen as well as carbon monoxide from the atmosphere, and also oxidises hydrocarbons.

Other equipment fitted includes activated charcoal filters; these are used to absorb a wide variety of contaminates such as vapours from cooking and diesel fuel and certain hydrocarbons. Electrostatic precipitators are fitted to remove dust and fine aerosols from the atmosphere.

Equipment under development includes a freon burner to absorb vapours released from refrigerant systems and a molecular sieve. The latter is a solid absorbent capable of removing many contaminants from the atmosphere including carbon monoxide, carbon dioxide, hydrogen and freons.

Atmosphere Monitoring

The simplest equipment is the Draeger tube—rather similar to the breathalyser. This works on the principle that a gas or vapour can cause a colour change of a chemical. The glass tube is packed with a chosen chemical in granular form and air is drawn through it by means of a hand pump. For a given volume of air pumped through the tube, the length of the chemical that changes colour indicates the concentration of the contaminant. A variety of tubes are carried to detect various possible contaminants.

There is also a range of other portable instruments, of which the principle ones used are for the detection of hydrogen, oxygen, CO_2, freon 12 and MEA.

Continuous monitoring for major atmospheric contaminants is provided by automatic analysers which give readings of levels and which operate alarms if set levels are exceeded. The type in use in nuclear submarines is based on gas chromatography. This is the technique of dividing a mixture into its component parts by making use of one or more of their physical properties. The system works on the principle that the components have different transit times when flushed through a suitable packed column by a carrier gas.

In the Pye gas chromatograph now in service use, three analysers are fitted all using high purity argon as the carrier gas. The first analyser searches for

FIG. 2—ENVIRONMENTAL MEDICINE UNIT AT THE INSTITUTE OF NAVAL MEDICINE

CO and freon 12, passing samples through a column packed with alumina. The second analyser determines the presence of particular hydrocarbons—benzene, toluene and zylene—passing samples through two columns packed with different substances. The third analyser determines the concentration of carbon dioxide, hydrogen and oxygen and uses four columns. A variety of detectors are fitted and a continuous print-out can be obtained.

An alternative analytical instrument is the Mass Spectrometer. This works on the principle that when an air sample is electrically charged and passed through a magnetic field the different behaviour of component gases can be detected and their proportions measured. Mass spectrometers are coming into use in USN nuclear submarines, and are under consideration for development for our submarines.

In spite of modern technology, traditional methods die hard—a canary was recently embarked for an SSBN routine patrol!

The Future

Mention has been made of some of the development work in hand on equipment and instrumentation.

Since the health of individual members of the crew is all-important, studies are undertaken into the effects of exposure to high levels of contamination. In the Environmental Medical Unit at the Institute of Naval Medicine at Alverstoke near Portsmouth, experiments are being carried out with naval volunteers. The first series is investigating the effect of various levels of carbon dioxide and will be followed by exposures to various levels of carbon monoxide. These will allow the maximum permissible concentrations to be re-defined in the light of the latest medical information.