# 15

## *Diving Equipment for Underwater Warfare in the Second World War*

Reference to the historical chapter in Part II of this book shows that the efforts of man to make use of the stealthy, covered attack under water, in order to surprise his enemies, go back to the earliest recorded times. It is particularly interesting to note that at the Siege of Tyre in 333 B.C., Alexander the Great employed divers to destroy the boom-defences of the harbour. The proposal described and illustrated (Fig. 576) for the destruction of enemy vessels by placing explosives under their hulls, during the Crimean War, however impractical, has a strong flavour of what was finally to be accomplished during the Second World War.

In 1914 the author designed and patented equipment which resulted in the development of the "human torpedo" and the midget submarine, or X-craft, used during the recent war. These designs, more fully described and illustrated in Part II, Chapter 4, embodied the idea of divers wearing self-contained breathing apparatus riding on a small torpedo; and, in the case of the midget submarine, a special emergence chamber in the craft which could be flooded and emptied by controls, enabling a diver wearing self-contained apparatus to leave the submarine, place his explosive charge on the enemy vessel and then return. Alternatively, the diver could obtain his air supply by means of flexible hose and reducing valve from compressed air cylinders in the vessel.

These ideas, however, seemed to be before their time, as the trend at that period was for larger, not smaller, submarines, and they were not put into practice.

It was left to our former enemies, the Italians, to introduce this mode of underwater attack for the first time, in 1941, when they attacked ships at Gibraltar and damaged the battleships *Queen Elizabeth* and *Valiant* in Alexandria harbour. However, once started, this country beat them at their own game.

### EXPERIMENTAL DIVING DURING THE SECOND WORLD WAR

Early in 1942 the Admiralty decided to develop in great secrecy and at very high priority, both the human torpedo and midget submarine (or X-craft). Both schemes were under the control of Admiral Sir Max K. Horton, K.C.B., D.S.O., then Admiral Commanding Submarines. To Siebe, Gorman & Co. Ltd. in conjunction with Lieutenant-Commander (now Captain) W. O. Shelford, R.N., Davis Submerged Escape Apparatus Instructional Officer H.M.S. *Dolphin*, and, later, Superintendent of Diving, H.M.S. *Vernon*, fell the task of developing and producing the special diving equipment required for these ambitious schemes. Such diving operations had never before been attempted on such a scale in this country.

Commander (now Captain) G. M. Sladen, D.S.O., D.S.C., R.N., fresh from his exploits in command of H.M. submarine *Trident*, was appointed in general charge of the "Human Torpedo" or "Chariot" (as it was known in the Royal Navy) scheme and Siebe, Gorman & Co. had the pleasure of many visits from this distinguished officer.

Early experiments soon showed that there were a number of unexpected problems with which to contend. The Admiralty Diving Committee, which had been formed under the chairmanship of Rear-Admiral R. B. Darke, C.B., D.S.O., Captain of the Fifth Submarine Flotilla, H.M.S. *Dolphin*, decided to establish the Admiralty

Experimental Diving Unit with its headquarters at Siebe, Gorman & Co.'s works at Tolworth.

This Unit consisted of a team of experimental divers, with diving officers and instructors to supervise the diving, medical officers and laboratory assistants and secretarial staff. The Medical Officer was Surgeon Lieutenant-Commander K. W. Donald, D.S.C., M.D., R.N., who was later joined by Surgeon Lieutenant-Commander (now Commander) W. M. Davidson, M.B., B.CH., R.N. The whole was under the command of the Superintendent of Diving.

Professor J. B. S. Haldane acted as adviser on certain physiological matters, and carried out a number of experiments on himself and his colleagues.

The whole of Siebe, Gorman & Co.'s experimental plant and equipment, and the facilities of their factory were placed voluntarily and unreservedly by Sir Robert Davis at the A.E.D.U.'s disposal. Thus, in a very short time after its inception, the Unit was able to start a most comprehensive experimental programme.

The first need was the development of a lightweight suit for the "Chariots", with a breathing apparatus of no less than six hours endurance under water; this is described in detail later. The depth required was comparatively shallow, so it was possible to use oxygen apparatus on the regenerative principle.

During the development of this set, however, it became obvious that some of the previously accepted limits for time and depth under water, when breathing *pure oxygen*, were somewhat misleading. As described in Chapter 1, it was early demonstrated that, whereas a pressure of three atmospheres absolute can be tolerated by most men when breathing pure oxygen under pressure in a pressure chamber, only two atmospheres absolute—equivalent to a depth of 33 feet—could be tolerated for any length of time by men actually under water. This might have proved a serious handicap to the projected operations, and it was imperative that more information should be obtained and passed on to the training and operational bases without delay. For this reason, for many years before the war, Siebe, Gorman & Co. had used, with specially-trained divers, pure oxygen and mixtures of oxygen and nitrogen for different depths. But with the large number of men unused to this form of diving equipment now to be trained, and the very diverse reactions of different individuals to oxygen or mixtures under pressure, the Admiralty very wisely decided to carry out a large number of experiments on different subjects in order to arrive at a formula which suited every man.

The A.E.D.U. undertook what was probably the most exhaustive programme of human experiments ever attempted on one aspect of diving. In all it involved over a thousand actual dives in "toxic" depths of water, and a large number of "dry" experiments. Many of the dives were taken to the point of unconsciousness and convulsions, and the young divers of the Unit showed great courage in submitting themselves cheerfully to these experiments. In spite of the risk and unpleasantness of the job, the experimental department was always a scene of cheerful activity.

The divers invented a mythical monster known as "Oxygen Pete" who was supposed to lurk at the bottom of the "Wet Pot", as the high pressure water chamber was called, ready to pounce on the unwary diver. Keen competition grew among the divers as to who could outwit "Pete" the longest, and so familiar did he become, that "getting a Pete" is now almost an accepted term of diving physiology.

## MIDGET SUBMARINES WITH DAVIS EMERGENCE (ESCAPE) CHAMBER

When the Admiralty decided to produce a prototype midget submarine, the author received a number of visits from the late Commander C. H. Varley, R.N. (retired), to discuss a suitable type of breathing apparatus to be worn by the crew, and also the smallest practicable size of emergence chamber, of the author's design, to accommodate the men

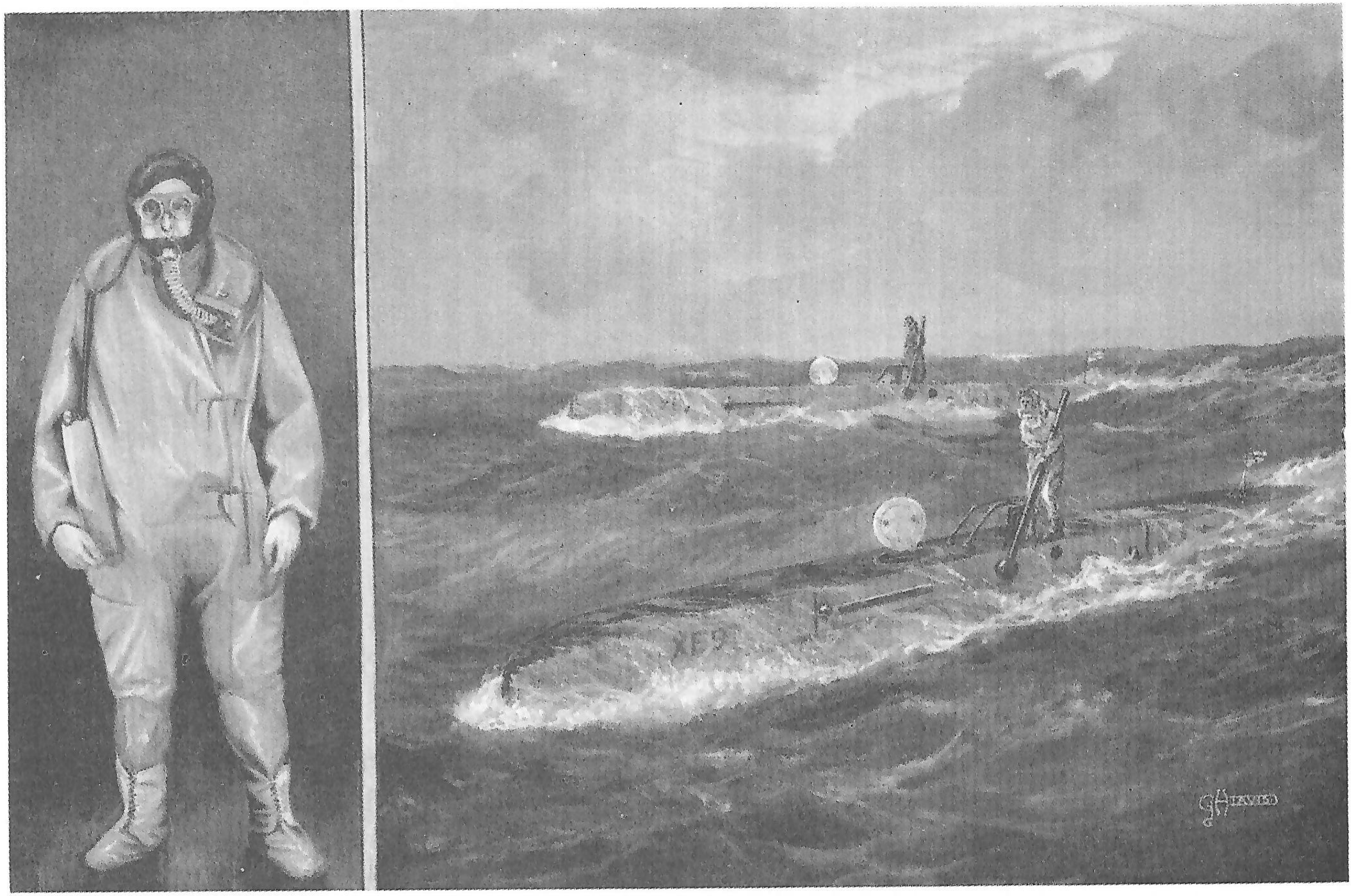


Fig. 286. Midget submarines (X-craft) on the surface, showing Siebe, Gorman & Co.'s special suit for the watch-keeper

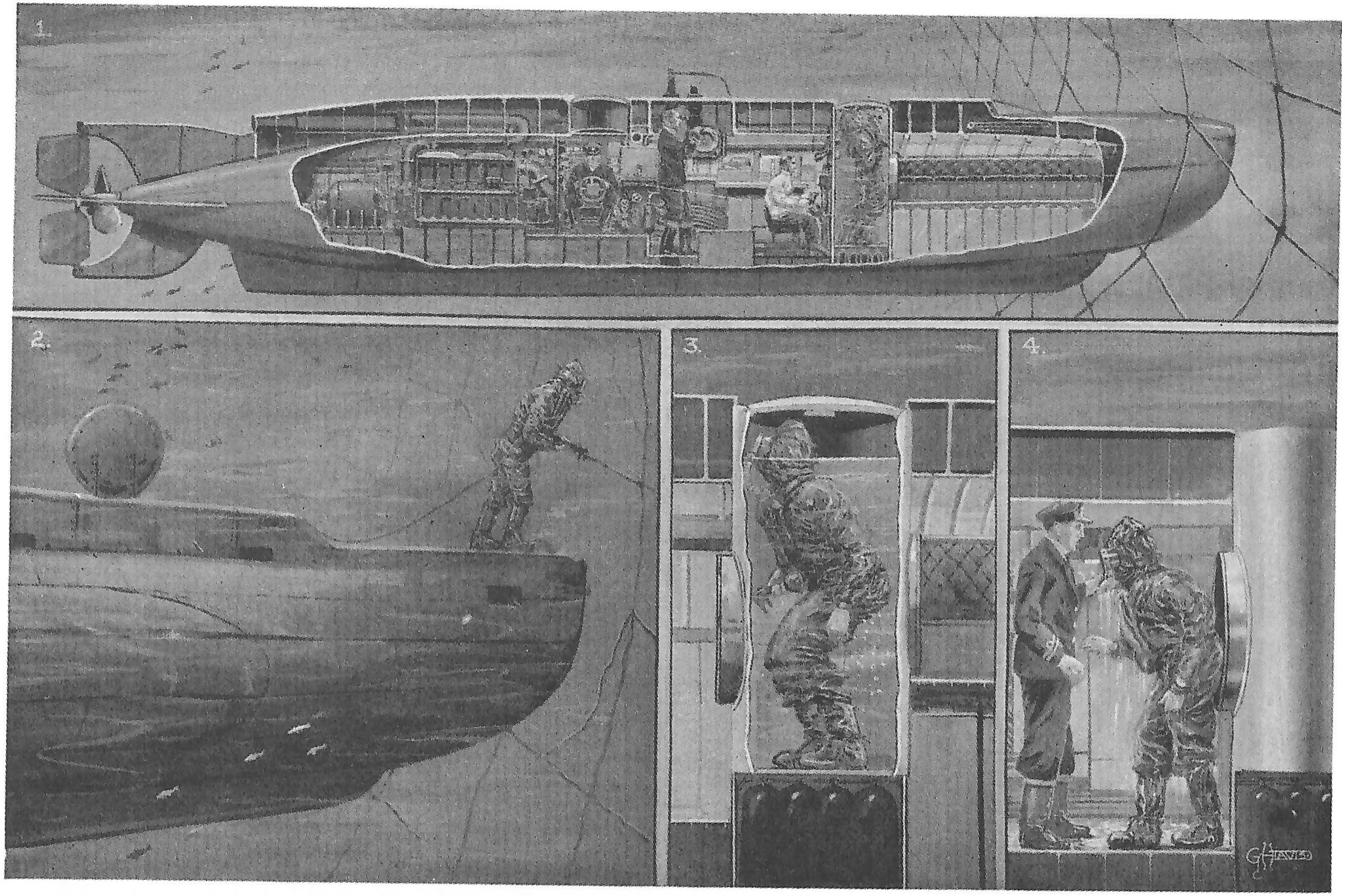
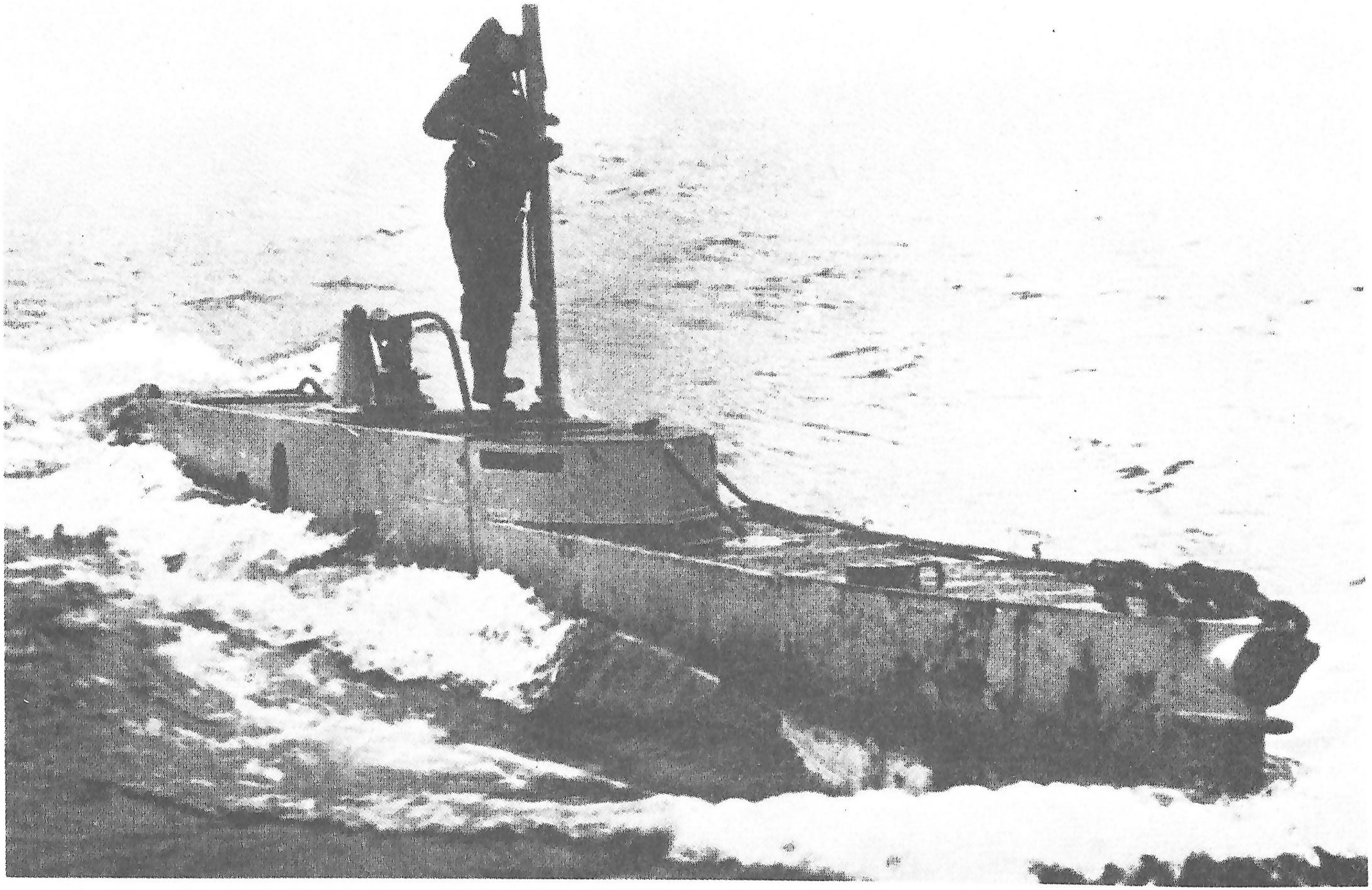



Fig. 287. (1) Section of midget submarine caught in anti-submarine net. Diver in flooded Davis emergence chamber about to open upper hatch. (2) Diver, having emerged, cutting the net. (3) Diver returned to emergence chamber which is emptying of water. (4) Diver returning to submarine



*Official Admiralty photograph*

Fig. 288. X-craft under way showing a member of her crew on the deck by the periscope

Various types of breathing apparatus were made by Siebe, Gorman & Co., and were demonstrated under water in the Company's experimental department. Commander Varley, on behalf of the Admiralty, had a wooden "mock-up" made of the emergence chamber and sent to the Siebe, Gorman works, in order to test with what facility a man, equipped with breathing apparatus, could operate the chamber as originally intended, viz.:

(*a*) From the submarine's compartment to enter the lower door of the emergence chamber, (*b*) close the door, (*c*) flood the chamber and open a valve to release the trapped air, thus equalizing the pressure in the chamber with the outside sea pressure, (*d*) open the upper hatch, (*e*) leave the vessel, (*f*) simulate the placing of an explosive charge on an enemy vessel, which was represented by a steel plate slung by a cable, (*g*) return to the emergence chamber and close the upper hatch, (*h*) expel the water from the chamber, and re-enter the compartment.

We were able to make several recommendations to Commander Varley. During the discussions, we also received letters and a visit from Admiral Sir Max K. Horton, K.C.B., D.S.O. Other visitors who were interested in similar projects were Major M. R. Jefferis and Captain K. Lund, on behalf of the War Office, the former in connection with amphibious tanks, the latter with a one-man submerged pedalling machine.

A "mock-up" in steel of the escape chamber and adjoining compartment, as already described, was produced and tried in the 60-feet deep torpedo testing tank at Portsmouth, the members of the crew (two at a time—one to work and leave the emergence chamber, the other to remain in the compartment for various duties) being Commander Varley, Commander Scott, Professor J. B. S. Haldane, Major Jefferis, and Captain Herbert, R.N. (retired), all of whom used the Davis submerged escape apparatus in the trials.

On different dates, the steel "mock-up", with its crew of two, was lowered on a platform to various depths; for example, on August 20th, 1940, to the 20-feet level with Commander Varley as the diver and Commander Scott in charge of the compartment; and again, later the same day, to the 25-feet level. The following day the same two occupants went to 40 feet. Other tests, in which all the above-mentioned took part, were later carried out at depths of 15 and 20 feet.

Mr. C. H. Burwood, R.N. (retired), of Siebe, Gorman & Co.'s staff, represented the firm at the trials.

The author was informed that the trials were considered very satisfactory, and the Admiralty proceeded to have their first midget submarine built. The world knows with what success the prototype and subsequent similar vessels were employed. He makes no claim to the design of the midget submarine vessel itself, of which several different forms have been produced from time to time. His sole claim is to its emergence, or escape, chamber, used in conjunction with self-contained breathing apparatus, as designed by him in 1914 (Patent 2562 of 1915).

At the same time, the firm made various close-fitting suits for the divers of midget submarines and by a process of trial and error a satisfactory suit was evolved and finally adopted for use. The divers were carried as part crew of the submarine primarily to cut the vessel's way through anti-submarine nets. As these little ships could keep the sea for a number of days, the diver could not be expected to wear his equipment all the time after leaving the base and would have to dress on board in a very confined space. At first, too, it was required that the diving apparatus should be capable of being worn as a protective suit when watch-keeping on the surface, and to act as a lifebelt should the officer on deck be washed overboard.

This problem, then, was not so much one of physiology or the development of special breathing gear, but of the ingenious construction of a suit which could fulfil all the above requirements. Many ideas were tried, but discarded for one reason or another. Finally, two suits were accepted, one a modified version of the "Sladen" gear for the underwater requirement, and the other a special light suit for surface watch-keeping.

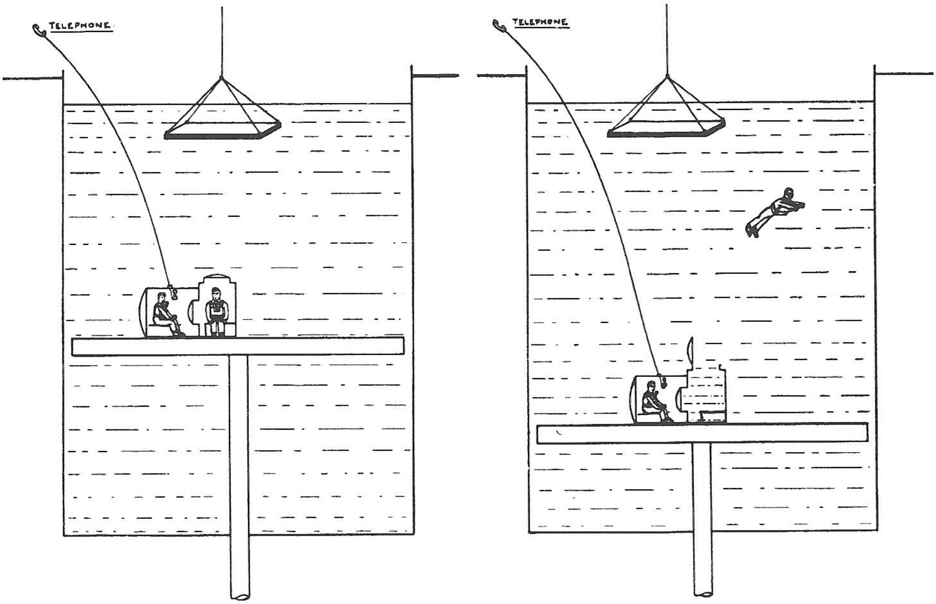



Fig. 288A

Diagrams showing how the steel "mock-up" Davis emergence chamber for midget submarines was tested in a 60-feet tank at Portsmouth in August, 1940

These dresses and breathing apparatus were used in such historic operations as the crippling of the German battleship *Tirpitz*, and the attack on Japanese cruisers in the Johore Strait at Singapore, of which the following are brief accounts:

## ATTACK ON THE GERMAN BATTLESHIP *TIRPITZ*

The despatches published as a supplement to the *London Gazette* of February 10th, 1948, describing the attack by X-craft on the *Tirpitz* on September 22nd, 1943, in Kaafiord, Norway, tell an enthralling story of heroism, dogged determination and skill on the part of those engaged in this operation. Of the six X-craft which set out, in tow by S- and T-class submarines, three succeeded in pressing home the attack. One of these, the X.5, was lost with all hands, and its movements and actions are in doubt.

X.6 (Lieutenant D. Cameron, V.C., R.N.R.), blinded by periscope trouble and its gyro-compass out of action, was spotted by *Tirpitz* inside the anti-torpedo net surrounding the ship. Despite this, Cameron and his crew, with cool audacity, backed their craft until its stern was scraping *Tirpitz* hull, and released the charges. Realizing that escape was hopeless, Cameron destroyed his most secret equipment and scuttled his craft, the crew of four being picked up by the Germans.

X.7 (Lieutenant B. C. G. Place, V.C., D.S.C., R.N.) after having been caught in the nets, and having overcome incredible difficulties, succeeded in penetrating them. Taking his craft right underneath *Tirpitz*, Place dropped his charges. In trying to get away, more trouble was encountered with the nets, and by the time X.7 was clear of them so much gear was out of action that the craft was uncontrollable and broke surface on several occasions. Place, therefore, decided to surface and abandon ship in preference to using the Davis escape apparatus, owing to the depth charging to which they were being subjected. She surfaced alongside a practice target on to which Place stepped, but, unfortunately, before the remainder of the crew could escape, X.7 sank.

Two hours and forty minutes later, Sub-Lieutenant Aitken came to the surface, having escaped by means of the Davis apparatus. No trace was found of the other two members of the crew. Place and Aitken were taken prisoners.

Although not sunk, *Tirpitz* suffered very considerable damage and it was not until April, 1944, that she was able to leave her anchorage, and then only to be further damaged and finally destroyed by air attack, from which she had been virtually immune in Kaafiord.

## ATTACK ON THE JAPANESE CRUISER *TAKAO**

A later and equally audacious operation, demanding gallantry and determination of the highest order, was that carried out successfully against the 10,000-ton Japanese cruiser *Takao* in the Johore Straits, in July, 1945. A later type of midget submarine, the XE craft, was now in use. In this operation, the explosive charges were not to be dropped under the vessel, but were to be actually fixed to the enemy's bottom by the diver of the craft. XE.3 (Lieutenant Ian Fraser, V.C., R.N.R.) located *Takao* in very shallow water which hardly allowed room for the craft to get underneath the cruiser's bottom. After several attempts, in which he got stuck each time between the bilges of the cruiser and the sea-bed, Fraser eventually forced his way under the bottom, almost under the bridge. There he was, in a puny 39-ton submarine firmly wedged between the bottom of a 10,000-ton cruiser and a hard sea-bed, being squeezed tighter and tighter on a falling tide. When the diver, Leading Seaman M'Ginnes, V.C., started to leave the craft to affix his mines, he found that the hatch could only be opened a quarter distance, as it fouled the *Takao's* bottom.

Nothing daunted, he deflated his breathing apparatus and managed to squeeze through the restricted opening. But his troubles were by no means over, for he found that the cruiser's bottom was so fouled with weeds and barnacles that the magnets of the mines would not stick. Back he went into his craft, fetched some rope and lashed the mines to the keel, having scraped off some of the barnacles with his bare hands to give the magnets a chance of holding. When he returned to his craft he was so exhausted that he could only just operate the valves for draining the emergence chamber.

Fraser now had the task of extricating his craft. For 50 minutes, which must have seemed like years, he tried everything that ingenuity could devise, going full speed ahead and full astern, pumping tanks and blowing them, and doing many other things besides. Then, without warning, he suddenly shot astern and, out of control, broke surface with a large splash only a few yards away from a liberty boat full of Japanese sailors, and less than 50 yards from the *Takao*. Without delay, he flooded everything and bottomed with a bump. During this eventful period, one of the mine containers had been damaged and was clinging to the starboard side of XE.3, making it unmanœuvrable. Without hesitation, M'Ginnes, armed with tools, again left the craft, put things right and returned. Fraser then steamed away and safely rejoined his parent submarine *Spark*. Fraser and M'Ginnes were awarded Victoria Crosses, and the remainder of the crew high decorations for this astounding operation.

## APPARATUS FOR MINE AND BOOBY-TRAP DISPOSAL

The Experimental Unit was next called in to assist in the counter-measures against the growing menace of German mine warfare. After the finding of the first magnetic mines, it became imperative that mines laid near the coasts should be examined before they were destroyed by sweeping, so that new methods of firing them could be detected at once. A number of officers and ratings were recruited for the hazardous task of examining and, if necessary, recovering these mines by diving on them. The use of ordinary diving equipment was prohibited, as it involved risk to too many lives in the diving boats, and various components were considered dangerous in the presence of

*Abridged account from "H.M.S. *Bonaventure*" by William Richmond in "Standeasy" (Clyde Reserve Fleet Magazine), December, 1947.

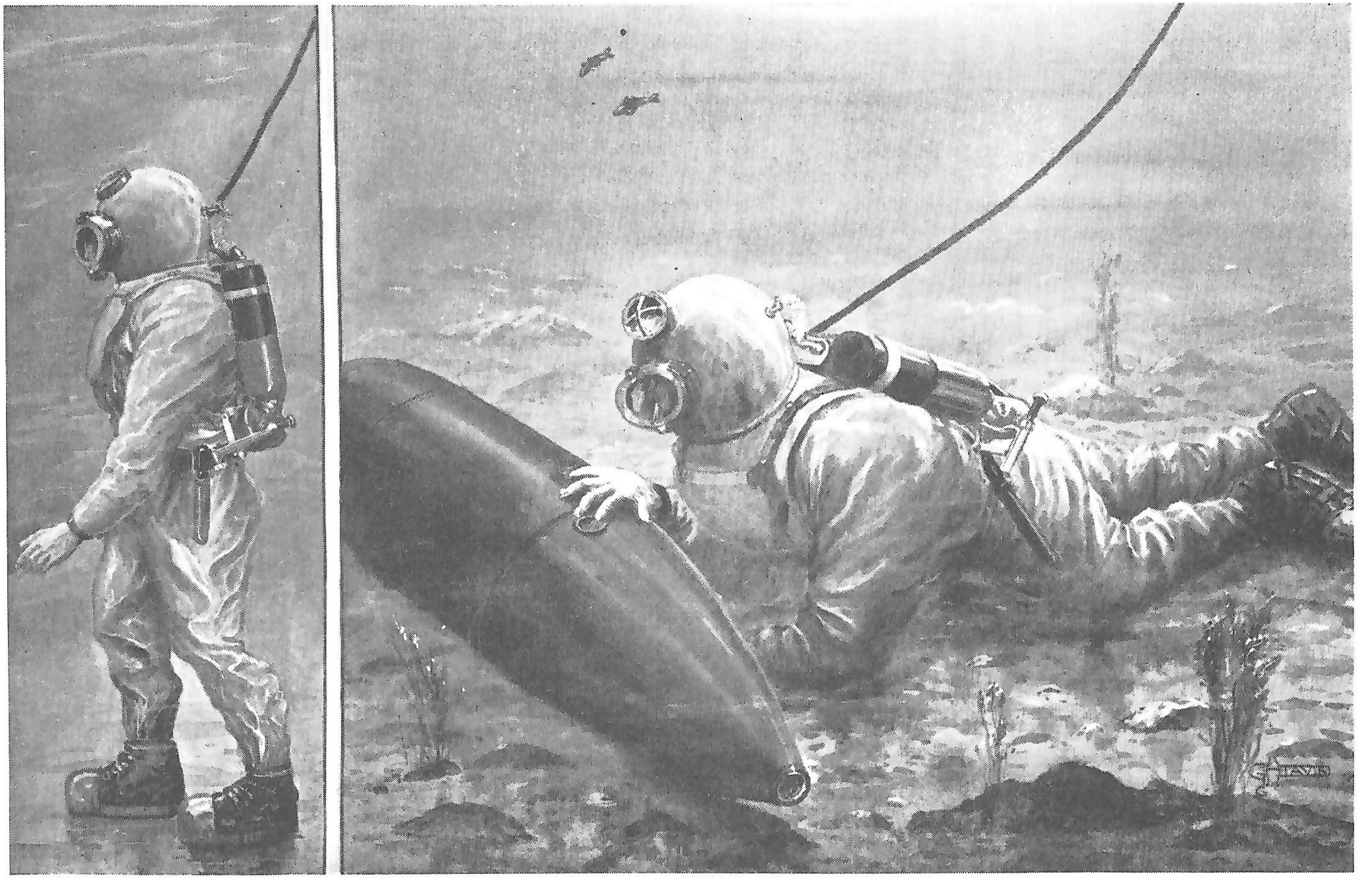


Fig. 289. Siebe, Gorman & Co.'s non-magnetic diving apparatus for rendering mines safe under water

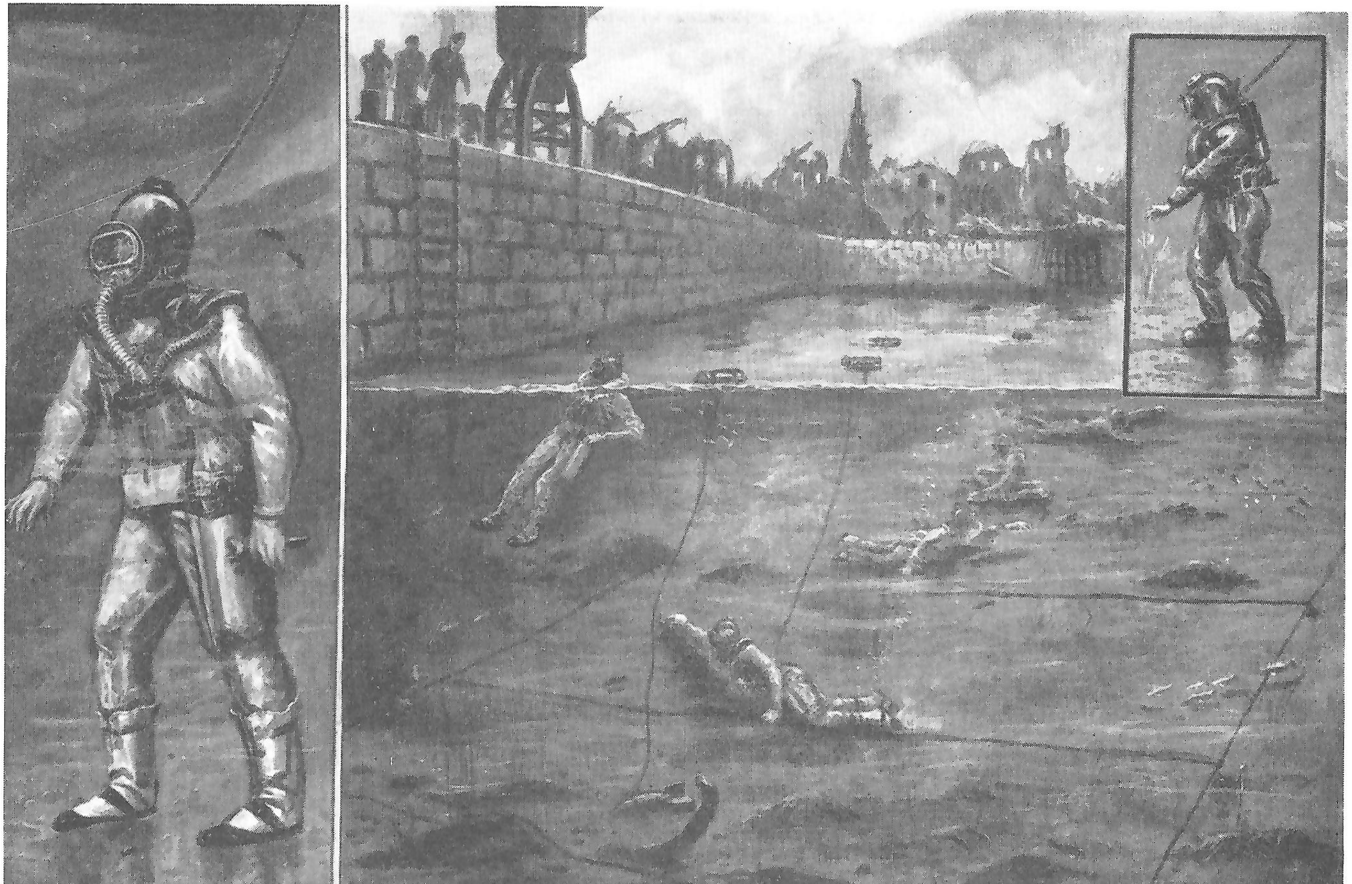


Fig. 290. Siebe, Gorman & Co.'s *"P-party" apparatus used for locating mines, booby-traps, etc. (Inset, top): Diver in M.R.S. who rendered them safe

* Now known as Clearance Divers.

magnetic and acoustic mines. It was desirable, too, for obvious reasons, that there should be no delay in regaining the surface, such as would be involved in the carrying out of routine decompression. Self-contained oxygen apparatus suggested itself, but the depth required was too great, as it may well be imagined that a visit from "Oxygen Pete" would have been most unwelcome when dealing with a mine.

The Experimental Unit further developed the oxy-nitrogen mixture system already used in Siebe, Gorman & Co.'s self-contained diving dress before the war. Formulæ were calculated so that suitable proportions of nitrogen and oxygen could be worked out for various depths and conditions in order that the risk of "bends" on the one hand, and of oxygen poisoning on the other, could be kept to a minimum.

This necessitated many more experiments, and a number of the officers and ratings of the Mine Recovery Section came to Siebe, Gorman & Co.'s works to take part and be trained in the technique of diving with these mixtures. Among the many officers may be mentioned Commander J. S. Mould, G.C., G.M., R.A.N.V.R., and Lieutenant-Commander L. V. Goldsworthy, G.C., G.M., D.S.C., R.A.N.V.R.

The experiments resulted in the adoption of the Siebe, Gorman Mine Recovery Suit (M.R.S.) (Figs. 289 and 305), a two-piece self-contained helmet suit (R. H. and R. W. G. Davis patent), using a mixture of oxygen and nitrogen which enabled the diver to surface freely from 72 feet without stops, and from 120 feet with only a few minutes on the shot rope. It was, in fact, possible to ascend immediately from 120 feet in emergency with only a slight risk of "bends".

Every piece of metal in this suit had to be non-magnetic; aluminium alloy cylinders were used and even such minor items as reducing valve springs and buckles on straps had to be specially made of non-ferrous metal. Non-magnetic steel knives were specially developed and tested.

Following quickly on this development came yet another mining requirement. The Normandy landing was approaching, and experience in the North African campaign had revealed that German thoroughness extended to the sabotage of ports and dock installations before surrendering them. All sorts of ingenious explosive devices were placed so that berths for supply ships were rendered impossible to use unless searched and cleared by divers. Speed in such a search was essential, and teams of divers who could work rapidly over the bottom of a dock or basin, ten or more at a time, were required. These became known as the famous *"P-parties" or "Human Minesweepers". More experiments at Siebe, Gorman & Co.'s works, produced the "P-party" diving equipment (Figs. 290 and 306). The suit was a modification of the "Chariot" dress while, as the depth was again too much for pure oxygen, the oxy-nitrogen principle was adapted for use in a closed circuit counter-lung breathing apparatus. The divers were enabled to work at high speed in depths up to 60 feet. The final version of this equipment allowed for one-and-a-half hours of really hard searching on the bottom. Many of these dresses and breathing sets and many auxiliary items were made. The work on the bottom of badly-damaged harbours was very hard on the equipment, and more and more replacements were urgently required as the speed of the Allied advance increased.

Thousands of training and operational dives were carried out in this gear, and never once was a case of "Pete" or of "bends" reported.

The gear continued to be used extensively in the clearing-up operations long after the "cease fire". Dutch, Norwegian and Belgian divers have also been trained in its use.

## TANK ESCAPE APPARATUS FOR AMPHIBIOUS OPERATIONS

One of the more interesting developments was the provision of escape equipment for the crews of amphibious tanks which played an important part in the invasion of Europe. The buoyancy of these machines was by no means excessive, and, even without being under fire, casualties had occurred and caused loss of life among the crews. The problem here was not only to produce some escape apparatus sufficiently light and

* Now known as Clearance Divers

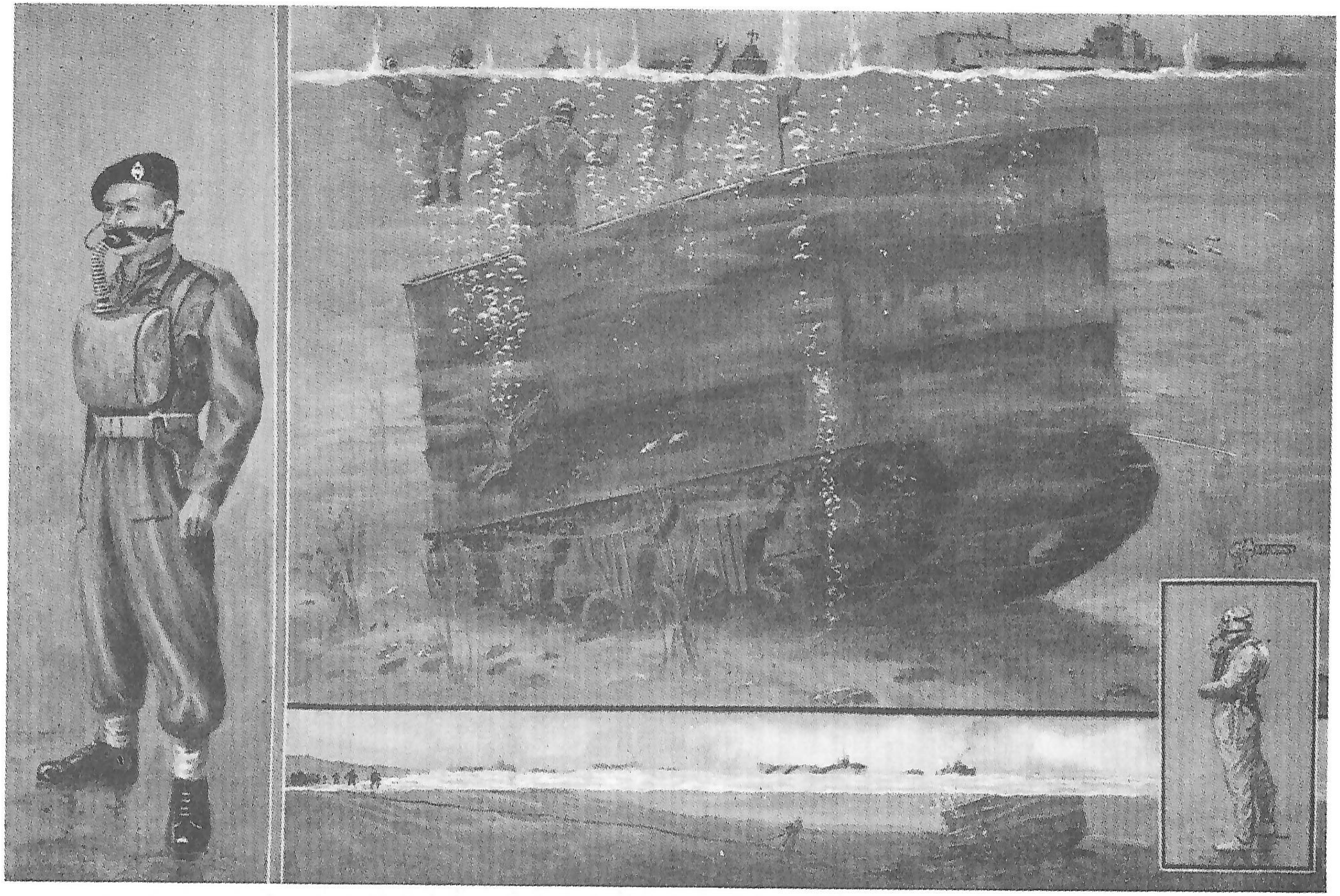


Fig. 291. Siebe, Gorman & Co.'s army tank escape apparatus for amphibious operations; also Mark I apparatus for recovery work

small to be worn continuously at the "ready" by the tank crews, and to be able to pass through the narrow hatches, but which could be produced in great numbers at very short notice. The Amphibious Tank Escape Apparatus (A.T.E.A.) (Figs. 291 and 308) which was produced was a very small version of the Davis Submerged Escape Apparatus (D.S.E.A.), and embodied its special patented feature. It was charged initially with oxygen from cylinders fitted in the tank landing craft. The charge held in the bag was sufficient for a few minutes' breathing, and gave enough buoyancy to maintain a fully-equipped man on the surface. Additional underwater life was given by the fitting of a D.S.E.A. "oxylet" cylinder which could be broken quickly to recharge the bag. In the heavy weather of D-Day, many lives were saved by this apparatus.

As the war began to draw to a close, the A.E.D.U. turned its attention to problems which were bound to arise immediately afterwards. Some experiments were also done to consolidate the wartime work. Accurate measurements of the oxygen consumption of divers under all conditions, at rest and at work, are important to many aspects of diving. An interesting series of experiments on a special underwater ergometer, and under actual conditions in the sea, produced some of the most detailed information available on this subject at the present time.

Another problem with which the Unit was faced was that of "Surface Decompression".

The Commanding Officer of the Deep Diving Vessel, H.M.S. *Tedworth* (the late Lieutenant-Commander G. E. Warren, O.B.E., R.N.) reported to the A.E.D.U. that, while he had been forced to make use of this method on many occasions in difficult salvage operations during the war, he felt that some authorized safety limits should be determined by experiment and firmly laid down. The A.E.D.U. decided upon a series of animal experiments as a preliminary to human work, and a veritable farmyard of goats and pigs was installed in suitable quarters in a field behind the Tolworth factory. As the experiments progressed, the animals became devoted pets of the naval divers, while an opportunist added chickens, ducks and rabbits to the menagerie. While not of much value as experimental animals, these latter contributed handsomely to the menu in the Siebe, Gorman canteen. Human experiments were then carried out.

The results of these experiments showed that surface decompression was practicable provided that very strict precautions were taken and ample preparations made, as described in Chapter 4.

A natural consequence of the successful rapid surfacing experiments after long periods on the bottom was an investigation into the possibility of rapid surfacing after short periods, but without subsequent recompression. Should such action prove possible, it would have an important bearing on submarine escape (see Chapter 14).

The combination of the Admiralty Experimental Diving Unit and Siebe, Gorman & Co., soon came to be recognized as the centre of diving development. Many and varied were the problems presented and, running in parallel with the main investigations, continuous programmes of trials on equipment and auxiliary problems were always in progress. Protection of hands against extreme cold, tropical underclothing for assault dives in the Far East, anti-dim preparations, special telephones, underwater cutting torches, underwater compasses and watches, protection against underwater explosions, all were tackled, and, while in more leisurely times better answers may be found, it may fairly be said that no one was sent away without a satisfactory solution.

In 1946 the need for regrouping into a peace-time organization led to the transfer of the A.E.D.U. from Siebe, Gorman & Co.'s Tolworth Works to Portsmouth to join the Experimental Diving Establishment of H.M.S. *Vernon*. Thus ended, with regret on both sides, a partnership between the Royal Navy and a private firm, whose contribution to the successful conclusion of the Second World War was invaluable, and whose influence was felt in many theatres of war. It established, too, a basis for permanent experimental work to maintain the theory and practice of diving at a modern level, both in war and peace, since, although separated geographically, the two sides with their experimental organizations will, of course, continue to work together in the common interest of the diver and the nation.

## HUMAN TORPEDOES

A "Human Torpedo" is, essentially, a small submersible craft whose crew of two is carried *outside* the pressure-tight hull, wearing diving apparatus, and is, therefore, subject to sea-pressure for the whole of the attack.

They differ from "Midget Submarines", whose crews are normally inside the pressure-hull and only wear diving dress or breathing apparatus to emerge from the vessel to cut nets or place explosive charges.

The object of the "Human Torpedo" attack is to penetrate heavily-defended harbours and to attach a heavy charge, out of all proportion to the size of the craft, right under the hull of a large enemy war vessel. The charges are exploded by mechanism which is timed to give the human torpedomen an opportunity to withdraw to safety. The explosion takes place in the most vulnerable position under the ship, and, since she is in harbour, and therefore in shallow water, the full force of the explosion is driven upwards into her hull. Thus a small machine manned by only two men can inflict severe, if not mortal, damage to a powerful fighting ship.

The "Human Torpedo" must rely on a stealthy approach, and her small size helps to defeat detection apparatus designed to detect far larger vessels such as the ordinary submarine. Nets of heavy steel wire-mesh are laid across harbour mouths and round the most important targets. With the two men riding outside the craft, and able to use their hands quite freely, the nets can be cut with hydraulic cutters, or lifted up so that the machine can slide underneath them. Nearing their target, the crew must move with even greater caution, hardly daring to raise their heads above water, and gliding in under the great hull in ghostly silence. In silence, too, they must attach the heavy explosive charge to the slippery weedy hull, for any metallic knock outside the hull will ring like a bell inside the ship's compartments.

All this, of course, takes time and many hours must be spent in the water. Not only must the crew be extraordinarily fit, and of iron nerve, but it is absolutely essential that the diving equipment should be of exceptional endurance and reliability.

"Human Torpedoes" are not "suicide weapons", as many people believe. The percentage of casualties on both sides in the last war was lower than in many other forms of warfare, though a number of the crews were inevitably taken prisoner.

This form of attack on large ships by small raiding vessels is a very ancient form of naval warfare, and has been used in many campaigns. In the old days of sailing ships, "cutting out" expeditions were but the same idea. In the First World War several special machines were built to penetrate boom defences. These machines took various forms, such as specially armoured boats to run the gauntlet of small-arms fire, floating tanks with caterpillars to crawl over the booms, and even an ordinary torpedo was once pushed into a harbour by two swimmers. It was not, however, until the Second World War that fully submersible craft were specially built and operated.

**The Human Torpedo—Mark I.** In its first form, the "Human Torpedo" was approximately torpedo-shaped. It was cylindrical, carried rudder, hydroplanes and propeller on a tapering conical tail, and had, at its fore-end, a heavy explosive charge or "war head". Here, however, the resemblance ended, for whereas the ordinary torpedo is driven towards its target at 30 or 40 knots, and is automatically controlled, the "Human Torpedo" crept in at no more than two or three knots and was steered and controlled by its crew of two. The low speed is necessary so that the crew can breathe in comfort, and that the minimum of tell-tale wake and underwater noise is created.

On top of the torpedo-shaped body, the Mark I Human Torpedo, or "Chariot", carried seats for two men to sit astride, the forward seat having steering and diving controls, luminous depth and pressure gauges, and a compass which is the crew's only guide to their destination during the attack. Between the seats is the main ballast tank, which causes the machine to sink or float at will, and behind the seats is the stowage for the hydraulic net-cutting equipment.

Inside the body are the main battery, the electric propelling motor, trimming tanks and air bottles and small electric pumps for controlling the trim tanks.

The "war head", which is fitted with a clock fuse, can be rapidly detached from the torpedo and left fixed to the targets by magnet. Unlike an ordinary torpedo, the machine is designed to run under water equally well with or without the "head", so that the crew can make good their escape under water after the attack.

**The Diving Apparatus—Early Experiments and the Mark I "Chariot" Dress.** This, then, was the machine for which Siebe, Gorman & Co., in the spring of 1942, were asked to design the diving apparatus. Naturally, at first, little information was available as to the exact requirements, since the tactics could not be worked out until some of the machines and their equipment were ready for use. The machines themselves were started about the same time, but it would inevitably be months before they could be ready to run. They were to be designed for six hours' endurance and 90 feet maximum depth. With this data, and some information gained from an Italian crew captured during an attack on Gibraltar, the firm set to work.

It is improbable that any self-contained breathing apparatus had been designed to last so long at that time. Oxygen was chosen as the breathing medium. In spite of its depth limitations which, as described in Chapter 1, were to prove worse than was feared, oxygen has two great advantages over all other gases. First, it requires to be supplied only at the rate of consumption by the diver, and so requires the minimum stowage space; and, second, since all the gas supplied is consumed, there are no tell-tale exhaust bubbles to rise to the surface and warn the enemy.

However, for an apparatus of this endurance, carbon-dioxide removal is an even greater problem than the oxygen supply. The amount of absorbent is proportional to the length of the dive, but resistance to breathing goes up rapidly if large quantities of absorbent are put in a badly designed canister. Siebe, Gorman & Co. designed a special canister which held the requisite amount without imposing undesirable resistance in the breathing circuit. For such a long dive, a very small increase in resistance will fatigue the delicate breathing muscles and cause distress to the diver.

The apparatus originally took a form similar to that of the Davis submerged escape apparatus, with breathing bag and $CO_2$ absorbent canister worn on the chest, and two steel cylinders slung beneath the bag. Oxygen was supplied through a single reducing valve, on the design of Siebe, Gorman & Co.'s well-known "Salvus" type, modified to allow for the extra depth. The rate of supply chosen after many experiments was 1·2 litres per minute. This is inadequate for heavy work, but a higher flow would have been wasteful, as the majority of the run was carried out with the crew at rest in their seats. Provision was made for occasional increases of flow by the use of by-pass valves, which the diver operated when changing depth or when doing heavy work such as cutting steel nets.

A few sets of this apparatus were ready by the summer of 1942, and many experiments were carried out with them, both in the tanks at the Tolworth works and at the preliminary training base at Portsmouth. Since there was no prospect of a machine being completed for some time, a full-scale dummy "Chariot" was made from a ballasted baulk of timber fitted with diving and steering controls. This was towed behind a motor-boat, and on it the crews started their long training, using the experimental sets and some Davis submerged escape apparatus specially modified to give more than its normal endurance. Many lessons were learnt on this crude "mock-up", and were quickly applied to the design of the apparatus then going into production. Two important lessons were not, unfortunately, learnt until much later, in June of that year, when the first British "Human Torpedo" did its running trials.

The first of these lessons was that the steel cylinders then in use had an adverse effect on the compass of the torpedo; and, secondly, they fouled the steering controls. To get them out of the way, the cylinders were moved on to the diver's back, together

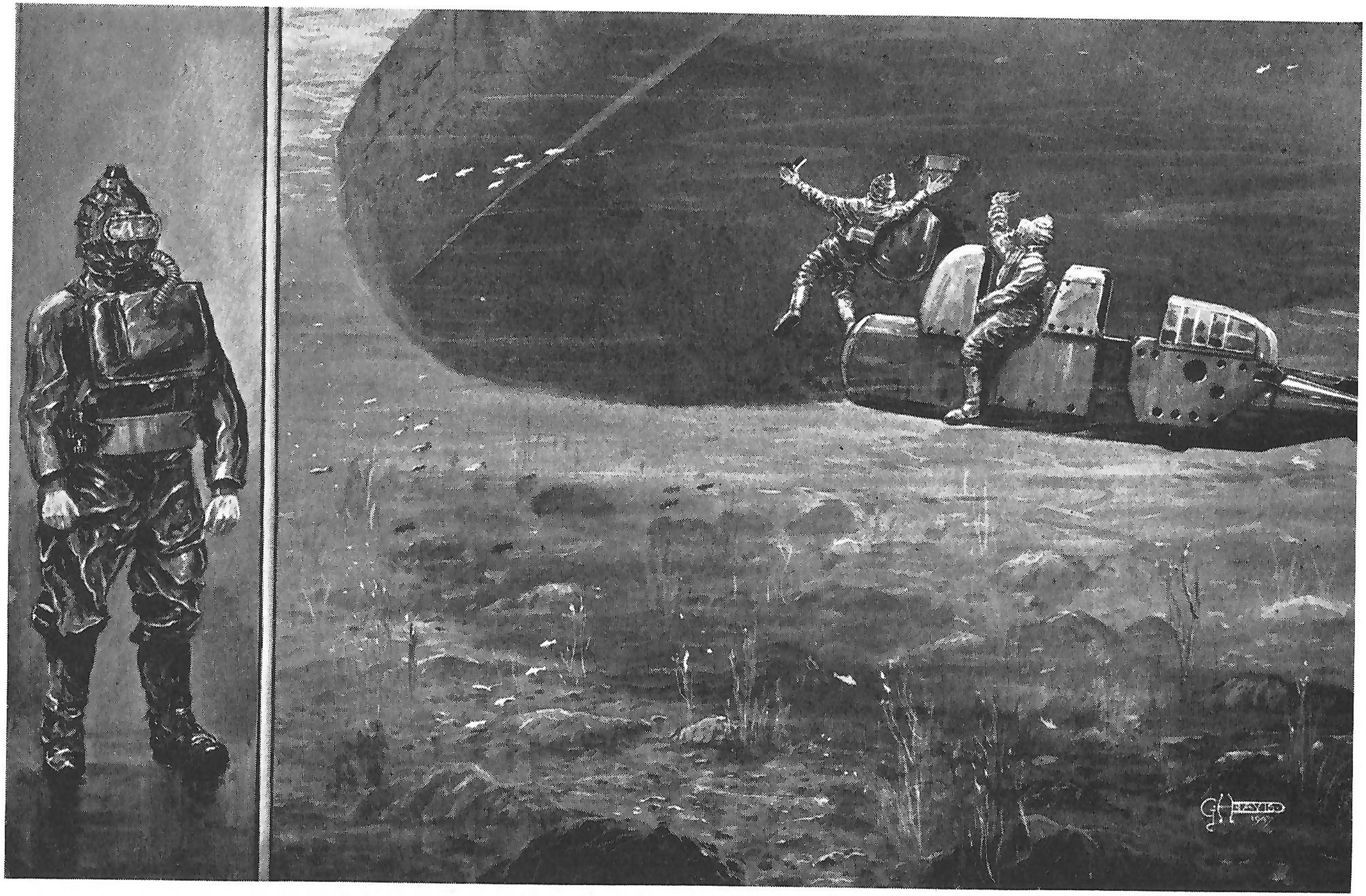


Fig. 292. Siebe, Gorman & Co.'s special diving equipment worn by crews of "Human Torpedoes"



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with the reducing valve. Although this meant the by-pass valve being behind the diver, it was found to be reasonably easy to reach, and so it was deemed unnecessary to alter the reducing valve assembly. Even with the cylinders behind the diver, the compass was still affected. This was no easy problem to solve, as no alloy cylinders were then being made in this country, but it was fortunately found that German bombers carried their oxygen supply in a large bank, or group, of aluminium alloy cylinders of almost the same shape and size as our own. Even the screw thread at the neck would take British cylinder valves.

Orders were given, therefore, for all shot-down aircraft oxygen cylinders to be collected, and the undamaged ones were tested, revalved and fitted to our breathing apparatus. Fortunately, the Royal Air Force maintained its toll of the Luftwaffe at a sufficiently high rate to meet the needs of the "Human Torpedo" scheme and, indeed, other special diving requirements, until production of similar cylinders could be started in England.

In the meantime, in the tanks at Siebe, Gorman & Co.'s works, endurance tests were proceeding with considerable success, and it was not long before the breathing apparatus was finally certified as being fully tested to six hours' operational use under water. In fact, continuous dives were made of even longer endurance, and it is probable that at that time these dives constituted a record for oxygen breathing under water.

It is of interest to note that no cases occurred of pulmonary irritation, such as had been suggested in the past would be inevitable if oxygen were breathed even at low pressure for as much as four hours.

The operational training was reaching an advanced state by August, 1942, and the training base was moved to a secret "hide-out" in Northern Scotland. Here, young men took incredible risks and exhibited amazing endurance in the cold waters of the loch. To visit the training ship and watch crews launch out into a dark and stormy night to attack an invisible target three or four miles away, returning in the early hours of the morning, was to be lost in admiration of their grit and determination.

So well did the training proceed that, in this month of August, operational plans were forming and everyone engaged in this scheme was thinking of the great German warships lurking in their Norwegian fiord "hide-outs". To attack them in the autumn would mean operating in water temperatures of about 45° F., and trials had to be done at once to find the effects of such temperatures on the crews. The fact that it was a very hot August did not help, and, on one occasion, several tons of ice had to be emptied into one of the training tanks to reduce the temperature.

Various combinations of underclothing were tried, it being by no means easy to find warm enough clothing which would go under the suits and not encumber the divers. Electrically-heated suits could not be considered, since the divers had to leave the craft during the attack, while chemically-heated pads were liable to overheat if the suit leaked, and let water on to them.

The final choice lay in silk underwear next to the skin, and kapok-padded jerkins and trousers under the waterproof suit, with woollens between them.

Hands remained a problem, as is always the case with divers, who rely so much upon their sense of touch under water, and cannot have their fingers encumbered with gloves. Many types of gloves were, however, tried by divers sitting in rows with their hands in basins of crushed ice. In the end, it had to be left to individual choice, a choice which usually reverted to bare hands protected only by Siebe, Gorman & Co.'s "Peddo" grease.

Many have heard of the gallant but unsuccessful attempt by two "Human Torpedoes" upon the *Tirpitz* in a Norwegian fiord in the autumn of 1942, when the machines were taken in, lashed beneath a Norwegian fishing vessel, only to be damaged in a storm at the last minute.

After this gallant failure, no more attacks were made until 1943, the interval permitting an overhaul of the design of the equipment.

The original dress was made of light rubberized cotton cloth, and the headpiece was formed by joining a hood on to the face-piece of an ordinary Service respirator. While comparatively simple to make, this equipment had several disadvantages. Once the diver was dressed, he could not open his face-piece in any way, while dual vision frequently occurred under water because the eye-pieces were not in the same plane.

**The Mark II Dress** (Fig. 305) was therefore produced with a metal face-plate designed by Siebe, Gorman & Co., having a single hinged window of "Perspex" which could be opened when the diver's head broke surface, and snapped shut as the machine dived. The window was wide enough to allow a pair of night binoculars to be used, a great advantage in seeking out targets in darkened harbours.

The breathing apparatus was also modified by bringing the reducing valve and by-pass forward, so as to be within easier reach of the diver.

This version of the "Human Torpedo" dress was used in the successful attacks on Italian shipping in January, 1943, by Lieutenant R. T. G. Greenland, D.S.O., R.N.V.R., and Sub-Lieutenant R. G. Dove, D.S.O., R.N.V.R., and in many other operations in the Mediterranean.

**The Mark II Human Torpedo.** By now, the shortcomings of the original design of the machine could be seen, and a new version was soon on the way. Sitting more or less upright outside the hull, with the legs astride, had always been considered bad streamlining, but a further disadvantage of this position was to be revealed.

During trials designed to increase the range of the torpedoes by towing them behind a small fast motor-boat, it was shown that a man riding astride was unable to breathe comfortably at any speed more than 2½ to 3 knots, due to the pressure of water on his breathing bag. As inshore defences in enemy harbours were being improved, it was becoming more and more difficult to get the "Human Torpedoes" within range of their targets. Neither the time endurance of the machines nor that of the breathing apparatus could be increased materially so that an increase of speed and, therefore, of mileage covered in the available time, seemed to be essential.

The solution of both problems lay in seating the divers in a "free-flooding" cockpit in the middle of the machine. Thus, the new machine reverted to the pure torpedo shape, the only projections outside the cylindrical hull being the two divers' heads, close together, as they now sat back-to-back. Though the cockpit was flooded, the breathing problem no longer arose, as the water in the cockpit moved with the machine and the divers sat in a sort of still pool or backwater. The only disadvantage of the increased speed to the divers was found to be that the face-plate of "No. 1", facing forward, was forced back upon his face, and another design of headpiece was necessary, with the face-plate extended further forward from the face.

What was hoped would prove a final design of dress and breathing apparatus, the Mark III, was now in production for use in either type of torpedo. In this dress, which was made of special rubberized cloth, a circular brass face-plate was bound into a moulded rubber hood, giving a smooth streamline to the exposed divers' heads. The entry was by a ventral skirt, which could be sealed by a metal clamp, while moulded and weighted rubber boots fitted closely round the ankles. This dress was later adopted generally by the Royal Navy, and is still used as the Shallow Water Diving Dress.

**The Mark IV, or "Detached Cylinder", Breathing Apparatus.** The Mark III Breathing Apparatus was almost identical with the earlier version except for an improved design of reducing valve. But a new requirement now arose from the Operational Training Base which necessitated a fourth re-design.

It had been found that the usual position for the oxygen cylinders on the diver's back was likely to cause the diver to become jammed in the cockpit of the Mark II "Chariot", and it was suggested that the cylinders could be mounted on the machine itself. Such an arrangement would free the diver generally from the encumbrance of the cylinders when he was manœuvring away from the craft at any time, provided he

*Official Admiralty photograph.*

Fig. 293. View of "Human Torpedo" under way

carried a smaller supply of oxygen on him. Space was quickly found for a group of cylinders between the two divers' seats where six were placed, three for each diver. This increased the oxygen supply and gave ample reserve for changing depth and for unusually hard work. The supply was led from the cylinder-group into the cockpit, where the reducing valve and by-pass were placed conveniently to the diver's right hand, and thence led to the diver's connection on the "dash-board".

A single cylinder was placed under the breathing bag, into which the oxygen was fed through a second and separate reducing valve.

Thus the diver could be either on "main supply" or "independent", according to whether he was riding in the craft or acting independently away from it. The same breathing bag and canister were used throughout, as they could not be changed without risk of flooding the bag or the dress. Fortunately, our earlier trials had shown that the canister had ample reserve endurance for the increased calls upon it which would now be made.

So far, this new set had called for little more than rearrangement and duplication of existing fittings, but a difficult hurdle had yet to be surmounted. This was the design of some form of quick-release connection between the diver's breathing bag and the main oxygen supply in the craft. Not only must this connection be capable of operation by a diver whose hands were numb with cold, but it must be completely gas-tight when made, and, when broken, must ensure no leakage of gas from the breathing bag, nor any water leakage into the breathing system. Finally, although a shut-off valve was provided for the diver to cut off the main oxygen supply before disconnecting, there was every chance that this might be forgotten, so that the connection also had to act as a relief-valve in order to prevent pressure building up on the low pressure side of the reducing valve while the diver was away. Siebe, Gorman & Co., after many trials with the divers of the A.E.D.U., produced the necessary valve in a small and workable fitting, which fulfilled all the requirements. The new rig, which was unique in this form of warfare, was fitted to all the "Human Torpedoes" which went out to the Far Eastern theatre of war.

In spite of the great risk to the crews had they fallen into enemy hands, successful operations were carried out with Mark II "Human Torpedo" and the Mark IV, or "Detached Cylinder", breathing set against Japanese shipping. In fact, those operations were remarkable in that they were the only occasions on either side throughout the war when "Human Torpedoes" were carried in to their objective by parent submarines, completed their task and returned unscathed to their rendezvous to be hoisted in and taken back to base without casualty or loss of any sort.

Thus ended the "Human Torpedo" war. The development and progress of this weapon was a fine example of co-operation between specialist industry (Siebe, Gorman & Co. Ltd.) and the Royal Navy. For three years, from the beginning of the initial training to the final operations in the Far East, these two organizations worked together to find out the best equipment and put it into production. Its great secrecy was well kept, even though it frequently hampered production, as those working on it could not have the full details of the job, nor even, in some cases, the real reason for urgency properly explained to them. Equally, the operational crews could not be expected to understand the factory's difficulties, the delays due to shortage of materials and transport, or the effect of air-raids and blackouts upon details of production. Nevertheless, the job was done, and it may be said that no operation was delayed by failure to "deliver the goods".

This account can only trace the main developments in this long period. Underlying these experiments was a constant experimental programme, producing tools and accessories for the maintenance of the new gear and trying and testing every detailed part of the main apparatus. Such items as gloves, boots, mouth-pieces, nose-clips, face-pieces and eye-pieces, anti-dim preparations, wristbands and cuffs, all were under constant revision for one reason or another.

As to the future of the "Human Torpedo", the very possibility of this weapon's use must always make an enemy fleet or squadron rest uneasy in its harbours, and must force the enemy to take extensive steps to secure his anchorages against attacks. It must also be understood that no automatic device, nor even a manned craft with the crew inside, can ever penetrate harbour defences as surely and effectively as the "Human Torpedo" with two highly-trained divers riding outside, free to use their hands, and to get on and off their machine at will. There is no form of fixed underwater obstruction that cannot be negotiated by determined and resolute crews such as manned the British "Human Torpedoes" in the Second World War.

The alternative detachable arrangement of an oxygen "main supply" in the vessel and an independent supply carried on the diver was the original idea of the author, and is one of the claims in his patent, as is also the emergence chamber as adopted in midget submarines and the escape chamber in larger submarines.

## "FROGMEN"

### (The Development of Underwater Swimming Apparatus)

There seems to be a general impression that the so-called "frogman" pedal swimming device is a purely wartime invention. But that is not true. As in the case of so many peacetime inventions which lie dormant or but little noticed, it takes the enterprising spirit engendered by the exigencies of war to bring them to life and into practical use.

Another fiction which has gained currency is that most of the wartime underwater work was done with the "frogman" swim-suit. This is probably due to the picturesque title "frogman"—coined by our newspaper Press with its well-known aptitude for the catchy word—which so caught the public fancy that most of the work done with self-contained diving dresses of the various types was attributed to the "frogman". In point of fact, the only things unusual about the "frogman" dress are its pedal appendages which give an increased turn of speed and greater manœuvrability.

In the 1935 edition of this book (see Part II, Chapter 4 of this edition) we described and illustrated a close-fitting swim-suit with web (frog) feet, designed by the 17th century Italian physiologist and physicist, Giovanni Borelli (1608-1679), a scientist remarkable for his prevision. Their use in the Second World War revived interest in them.

Borelli studied the movements of animals, including man, and likened the working of their bones and muscles to the parts of a machine in producing motion—in other words, the mechanics of their anatomy. His studies of amphibians—seals, frogs, etc.—which, like man, have to come to the surface to breathe, led him to design an apparatus to enable man to remain under water much longer than the unaided swimmer, and, as he says, "to walk on the bottom like a crab, or swim like a frog with his palms and his web feet". His original description says that the helmet was made of metal, but the Swiss scientist, Bernouilli (1654-1705), criticizing Borelli's design, rightly pointed out the danger of the rigid helmet owing to the fact that the body of the swimmer, clad in a close-fitting flexible suit of goat-skin, would be subjected to the pressure exerted by the water, while his head in the rigid helmet would be protected from the pressure. Since a plate from Borelli's book "De Motu Animalium", published in 1680 after his death, shows a helmet of *flexible* material, it may be assumed that he himself or his successors had become aware of the necessity for this construction.

That the Germans, a century after Borelli, had already found certain advantages in the Italian's idea, is shown by a plate from "Theatrum Pontificale oder Des Schau-Platzes der Brücken und Brücken-Baues", published at Leipzig in 1726. It must not be thought, however, that Borelli's idea remained amongst the forgotten things in the interim. As a matter of fact, in the warmer, crystal-clear waters of parts of Southern Europe, Asia and the Southern States of America for many years up to the outbreak of war, the use of rubber "frog-feet", developed by a French inventor, de Corlieu, in submerged and surface swimming at bathing resorts was a popular pastime with both

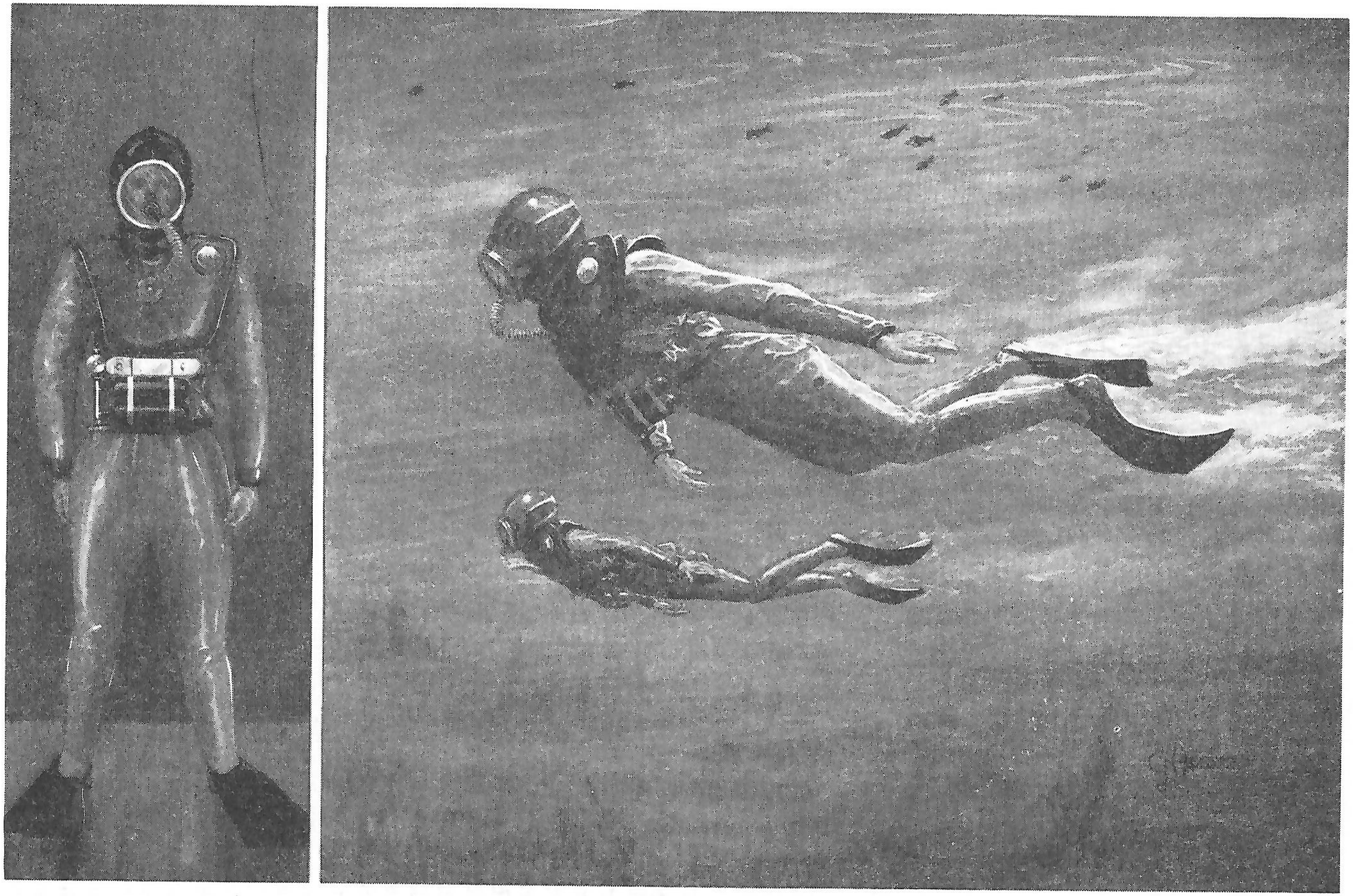

Fig. 294. Siebe, Gorman & Co.'s swim-suit and breathing apparatus for "Frogman"

men and women. Many of the swimmers were also equipped with a simple breathing mask connected via a reducing valve to a cylinder of compressed air, enabling them to remain submerged for a relatively long time. Some also indulged in the sport of fish-spearing with a special type of gun. With the return of peace, these submarine pastimes have been resumed. Doubtless they would also have become popular at our own bathing resorts had climatic conditions been more favourable.

Fig. 295

Fig. 295, taken before the war, shows a French swimmer wearing "frog-feet" and an additional aid in the shape of what we will call "paddle-palms". Borelli, it will be remembered, refers to the palms in his description.

In the late war, rubber web-foot propellers were worn by combatant swimmers on both sides, in conjunction with close-fitting watertight suits and breathing apparatus on the well-known principle, using oxygen and $CO_2$ absorbent, originally designed by H. A. Fleuss in collaboration with Siebe, Gorman & Co., and adapted by them to various forms of breathing and diving apparatus during the past 70 years.

The swim-suits with frog-feet used by the Germans in the late war were actually made for them by the Italians (Fig. 296): this would seem to be in the fitness of things, since Borelli, the original designer of the device, was an Italian.

The obvious objective of our efforts to equip divers with lightweight mobile gear must be to make men as fish-like as possible. In the "Human Torpedo" breathing set we had succeeded in making men completely self-sufficient under water for a number of hours. No surface supplies of gases were needed to maintain the diver's life, nor was there any need for ventilating gases to escape into the surrounding water. The "Human Torpedoman's" dress was indeed close-fitting and light compared with the standard diver's 180 lbs. of equipment, and the mobility of these men was remarkable. Nevertheless, they still did their work in the erect position, using their arms and legs for walking and climbing like land animals, and were hardly able to swim at all.

Fig. 296

The use of "Swim-fins" or "Frog-feet" immediately converts ordinary man into a swimming creature, giving him amazing control under water, and power and endurance beyond that of even the most powerful human swimmer. The earlier crude versions were usually some form of board or paddle strapped to the feet, and sometimes to the hands as well. In its modern efficient form, the "swim-fin" is scientifically designed and moulded from rubber to be fitted as a natural continuation of the foot and ankle. Nothing is worn on the hands, and in fact the hands are not used in underwater swimming at all.

Before going further we must understand the action of fin-swimming. The name "frogman" is a misnomer, since the frog swims with a breast-stroke kick, expanding the webs of his feet for the power stroke, and contracting them for the recovery. Rubber fins cannot be made to "feather" like this, so that a human "frog-man" would make no progress with such a stroke. The design of the fins is such that by using the up-and-down beat of the crawl kick, the driving motion of a fish's tail is reproduced (Fig. 297). A fish derives all its forward motion from its tail, and only uses its fins to steer and steady itself.

The introduction to this country of underwater swimmers in their present guise, was brought about by Lieutenant-Commander Bruce Wright, R.C.N.V.R.

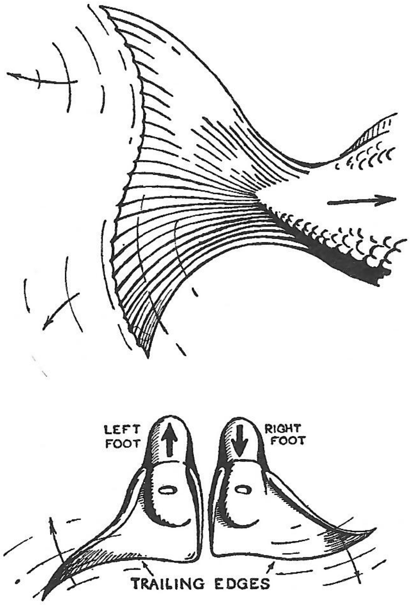


Fig. 297

Wright, a long-distance swimmer and spear-fisherman of considerable experience, put forward a scheme for using the whole spear-fishing technique and much of the gear for underwater sabotage. Colonel Hasler, then serving with Combined Operations, was developing small raiding forces using canoes and surface swimmers, and immediately saw the advantages of underwater swimmers in conjunction with such forces. Thus, early in 1943, the idea was brought to the Admiralty Experimental Diving Unit for the design and development of the necessary equipment to implement the new scheme.

Once again, the problem of protecting the divers against extremes of cold was prominent, and some sort of streamlined close-fitting suit had to be developed to cover the diver from head to foot. Spear-fishermen in sub-tropical waters are amply dressed, in fins, goggles and trunks; such clothing is hardly adequate for Northern European waters.

Experiments quickly showed that existing designs of lightweight suits were unsuitable because they were made of non-stretch material. A suit which is inelastic must be made large enough to allow the diver to dress, and once dressed, to move about without restriction. Under water, the spare material collapses in folds upon the wearer's body, and the folds set up a resistance to swimming through the water, which cannot be tolerated for long. These folds also trap air in small pockets, and thus give unnecessary buoyancy. This buoyancy can only be overcome by adding ballast weights, and no swimmer can give of his best with lead weights hung about him.

To solve the problem, the assistance of the Dunlop Rubber Company, with its large range of rubber manufacturing techniques, was enlisted. Mr. W. G. Gorham, manager for that company's Special Development Section, put all his energies and experience into the task.

The suit developed was the prototype of the now well-known range of underwater swim-suits. Made of rubber spread upon stockinette, fitted with lightweight Latex rubber cuffs and Plimsoll rubber feet, it is entered by a 4-inch hole in a special, highly stretchable, but almost untearable rubber neck yoke. The entry hole is sealed by clamping on a lightweight tight-fitting Latex hood. The whole suit fits almost like a second skin, giving protection against cold and abrasion, yet having sufficient stretch to allow the diver free movement under water.

With the development of the suit came the usual call for accessories, and ancillary gear to use with it. Most important of all was the need to design and establish the manufacture of "fins", since without them the suit and other equipment could not be satisfactorily tried out. In 1943, no "swim-fins" were known to be in existence in Great Britain. The only clue to their construction lay in some photographs in an American publicity pamphlet. In this a Hollywood beauty was depicted, draped over the edge of a swimming pool, wearing fins on the wrong feet! However, samples of fins were sent for from America at high priority. Unfortunately, the first consignment was sunk by a U-boat in mid-Atlantic, and trials had to be started with a crude set cut from heavy sheet rubber. Finally, a second batch of samples arrived safely.

The hood and face mask were a fine example of "Latex-dipping" technique. Several models were made incorporating hood and mask in one. But operational requirements called for a mask which could be slipped on and off in the water, to enable the swimmers to take a "look-see", and get their bearings. The final design of the flanged joint between mask and close-fitting hood was an excellent example of the rubber-worker's skill.

Before the final suit was evolved, many other details had to be worked out and put into production. These included special zip-fastened undersuits, goggles, "swim-shoes", and camouflaged caps for "naked" swimmers Whole suits in camouflage, and even different coloured fins, as well as a large range of test and maintenance equipment were required.

Thus the British "frogman" became the best equipped in the world. His rivals on the Axis side used an Italian designed suit of thin black sheet rubber, finishing at the neck. Though very light and easy to wear, such a suit gave no cold protection and was easily damaged.

Underwater swimming calls for a new diving technique unlike anything used before. The swimmer is horizontal in the water, instead of standing or crouching; he frequently dives down head first, and his leg muscles are in constant action; he swims with his legs alone, with his hands free to operate his breathing set or to steady and guide him. In fact, the Italians refer to their swimmers and human torpedomen as "sommozzatori" or "plungers".

The swimmer must have absolutely neutral buoyancy; any weight he carries must not be on his neck, shoulders or feet, but exactly in the middle of his body. In fact, he is like a submarine. If trimmed too heavily, he will sink slowly to the bottom. On the other hand, if too light, his feet will come up, as he strives to drive himself down against his own buoyancy, and he will end up by kicking fruitlessly on the surface, splashing violently and making no progress at all.

*(By courtesy of The Dunlop Rubber Coy)*

Fig. 298
The Dunlop "Frogman's" equipment

Depth and direction-keeping are difficult. Swimmers usually wear a wrist compass to guide them to their target, but they have to learn to steer by natural aids such as by keeping sun or moon on a definite bearing, or by coming up for quick looks at their surroundings. Depth-keeping must come almost entirely by training, and the swimmer must learn to judge his depth by feeling the pressure changes on his ears, the temperature gradient of the water, or by the appearance of the surface above him, or by the sea-bed below.

All these requirements mean that special care must be given to the design of the breathing set. It must be designed so that the essentially heavy items such as cylinders and reducers do not upset the delicate balance of the "frogman", and it must give comfortable, effortless breathing in any and every position that the diver may assume.

Siebe, Gorman & Co.'s "Amphibian" Mk. III and Mk. IV, Dunlop's Underwater Swimming Breathing Apparatus (U.W.S.B.A.) and the Admiralty "Universal" are all designed with this end in view. The design of the breathing system is based upon confirmatory work done at the National Institute of Medical Research for the Admiralty by Doctors Sands and Paton.*

These workers determined the maximum resistance, expressed in terms of millimetres head of water, which could be tolerated by divers in all positions under water without interference with normal respiration. The ideal position for the breathing bag relative to a diver's ear was named the "Eupnoeic depth", and it was shown how this depth varied with the depth of respiration. By designing the breathing set so that the "Eupnoeic depth" is never exceeded under any conditions, the best breathing conditions possible are obtained.

* U.P.S. Report No. 61.

In the course of the development of these sets, the first trials of the "frogman" gear, and indeed the early training of the operational teams, were not without incident. It seemed that underwater swimmers were unduly susceptible to a phenomenon known as "Shallow Water Black-out". This black-out had been experienced occasionally before by other oxygen divers, but never so frequently as by the "frogmen". Many theories were put forward and remedies tried, but the true answer was elusive. This

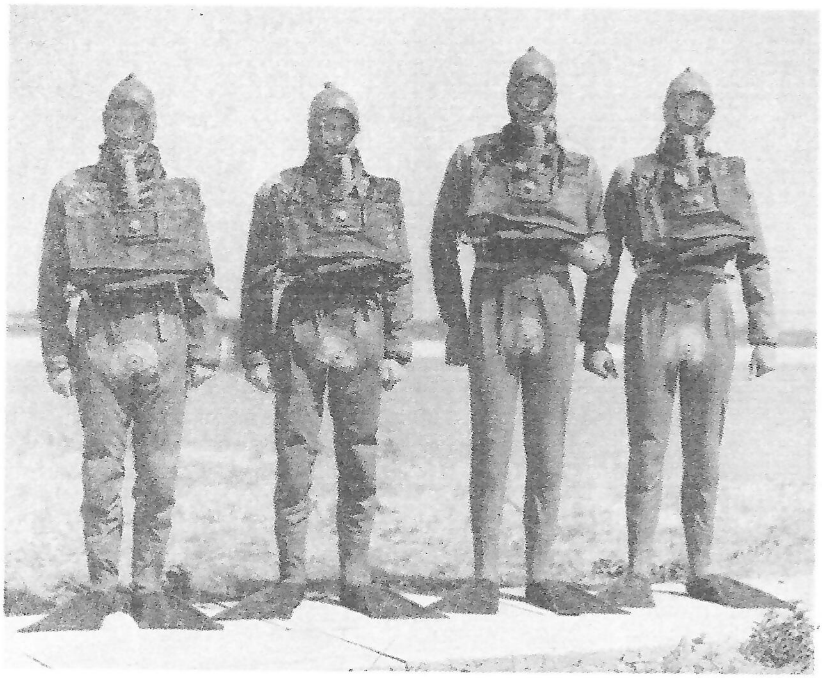

Fig. 299
An early British "Frogman" training apparatus incorporating the Davis submerged escape apparatus

trouble took the form of temporary mild unconsciousness and mental dissociation, and occurred at depths too shallow to be attributed to oxygen poisoning or other causes due to pressure.

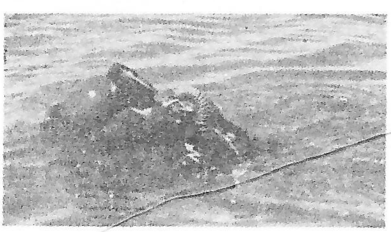

Fig. 300
"Frogman" as in Fig. 299, on the surface; showing how the D.S.E.A. throws back the head clear of the water

*Dr. Kenneth Donald, D.S.C., M.D., of the A.E.D.U., demonstrated that men breathing a high percentage of oxygen did not appear to receive the normal warning of the onset of $CO_2$ intoxication. In other words, the respiratory centre was failing to react or to take the natural precaution of hyper-ventilation. Simultaneously, it was shown that the oxygen uptake of underwater swimmers is far in excess of that of any other type of diver. For instance, while an ordinary diver carrying out the recognized hard work of a fast search over rough and muddy bottom, may consume 1·75 to 2 litres of oxygen per minute, a "frogman" doing a fast length of a swimming bath, will

* A.E.D.U. Report No. XVI: "Oxygen Poisoning in Man"—K. W. Donald.

use as much as 3·0 to 3·5 litres per minute, in spite of the apparently easy swimming motion. This additional consumption is probably due to the constant action of the heavy leg and thigh muscles, and a correspondingly high rate of $CO_2$ evolution results. Thus the underwater swimmer was unsuspectingly pouring out carbon-dioxide into apparatus designed to normal standards, and to make matters worse nature's defensive mechanism against $CO_2$ intoxication was failing to function correctly.

So much attention has since been paid to the design of canisters, to the composition of $CO_2$ absorbent materials, and to the elimination of dangerous "dead-space" that "shallow water black-out" is becoming a rarity, and if it occurs now it can nearly always be attributed to defective or badly maintained equipment.

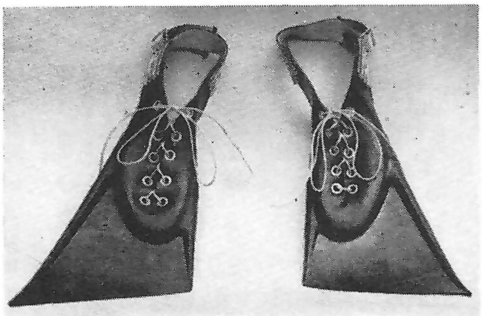

Fig. 301
Laced swim-fins with adjustable ankle straps

This, then, is the "frogman" equipment of which so much has been heard and with which so much has been achieved. The development was again a "top secret", high priority, achievement, to which the best available industrial and scientific resources were harnessed.

In war, the "frogmen" carried out sabotage operations against enemy shipping, and counter-sabotage defence diving, searching for "limpets" and infernal machines which may have been attached to our ships by enemy divers. The biggest scale users, however, were the Landing Craft Obstruction Clearance Units—those teams of courageous young men who leapt into the sea ahead of our invading troops off Normandy, Holland and Burma, and, swimming under water, blasted great gaps in the enemy's bristling hedgehog defences on the beaches, thus allowing the first waves of landing craft to sweep in and discharge their cargoes of fighting men and vehicles.

Now, in peace, the "frogmen" have turned their efforts to a host of different pursuits. "Cave-divers", who explore the underground caverns and rivers in the limestone hills of Great Britain, have adopted "frogmen" methods for penetrating flooded chambers. Another group has adopted the technique for minor repairs to damaged ships, and the rapid survey of sunken wrecks in shallow water. A young scientist on an Antarctic whaling expedition, used "frogman" gear to dive under the great carcases of whales to record their body temperatures and other data.

So man's challenge to the world of fish and other marine creatures grows with every fresh development. The "frogman's" speed and agility and his independence of bottom conditions give him many advantages for certain types of work in shallow water.

Although there will always be work under water which requires other, and heavier, equipment for its proper fulfilment, and while there are operations of war for which the normal "frogman" may not be properly equipped, nevertheless underwater swimming is now recognized as a serious form of diving, whether it be for war, for the routine work of peacetime, or for sport.

## THE SMALLEST UNDERWATER CRAFT IN THE WORLD

Designed by Major H. Q. A. Reeves, M.A., A.M.I.MECH.E., M.CONS.E., for underwater attack, the motorized submersible canoe is a small electrically-propelled surface canoe which can be flooded by means of valves for diving and proceeding under water. The pilot wears a Siebe, Gorman thin, close-fitting waterproof rubber suit with a specially-designed oxygen breathing apparatus for use under water (see Figs. 302, 304 and 305), the development of which preceded that of the suit for midget submarines.

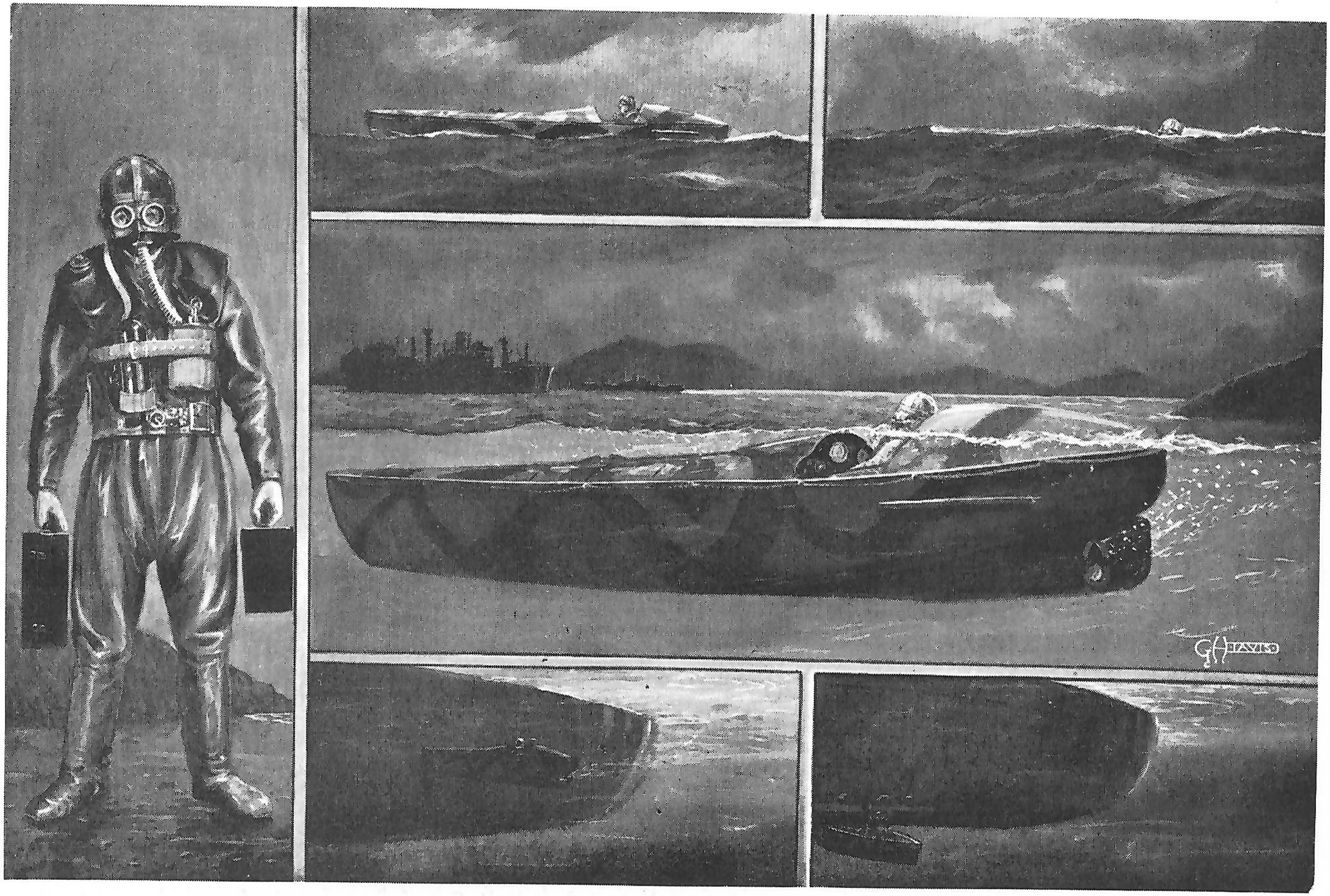

Fig. 302. Siebe, Gorman & Co.'s Amphibian Mark II apparatus as used in submersible canoes

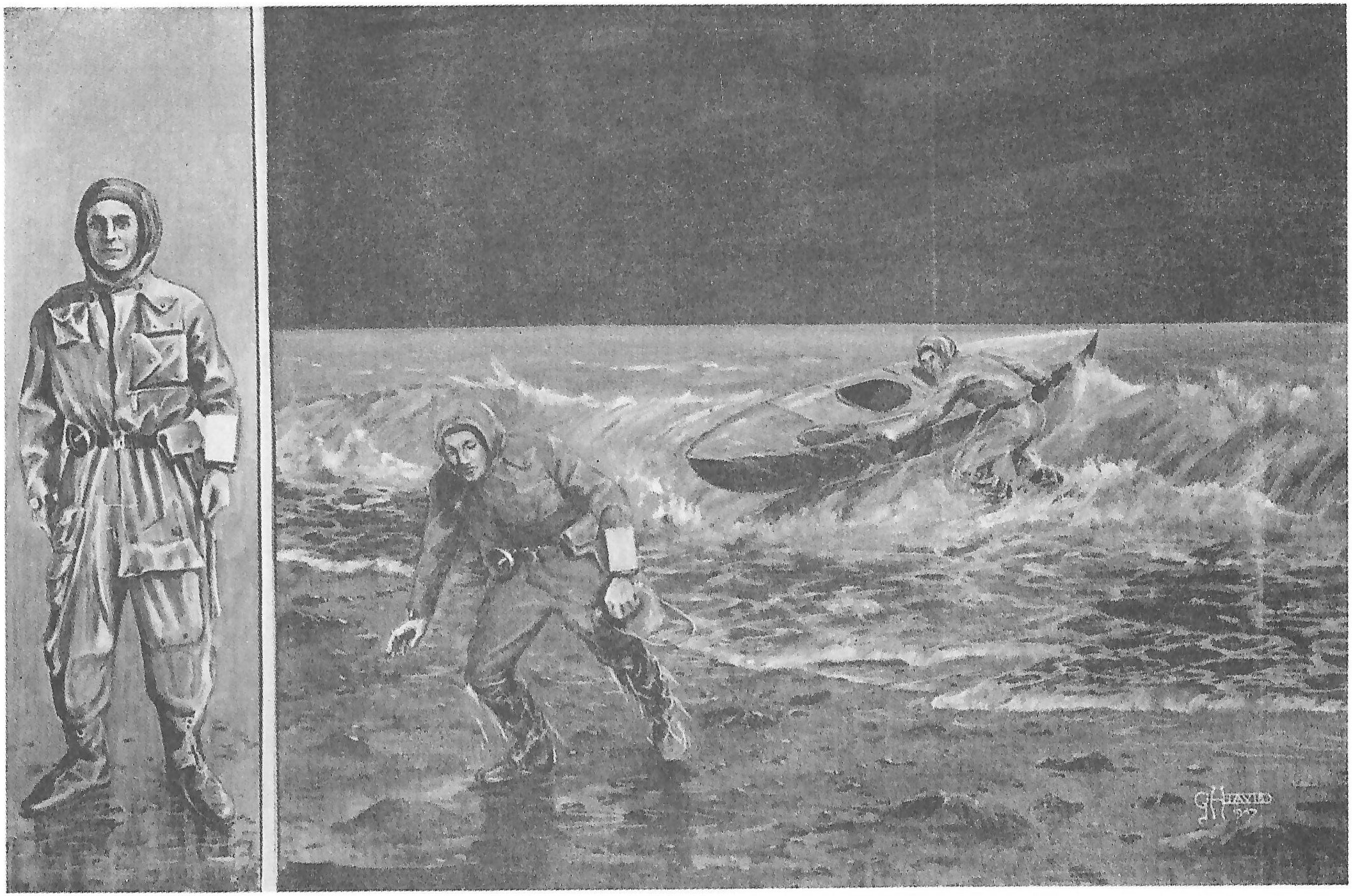

Fig. 303. Siebe, Gorman & Co.'s special boat section suit used for landing on hostile coasts

The canoe is 12 feet 8 inches long with a beam of 27 inches and is made of thin steel with an aluminium deck. An electric motor of $\frac{1}{2}$ h.p., together with lead-acid storage batteries, is the means of propulsion.

The M.S.C. is the first "surface craft submersible" of this kind ever to have been successfully designed, built and put into operation.

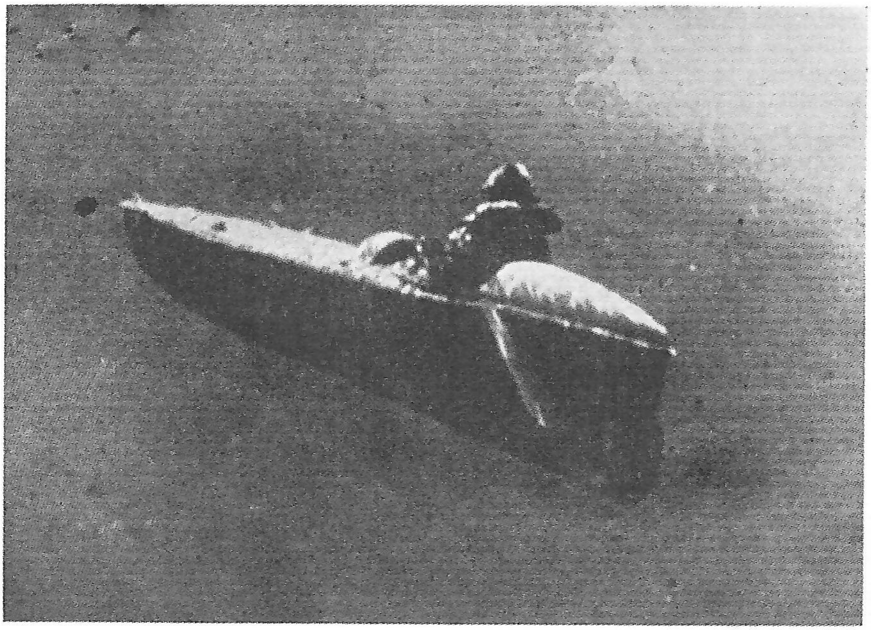

Fig. 304. Photograph of submersible canoe under water

On the surface, the canoe acts as a normal dry and highly efficient surface boat. After flooding the hull by means of valves, the craft just floats with its top deck almost level with the surface of the water, being held up by the buoyancy of its various air tanks. By admitting water to the ballast tanks, the canoe is made slightly heavier than water, so that it can proceed under water propelled by its electric motor, and controlled by two hydroplanes fitted aft of the cockpit.

Like an aircraft, the canoe has a single stick control which operates the rudder and the hydroplanes, and, unlike the normal submarine, is very flexible in control, so that rising and diving at steep angles can be rapidly effected by lowering or raising the control-stick.

When the pilot has completed his underwater run he surfaces by means of his hydroplanes, and then expels the water from the ballast tanks by means of compressed air. The canoe is once again on the surface, but the cockpit and the other parts of the craft are still full of water. In order to remove the water from the remainder of the craft, the pilot erects a waterproof canvas cockpit cover, fastening the top of it around his neck, so as to obtain a closure from water which would otherwise spill into the cockpit. A special pumping-out valve is operated, which connects the flooded inside of the craft, via the hollow keel, to two nozzles, placed in the vertical above and below the propeller shaft, which suck the water from the inside of the craft, due to the action of the propeller blades passing close to the nozzles. Driving the craft at full speed ahead, the water is sucked out, leaving the craft dry in about four or five minutes. As the water is expelled from inside the hull, the canoe rises on the surface of the water, at the same time gaining speed. When all the water has been removed from the hull, the air is sucked from the hull and expelled under water by the nozzles, until the "pumping-out valve" in the cockpit is closed.

**Special Boat Section Suit** (Figs. 303 and 308). Although having no breathing apparatus, this suit is included as an interesting example of the type made for reconnaissance on enemy beaches prior to landing operations. An inflatable life-jacket was incorporated in the upper part of the suit to give buoyancy to the wearer when swimming to and from the shore. A measuring line and stake were carried attached to the waistbelt as shown in the illustration. In the various pockets provided or attached in other ways were watertight compass and watch, maps and charts, scribbling pad and pencil, emergency ration and stimulant, revolver and ammunition, knife, etc.

**Protective Suit for Inshore Patrolling** (Fig. 308). Another type of waterproof suit, without breathing apparatus, designed for the protection of personnel in coastal craft, lighters, etc., against the elements.

## ANTI-CONCUSSION DEVICES

Should a bomb drop in the sea in the vicinity of a diver working below, he might be seriously injured by the resultant shock wave. Water being incompressible, a shock wave travels a much greater distance than in air before its force is expended. During the war, the following devices were made for the divers' protection against the effects of underwater explosions: Headpieces covering the skull, ears and chin, and jackets covering the upper part of the body from neck to crutch.

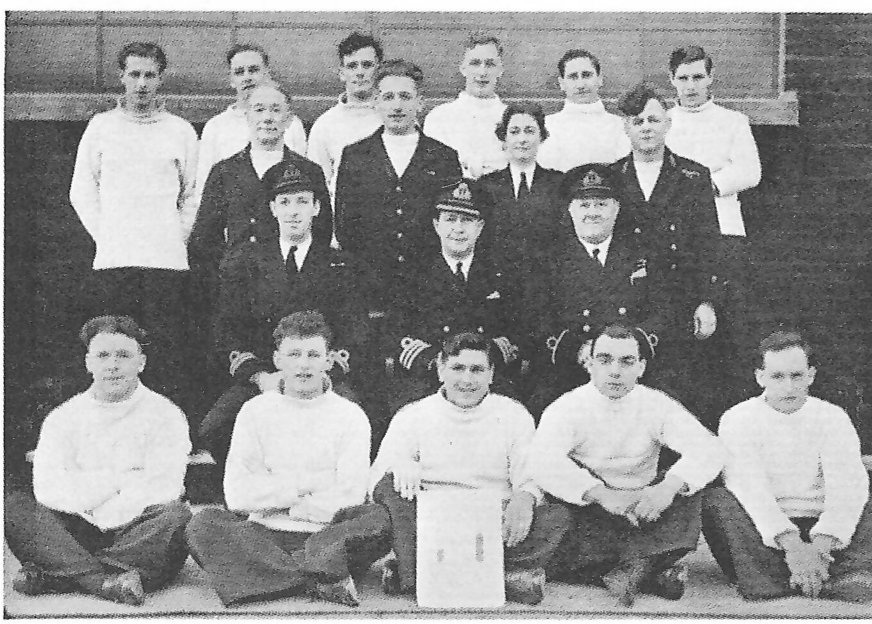

Fig. 304A. Admiralty Experimental Diving Unit at Siebe, Gorman & Co.'s Works, Tolworth. Staff and a few of the trainees, January, 1944. (Sitting): Surgeon Lieutenant (later Lieutenant-Commander) K. W. Donald, D.S.C., R.N.; Commander (now Captain) W. O. Shelford, R.N.; Commissioned Gunner E. Crouch, R.N

Fig. 305

*Top Left:* Amphibian Mark I suit for shallow-water work—also used by Army in rivers and canals.

*Bottom Left:* Suit worn by crew of "Human Torpedo".*

*Top Right:* Mine recovery suit of non-magnetic material

*Bottom Right:* Amphibian Mark II suit for shallow-water work and special operations (submersible canoes).

* This is an enlarged version of the D.S.E.A., i.e. larger cylinders and $CO_2$ absorbent chamber, and with a reducing valve on a neck extension of a cylinder, as in the Davis "Proto" apparatus.

Fig. 306

*Top:* *"P-party" Mark II suit for clearing mines from beaches, harbours, etc.

*Left:* Shallow-water diving suit embodying "Salvus" A.N.S.

*Right:* *"P-party" Mark I suit for similar work to the Mark II.

* Now known as Clearance Divers.

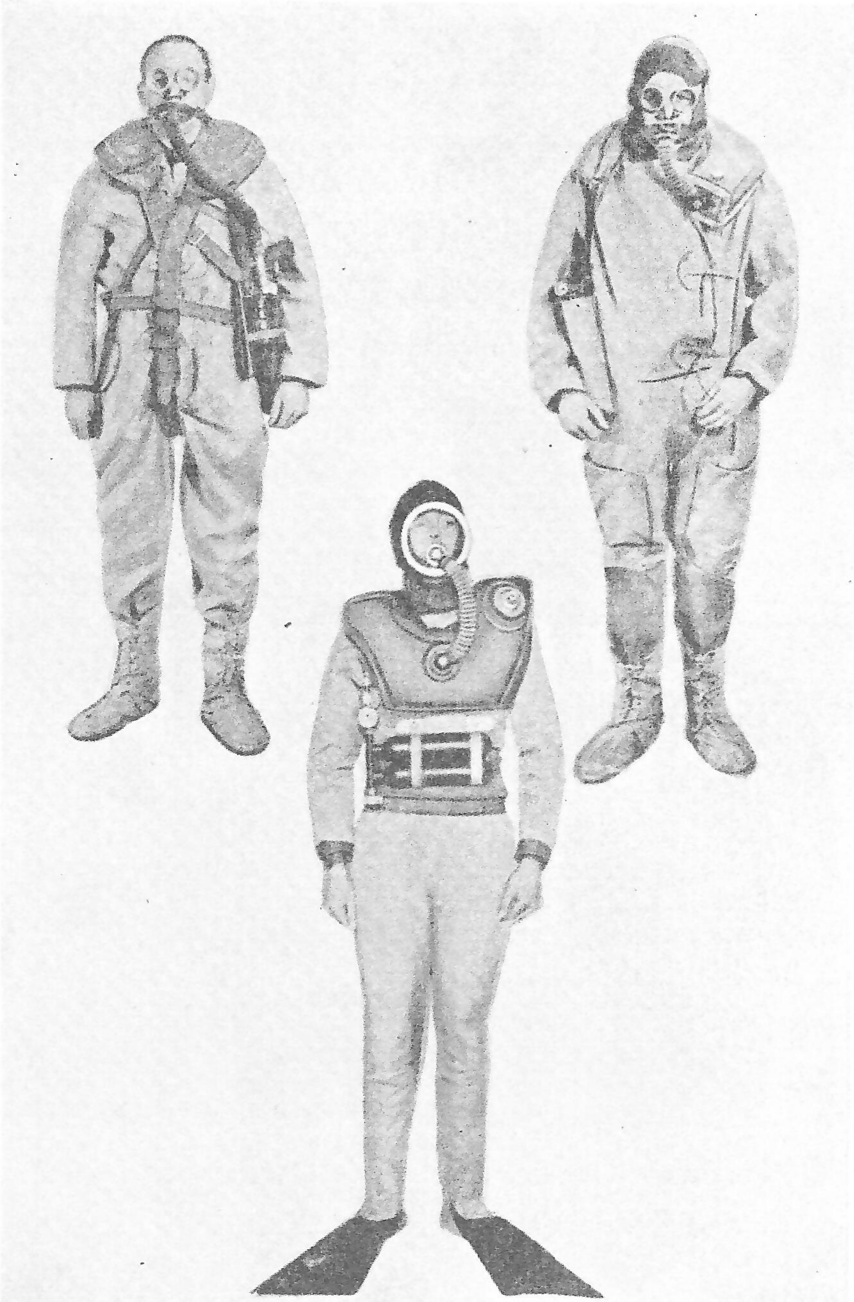

Fig. 307

*Left:* Beach recovery suit as used in Normandy and other landings.

*Right:* Special suit for watch-keeper of midget submarine (X-craft).

*Bottom:* Swim-suit or "Frogman".

Fig. 308

*Top Left:* Davis submarine escape apparatus.

*Bottom Left:* Protective suit for in-shore and patrol work. (No breathing apparatus.)

*Top Right:* Army tank escape apparatus for amphibious operations.

*Bottom Right:* Special boat section suit for landing on hostile shores. (No breathing apparatus.)

# 16

## *Useful Data Relating to Diving**

### WATER

**Its weight.** A cubic foot of salt water weighs 64 lbs.
A cubic foot of fresh water weighs 62·5 lb.

**Pressure.** Every one foot depth of salt water increases the pressure by nearly ½ lb. on the square inch.

A column of salt water 33 feet high presses on the bottom with a pressure of about 15 lbs. per square inch, or one atmosphere.
A column of water 27 inches high = about 1 lb. pressure per square inch.
A ton of fresh water = 35·90 cubic feet = 224 gallons.
A ton of sea water = 35 cubic feet = 218¾ gallons.
Boiling Point 212° F. = 100° Centigrade.
Freezing Point 32° F. = 0° Centigrade.

### DEPTHS AND EQUIVALENT PRESSURES

The following table gives the additional pressure above atmospheric pressure per square inch for every fathom of depth (salt water) up to 70 fathoms, with the nearest equivalents in metres and kilogrammes per square centimetre respectively:

| Fathoms | Feet | Metres | Lbs. pressure per square inch | Kilograms per square centimetre | Fathoms | Feet | Metres | Lbs. pressure per square inch | Kilograms per square centimetre |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 1·8 | 2·7 | 0·19 | 36 | 216 | 65·8 | 96·1 | 6·75 |
| 2 | 12 | 3·6 | 5·3 | 0·37 | 37 | 222 | 67·6 | 99·0 | 6·90 |
| 3 | 18 | 5·5 | 8·0 | 0·56 | 38 | 228 | 69·6 | 101·4 | 7·12 |
| 4 | 24 | 7·3 | 10·7 | 0·75 | 39 | 234 | 71·3 | 104·0 | 7·30 |
| 5 | 30 | 9·1 | 13·3 | 0·93 | 40 | 240 | 73·1 | 107·0 | 7·50 |
| 6 | 36 | 11·0 | 16·0 | 1·12 | 41 | 246 | 75·0 | 109·4 | 7·70 |
| 7 | 42 | 12·8 | 18·7 | 1·32 | 42 | 252 | 76·8 | 112·0 | 7·87 |
| 8 | 48 | 14·6 | 21·3 | 1·50 | 43 | 258 | 78·6 | 114·7 | 8·06 |
| 9 | 54 | 16·5 | 24·0 | 1·70 | 44 | 264 | 80·5 | 117·3 | 8·25 |
| 10 | 60 | 18·3 | 26·7 | 1·87 | 45 | 270 | 82·3 | 120·1 | 8·43 |
| 11 | 66 | 20·1 | 29·3 | 2·06 | 46 | 276 | 84·1 | 122·7 | 8·62 |
| 12 | 72 | 21·9 | 32·0 | 2·25 | 47 | 282 | 85·9 | 125·3 | 8·80 |
| 13 | 78 | 23·8 | 34·7 | 2·45 | 48 | 288 | 87·8 | 128·0 | 9·00 |
| 14 | 84 | 25·6 | 37·4 | 2·62 | 49 | 294 | 89·6 | 130·6 | 9·13 |
| 15 | 90 | 27·4 | 40·0 | 2·82 | 50 | 300 | 91·4 | 133·3 | 9·37 |
| 16 | 96 | 29·3 | 42·6 | 3·00 | 51 | 306 | 93·3 | 136·1 | 9·56 |
| 17 | 102 | 31·1 | 45·2 | 3·17 | 52 | 312 | 95·1 | 138·8 | 9·75 |
| 18 | 108 | 32·9 | 48·0 | 3·37 | 53 | 318 | 96·9 | 141·4 | 9·94 |
| 19 | 114 | 34·7 | 50·7 | 3·57 | 54 | 324 | 98·8 | 144·0 | 10·12 |
| 20 | 120 | 36·6 | 53·4 | 3·75 | 55 | 330 | 100·6 | 146·7 | 10·30 |
| 21 | 126 | 38·4 | 56·1 | 3·90 | 56 | 336 | 102·4 | 149·4 | 10·49 |
| 22 | 132 | 40·2 | 58·7 | 4·12 | 57 | 342 | 104·2 | 152·1 | 10·68 |
| 23 | 138 | 42·0 | 61·4 | 4·32 | 58 | 348 | 106·1 | 154·8 | 10·87 |
| 24 | 144 | 43·9 | 64·0 | 4·50 | 59 | 354 | 107·9 | 157·4 | 11·05 |
| 25 | 150 | 45·7 | 66·7 | 4·68 | 60 | 360 | 109·7 | 160·1 | 11·24 |
| 26 | 156 | 47·6 | 69·4 | 4·88 | 61 | 366 | 111·5 | 162·8 | 11·42 |
| 27 | 162 | 49·4 | 72·0 | 5·06 | 62 | 372 | 113·3 | 165·4 | 11·61 |
| 28 | 168 | 51·2 | 74·7 | 5·25 | 63 | 378 | 115·1 | 167·1 | 11·80 |
| 29 | 174 | 53·0 | 77·3 | 5·45 | 64 | 384 | 117·0 | 170·8 | 11·99 |
| 30 | 180 | 54·9 | 80·1 | 5·60 | 65 | 390 | 118·8 | 173·4 | 12·18 |
| 31 | 186 | 56·7 | 82·8 | 5·80 | 66 | 396 | 120·6 | 176·1 | 12·37 |
| 32 | 192 | 58·5 | 85·4 | 6·00 | 67 | 402 | 122·4 | 178·8 | 12·55 |
| 33 | 198 | 60·3 | 88·1 | 6·20 | 68 | 408 | 124·2 | 181·4 | 12·74 |
| 34 | 204 | 62·2 | 90·7 | 6·37 | 69 | 414 | 126·1 | 184·1 | 12·93 |
| 35 | 210 | 64·0 | 93·4 | 6·50 | 70 | 420 | 128·0 | 186·8 | 13·12 |

*[continued overleaf*

* The figures given above may be assumed sufficiently accurate for all practical purposes.

## DEPTHS AND EQUIVALENT PRESSURES
(in lbs. per square inch and kilograms per square centimetre)

## OF SEA WATER FROM 75 FATHOMS TO 170 FATHOMS
increasing by increments of 5 fathoms = 9·2 metres = 30 feet

From 75 fathoms = 450 feet = 137·2 metres to 170 fathoms = 1,020 feet = 310·9 metres.

| Fathoms | Feet | Metres | Lbs. pressure per square inch | Kilograms per square centimetre | Fathoms | Feet | Metres | Lbs. pressure per square inch | Kilograms per square centimetre |
|---|---|---|---|---|---|---|---|---|---|
| 75 | 450 | 137·2 | 200·0 | 14·06 | 125 | 750 | 228·6 | 333·3 | 23·43 |
| 80 | 480 | 146·3 | 213·3 | 15·00 | 130 | 780 | 237·7 | 346·7 | 24·37 |
| 85 | 510 | 155·4 | 226·7 | 15·93 | 135 | 810 | 246·9 | 360·0 | 25·31 |
| 90 | 540 | 164·6 | 240·0 | 16·87 | 140 | 840 | 256·0 | 373·3 | 26·24 |
| 95 | 570 | 173·7 | 253·3 | 17·81 | 145 | 870 | 265·2 | 386·7 | 27·18 |
| 100 | 600 | 182·9 | 266·7 | 18·75 | 150 | 900 | 274·3 | 400·0 | 28·12 |
| 105 | 630 | 192·0 | 280·0 | 19·68 | 155 | 930 | 283·5 | 413·3 | 29·06 |
| 110 | 660 | 201·2 | 293·3 | 20·62 | 160 | 960 | 292·6 | 426·7 | 30·00 |
| 115 | 690 | 210·3 | 306·7 | 21·56 | 165 | 990 | 301·8 | 440·0 | 30·93 |
| 120 | 720 | 219·5 | 320·0 | 22·50 | 170 | 1020 | 310·9 | 453·3 | 31·87 |

## STRENGTH OF TIDE IN WHICH DIVERS CAN DO USEFUL WORK

The strength of tide in which a diver can work is often the subject of debate amongst those engaged in submarine operations. Divers themselves frequently miscalculate the velocity, their estimates tending, quite unwittingly, to exaggerate it.

Speaking generally, however, the strongest current in which a diver can do useful work is from 2 to 2½ knots. When it exceeds this, the strain on air-pipe and life-line is liable to pull him away from his job, unless he is lashed to it. But if he is sheltered—say in the hold of a ship or behind a wall—the current does not affect him except on his way up and down.

In all cases where the velocity is, say, 1·5 knots and upwards, it is necessary for the diver to make himself heavier than usual by wearing a weighted belt (see page 76), in addition to the usual chest and back weights. The extra weight necessarily somewhat increases the diver's work on the bottom, but this is unavoidable.

As to the time taken to reach bottom in a tideway, the following table gives the result of a diver's descent to a depth of 20 fathoms in tides up to 1½ knots velocity.

| Tide. | Reached bottom. | Depth. |
|---|---|---|
| 0 | About 50 seconds | 20 fathoms. |
| ½ knot | " 1¼ minutes | |
| 1 knot | " 1¾ minutes | |
| 1½ knots | " 2½ minutes | |

## THE HEIGHT OF WAVES, THEIR FORCE, AND THE DEPTH TO WHICH THEIR ACTION EXTENDS

**Height.** The height varies considerably with different localities. At Dover, for instance, the greatest height recorded during the past 30 years is 18 feet from crest to trough; at Peterhead and Fraserburgh in Scotland, and at the mouth of the Tyne, waves measuring as much as 40 feet high have been observed and in the open ocean they run to 50 or 60 feet.

**Force.** The force exerted by waves is well exemplified by what occurred during a storm at Peterhead some years ago, when blocks weighing 41 tons apiece were displaced at a level of 37 feet below low water, spring tides, the rise of the latter being 11 feet. On the same occasion a section of blockwork, weighing 3,300 tons, was shifted bodily 2 inches without dislocation. To move this mass, an energy equal to 2 tons per square foot must have been exerted simultaneously over the affected area.

Something similar happened at Colombo during the construction of a breakwater there; a length of wall at the outer end, 150 feet by 28 feet wide, founded at a depth 20 feet below low water, being shifted inward as much as 15 inches, necessitating the resetting of that portion of the work.

At the Tyne north pier works much damage occurred for several winters in succession from the same cause, necessitating the reconstruction of an outer section 1,500 feet in length.

**Depth to which Wave Action Extends.** It should be added, however, that wave disturbance occurs at considerably greater depths than those at which existing sea works are founded. For example, Sir James Douglass, the well-known lighthouse engineer, recorded the fact that coarse sand was found on the gallery (120 feet above water level) of the Bishop Rock Lighthouse, off Scilly, where the depth of water is about 150 feet. Seeing that the sand could have come from nowhere else, it follows that the material must have been washed up from the sea bottom and hurled into the air, a total height, from sea bed to gallery, of 270 feet.

## DEPTH TO WHICH DAYLIGHT PENETRATES UNDER WATER

This varies with the locality. For instance, in some of the Scottish lochs the water is so dark that daylight is lost to the diver when but a few feet below the surface. In most tropical waters he can see perfectly clearly when 30 fathoms or more down, and a diver at a depth of 45 fathoms, on a bright, sunny day, has been able to see the entire length of a submarine wrecked off Honolulu. On the wreck of the *Egypt*, sunk off Ushant in 66 fathoms, the divers in their observation chamber could see sufficiently clearly through the windows to direct the working of grabs, etc. In many places, however, the movements of the diver on the bottom stir up the silt to such an extent as to create a fog which the most powerful submarine lights fail to penetrate.

## SUPERFICIAL AREA AND DISPLACEMENT OF A DIVER

**Superficial Area of a Naked Man's Body and the Pressure thereon.** The superficial area of an ordinary-sized man's body is about 2,160 square inches, so that in atmospheric air the total pressure on the man's body is $2,160 \times 14{\cdot}7$ lb. $= 31,752$ lb. At a depth of 33 feet of sea-water, the total pressure would be 63,504 lb. So long as the pressure is equally distributed throughout the body by the body fluids, it has no effect.

**Weight of a Diver Fully Equipped.** The total weight of a diver's equipment (i.e. the part which he actually wears, and exclusive of his air-pipe) is about 175 lb.; therefore a diver (say, a 12-stone man), fully equipped, would have a total weight of 343 lb.

**Displacement of a Man with and without Diving Dress.** An ordinary-sized man (naked) displaces about ·075 ton of sea-water; a fully-equipped diver, with dress deflated, about 0·15 ton, and with dress fully inflated, about 0·31 ton. But if fully inflated he would float, and in so doing would displace exactly the weight of himself and dress, or 343 lb. $=$ ·153 ton, as his displacement would be greater than the equivalent weight of water if entirely submerged.

## BUOYANCY OF SUBMERGED OBJECTS

A submerged body displaces in the sea a weight of water equal to the cubic capacity of the body $\times$ 64 lb. (the weight of a cubic foot of sea-water). Thus a pontoon or camel, measuring 15 feet long by 4 feet diameter $= 188{\cdot}5$ cubic feet, would displace nearly 5·4 tons of sea water if entirely submerged, and its buoyancy would be represented by this figure, minus the weight of the pontoon itself.

**Constituents of Atmospheric Air.** The chief constituents of atmospheric air and their proportions are:

| | |
|---|---|
| Nitrogen .. .. .. .. | 79·1 per cent by volume |
| Oxygen .. .. .. .. | 20·9 " " |
| Carbon dioxide ($CO_2$) .. .. | ·03 " " |

Aqueous vapour is also present in varying quantity

Nitrogen has neither taste nor smell nor colour, and, although it is non-poisonous, it will support neither life nor combustion. Its chief use appears to be to dilute the oxygen which is the life supporting component of the atmosphere, and it is also odourless, tasteless and colourless.

**Its Weight.** The weight of the atmosphere is 14·7 lb. to the square inch; thus, in speaking of one atmosphere we mean 14·7 lb. on the square inch; two atmospheres 29·4 lb., and so on.

**To convert temperature** Centigrade to Fahrenheit, and vice-versa:

$$\text{Fahrenheit} = \frac{\text{Temperature Centigrade} \times 9}{5} + 32$$

$$\text{Centigrade} = \frac{\text{Temperature Fahrenheit} - 32}{9} \times 5$$

**Column of Mercury.** A column of mercury 30 inches high = 1 atmosphere = say, 14·7 lb. pressure. A column of mercury 2 inches high = say, 1 lb. pressure.

**Expansion.** Air expands $\frac{1}{493}$ of its volume for every increase of 1 deg. F., and its volume varies inversely as the pressure.

**Quantity of Air Breathed by Man.** Normally, the volume of air breathed by an average healthy adult male is about 30 cubic inches per inhalation × 15 inhalations = 450 cubic inches = about ·25 cubic feet = 7·3 litres per minute. Exhaled air contains on the average 79·1 per cent of nitrogen, 16·5 per cent of oxygen, 4·4 per cent of carbonic acid ($CO_2$). The "dead space" formed by the larger air tubes is about 10 cubic inches. The air in the lung contains about 14 per cent $O_2$ and 5 per cent to 6 per cent $CO_2$.

**Volume of Air Breathed and Oxygen Consumed by Man during Various Degrees of Effort.** The late Professor J. S. Haldane, and Dr. C. G. Douglas, F.R.S., of Oxford University, using the latter's well-known bag method for determining the respiratory exchange in man carried out an exhaustive series of experiments to ascertain exact data for

(*a*) Volume of air breathed (*b*) oxygen consumed and (*c*) $CO_2$ given off during varying degrees of effort.

The following were the results obtained:

| Work done | Oxygen consumption in c.c. per min. | $CO_2$ production in c.c. per min. | Litres of air breathed per min. | Volume of each breath in c.c. | Breaths per min. | $CO_2$ per cent in expired air |
|---|---|---|---|---|---|---|
| Resting (in bed) | 237 | 197 | 7·67 | 457 | 16·8 | 3·19 |
| Standing | 328 | 264 | 10·4 | 612 | 17·1 | 3·14 |
| Walking 2 m.p.h. (grass) | 780 | 662 | 18·6 | 1,271 | 14·7 | 4·39 |
| do. 3 m.p.h. | 1,065 | 992 | 24·8 | 1,535 | 16·2 | 4·62 |
| do. 4 m.p.h. | 1,595 | 1,398 | 37·3 | 2,064 | 18·2 | 4·67 |
| do. 4½ m.p.h. | 2,005 | 1,788 | 46·5 | 2,524 | 18·5 | 4·72 |
| do. 5 m.p.h. | 2,543 | 2,386 | 60·9 | 3,145 | 19·5 | 4·79 |

From these results, it will be seen how greatly the consumption of air increases with the worker's effort.

**Oxygen Want—Holding the Breath—Forced Breathing.** Professor J. S. Haldane and Dr. Priestley say: "... the immediate cause of death of the body as a whole is practically always want of oxygen, due to failure of either the circulation or the breathing. This fact arises from the circumstance that the body has hardly any internal storage capacity for oxygen, but depends from moment to moment on its supply from the air. We can deprive the body for long periods of its external supplies of food or even of water, or we can prevent for some days the excretion of urinary products, without causing death. We can even obstruct the removal of $CO_2$ for some time, but we cannot interfere with the supply of oxygen to the blood without producing at once the most threatening symptoms. Almost the only appreciable storage capacity for oxygen at sufficient pressure in the body is in the lungs. In virtue of this small store—about 400 cc. of oxygen—breathing can be prevented for about one-and-a-quarter minutes in a man at rest, and previously breathing normally, before urgent symptoms of oxygen-want appear. The factors which determine the ability of a man to hold his breath voluntarily are partly psychological, partly physiological. The latter again include anoxaemia and accumulation of $CO_2$. Some experiments by Schneider illustrate their effect and the results of varying the store of oxygen in the lungs. The results of observation on 20 subjects were as follows:

| | The breath could be held for |
|---|---|
| (1) After a moderate inspiration .. .. .. | 30 to 105 seconds |
| (2) After a very deep inspiration .. .. .. | 45 to 123 " |
| (3) After forced breathing for two minutes .. | 65 to 260 " |
| (4) After three deep breaths of pure oxygen .. | 130 to 340 " |
| (5) After forced breathing and three deep breaths of oxygen .. .. .. .. .. .. | 210 to 842 " |

On one occasion another man held his breath for 913 seconds (15 minutes 13 seconds) after forced breathing and inhalation of oxygen."

## METRIC WEIGHTS AND MEASUREMENTS WITH ENGLISH EQUIVALENTS

| | | |
|---|---|---|
| 1 metre | = | 39·37 inches = 3·281 feet |
| ·915 metre | = | 1 yard |
| ·3048 metre | = | 1 foot |
| 1 millimetre | = | 1/25 inch = ·03937 inch |
| 1 centimetre | = | ·3937 inch |
| 2·54 centimetres | = | 1 inch |
| 25·4 millimetres | = | 1 inch |
| 1 kilometre | = | 1093·61 yards = 3280·9 feet |
| 1·609 kilometre | = | 1 mile |
| 1 imperial gallon | = | 277·274 cubic inches |
| " " | = | ·16 cubic foot |
| " " | = | 10·00 lbs. |
| " " | = | 4·543 litres |
| 1 cubic inch of water | = | 252·6 grains |
| " " " | = | ·03612 lb. |
| " " " | = | ·003607 imperial gallon |
| 1 cubic foot of water | = | 6·235 imperial gallons |
| " " " | = | 28·315 litres |
| " " " | = | ·0283 cubic metre |
| " " " | = | 62·355 lb. |
| 1 lb. of water | = | 27·632 cubic inches |
| " " | = | ·10 imperial gallon |
| 1 cwt. of water | = | 11·2 imperial gallons |
| " " | = | 1·795 cubic feet |
| 1 ton of water | = | 224 imperial gallons |
| " " | = | 1017 litres (approx.) |
| " " | = | 1 cubic metre (approx.) |

| | | |
|---|---|---|
| 1 litre of water | = | ·022 imperial gallon = $1\frac{3}{4}$ pints |
| " " | = | 61 cubic inches |
| " " | = | ·0353 cubic foot |
| 1 cubic metre of water | = | 220·1 imperial gallons |
| " " " | = | 1·308 cubic yards |
| " " " | = | 61,025 cubic inches |
| " " " | = | 35·3156 cubic feet |
| " " " | = | 1000 kilos |
| " " " | = | about 1 ton |
| " " " | = | 1000 litres |
| 1 kilo | = | 2·2046 lb. |
| 1 atmosphere | = | 1·0335 kilos per sq. cm. = 14·7 lb. per sq. in. |
| 1 gramme | = | 15·432 grains (Troy) |
| 1 kilogram | = | 2·2046 lb. or $2\frac{1}{5}$ lb. |
| 1 millier (metric ton) | = | 2204·62 lb. or 0·9842 ton |
| 1 ounce (avoirdupois) | = | 28·35 grammes |
| 1 lb. | = | ·4536 kilogram |
| 1 cwt. | = | 50·80 kilograms |
| 1 ton of 2240 lb. | = | 1016 kilograms |
| " " | = | 1·016 metric tons |
| 1 square inch | = | 6·45 square centimetres |
| 1 square foot | = | 0·092 square metres |
| 1 cubic inch | = | 16·38 cubic centimetres |
| 1 cubic foot | = | 0·028 cubic metres |
| 1 lb. per square inch | = | 0·07 kilogrammes per square centimetre |
| 1 lb. per square foot | = | 4·88 kilogrammes per square metre |

## DEFINITIONS OF SOME PHYSIOLOGICAL AND MEDICAL TERMS

*Alveolar Air. The air contained in the endings of the air tubes.* These branch *into* the lungs like a tree on a tiny scale. The ends of each tiny branch open into minute spaces comparable to the leaves of a tree, and the walls of these are covered with a network of capillaries containing blood, through which the exchange of gases between blood and air takes place.

*Anoxaemia.* Insufficient oxygen in arterial blood.

*Anoxia.* A state resulting from insufficient oxygen.

*Aphasia. Loss of speech, spoken or written,* resulting from injury to, or disease of certain parts of the brain.

*Apnoea.* The cessation of breathing which results after rapid deep breathing, due to the increased ventilation of the lungs taking much carbon-dioxide out of the blood; this being the natural stimulus of breathing.

*Artificial Respiration.* Breathing produced artificially by mechanical means.

*Asphyxia.* A death-like condition caused by want of oxygen, produced by stoppage of breathing by suffocation, drowning, or breathing of poison gases.

*Blood, Arterial.* The blood which, having passed through the lungs and become bright red by taking up oxygen, is expelled by the contraction of the heart and driven along the arteries. The right side of the heart receives venous blood and drives this through the pulmonary artery to the lungs where carbon-dioxide is given up and oxygen taken in.

*Blood Venous.* The dark bluish-red blood in the veins coming from the capillaries of the tissues, which have taken away oxygen and so changed the colour from bright red to bluish-red. The pulmonary veins take bright red blood from the lungs to the left side of the heart. All the other veins join up to empty their blood into the right side of the heart.

*Compression.* Signifies the putting of men under the action of compressed air.

*Decompression.* The letting out of compressed air from a caisson or diving dress, and of the nitrogen from the body of a man who has been subjected to such pressure.

*Ear Drum or Tympanum.* The membrane which separates the outer from the middle ear, and receives and transmits the waves of sound.

*Embolism.* The plugging of a blood-vessel by an embolus; for example, by air bubbles or a clot of blood, so as to obstruct the flow of blood.

*Eustachian Tube.* Connects the middle cavity of the ear with the back of the throat, and equalizes the air pressure between the two. There is one on each side at the back of the nose; they may be closed by catarrh.

*Heat Transmission.* This occurs by conduction along a material such as an iron rod, or by convection through the movement of air, and by radiation by rays from the sun, or a fire.

*Irrespirable.* Dangerous to breathe.

*Larynx.* The upper part of the windpipe, within the Adam's apple, where the voice is produced.

*Metabolic Rate.* The rate at which metabolism is taking place, as measured by the uptake of oxygen in a given period.

*Metabolism.* The sum total of the chemical changes which take place in the living body.

*Paralysis.* Loss of power in, or function of, a part of the body.

*Partial Pressure of a Gas.* The pressure which a gas would exert were it confined alone, separate from a mixture of gases.

*Pharynx or Throat.* The part between the gullet, or oesophagus, and back of the nose and cavity of the mouth, into which open the passages of the nose and the Eustachian tubes and larynx.

*Protoplasm.* The living substance in all cells which make the structure of plants and animals. Microscopic in size, the cells of our bodies are myriad in numbers, and form organs with varying cell substance and function.

*Protozoa.* The simplest forms of animal life of microscopic size consisting of a single cell with a nucleus such as the amoeba, which moves and eats by flow of its protoplasm and reproduces itself by dividing into two. The nucleus is a differentiated and essential part of a living cell controlling its division.

*Recompression.* Compressing a diver or caisson worker after decompression, in case of need.

*Respiration.* Breathing, consisting of inspiration and expiration. *On inspiring,* air is drawn into the lungs by the enlarging of the chest, chiefly by the descent of the diaphragm or midriff. *Expiration,* when not forced, takes place chiefly by the return of the elastic stretched parts to the resting position. Only a small part of the total air in the lungs is replaced by a quiet respiration; *much more* by *deep expiration and inspiration.*

*Solution.* The process by which a substance, solid, liquid or gaseous, is dissolved and perfectly mixed with another liquid, thus forming a solution.

*Specific Gravity.* The weight of a given volume of a substance compared with that of an equal volume of water. In the case of gases, air is used as the standard, weighed at 0° Centigrade and 760 mm. pressure.

*Tissue.* An aggregation of cells and inter-cellular substance forming one of the structures of which the body is built.

*Trachea.* The windpipe, a stiff tube by which air passes to and from the lungs, about 4 inches long and one inch wide, extending in front of the neck from the larynx to where it divides into two bronchi—one to each lung. The bronchi divide into bronchioles which divide and sub-divide and finally open into the alveoli.

*Vertigo.* Dizziness and difficulty of standing. It may result from ear or brain trouble.

*Vital Capacity.* The amount of air which, after the deepest inspiration, can be breathed out by the following deepest expiration.

## TABLE OF GAS DATA

| GAS | Density of gas relative to hydrogen at N.T.P. | Boiling point °C. | Melting point °C. | Critical temp. °C. | Critical press. ats. | Vol. of 1lb. at 15°C. and 1 at. abs. in cu. ft. | Weight of 1,000 c. ft. at 15°C. and 1 at. abs. in lb. | Density of liquid at boiling point | Weight of 1 litre of liquid at its B.P. in lb. | Weight of 1 gall. of liquid at its B.P. in lb. | Vols. of gas at 15°C from 1 vol. of liquid at its B.P. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrogen | 1·000 | —252 | —259 | —241·2 | 11 | 188·01 | 5·319 | ·070 | ·15 | ·70 | 821 |
| Helium | 1·991 | —269 | —272 | —268 | 2·75 | 94·7 | 10·56 | ·154 | ·34 | 1·54 | 910 |
| Methane | 7·978 | —164 | —184 | —82·85 | 45·6 | 23·6 | 42·4 | ·415 | ·91 | 4·15 | 612 |
| Ammonia | 8·577 | — 33·5 | — 75 | +130 | 115 | 21·920 | 45·62 | at 0°C. ·623 | at 0°C. 1·37 | at 0°C. 6·23 | (Liq. at 0°C) 854 |
| Neon | 10·017 | —239 | — | —213 | 29 | 18·771 | 53·28 | — | — | — | — |
| Acetylene | 13·027 | — 85 | — | + 36·5 | 61·6 | 14·430 | 69·29 | at 0°C. ·451 | at 0°C. ·99 | at 0°C. 4·51 | (Liq. at 0°C) 401 |
| Carbon monoxide | 13·913 | —190 | —207 | —138·7 | 34·6 | 13·515 | 73·99 | ·793 | 1·75 | 7·93 | 670 |
| Nitrogen | 13·916 | —196 | —210·5 | —144·7 | 33·65 | 13·513 | 74·00 | ·804 | 1·77 | 8·04 | 678 |
| Air (dry) | 14·385 | —194 | — | —140 | 39 | 13·074 | 76·49 | ·875 | 1·93 | 8·75 | 714 |
| Nitric Oxide | 14·912 | —153 | —167 | — 93·5 | 71·2 | 12·607 | 79·32 | — | — | — | — |
| Oxygen | 15·900 | —183 | —219 | —118 | 49·3 | 11·827 | 84·56 | 1·14 | 2·52 | 11·4 | 842 |
| Sulphuretted Hydrogen | 17·112 | — 61·5 | — 86 | +100 | 88·7 | 10·987 | 91·02 | at 15°C. ·9 | at 15°C. 1·98 | at 15°C. 9·0 | (Liq.at 15°C) 618 |
| Argon | 19·816 | —186 | —188 | —122·6 | 48 | 9·483 | 105·45 | 1·4046 | 3·09 | 14·046 | 831 |
| Carbon Dioxide | 21·996 | — 78·5 | — 65 | + 31·1 | 73 | 8·556 | 116·88 | ·84 at 15°C 1·2 solid | at 15°C. 1·85 | at 15°C. 8·4 | (Liq.at 15°C) 450 |
| Nitrous Oxide | 22·006 | — 88·7 | —102 | + 38·8 | 77·5 | 8·551 | 116·95 | ·91 at 0°C. 1·226 | 2·70 | 12·26 | 656 |
| Sulphur Dioxide | 32·565 | — 11 | — 76 | +155·4 | 78·9 | 5·794 | 172·61 | 1·46 | 3·21 | 14·6 | 529 |
| Chlorine | 35·845 | — 33·6 | —102 | +146 | 93·5 | 5·245 | 190·66 | at 0°C. 2·49 | at 0°C. 5·48 | at 0°C. 24·9 | (Liq. at 0°C) 816 |
| Krypton | 41·248 | —152 | —169 | — 62·5 | 54·3 | 4·558 | 219·4 | 2·155 | 4·74 | 21·55 | 614 |
| Xenon | 64·949 | —109 | —140 | + 16·6 | 58·2 | 2·895 | 345·4 | 3·06 | 6·73 | 30·6 | 553 |

# CONSTITUENTS OF THE AIR WE BREATHE

## AND THE MEN WHO DISCOVERED THEM

It will doubtless surprise many to know that the constituents, including the "rare" gases, of the atmosphere which we breathe from birth to death, have only become known in their entirety during the past sixty years.

In 1774, Joseph Priestley, the English scientist (1733–1804), born at Fieldhead, Yorkshire, and Antoine Lavosiere (1743–1794), the French scientist, born in Paris, independently and almost at the same period discovered that the Earth's atmosphere contains 21 per cent Oxygen and 79 per cent Nitrogen. The name first given Oxygen by Priestley was "dephlogisticated air".

But the story of the discovery of the "rare" gases does not begin until 1869 when Sir Joseph N. Lockyer (1836–1920), photographing the spectrum of the solar corona during an eclipse, discovered a hitherto unknown brilliant yellow-orange band which gave rise to much discussion in scientific circles. For want of a better solution some of the scientists ascribed the mysterious band to the presence of an already-known gas – Hydrogen. But others were not satisfied; they were convinced that the Sun contained an element that had not yet been discovered on Earth, and named it Helium, from the Greek word *helios* – the Sun.

A decade later, the Italian scientist, Palmeiri, observed the same yellow-orange band in the spectrum of the luminous gases ejected by a Vesuvius eruption, thus giving the geologists food for investigation, and proving for the first time that Helium also exists on this Earth of ours of timeless age, which has given the breath of life to all humanity, the vast majority of whom have long been lost in oblivion.

Palmeiri's discovery set certain research scientists the task of solving the mystery, and the credit for successfully separating Helium from the atmosphere goes to Sir William Ramsey (1852–1919), born in Glasgow, who abstracted the first samples of the lightest of the rare gases in 1895.

The apothesis of William Prout (1785–1850) on atomic weights of the elements, inspired Lord Rayleigh, John W. Strutt (1842–1929), Order of Merit, Nobel Prize Winner, F.R.S., etc. to start a series of experiments on the densities of gases. Ramsey, who was working on Nitrogen at the time, collaborated with Rayleigh in the later stages of these experiments, and the two great scientists solved the problem when they proved that the difference in certain densities was due to the presence in the atmosphere of a heavy, hitherto unknown, gas which they extracted, and which they christened "Argon".

The successes so far obtained by the scientists encouraged them to seek further hitherto unknown gases, and their research work continued unabated, with the result that Neon, Krypton and Xenon followed in relatively quick time. These rare gases, all inert and entirely resistant to chemical action, are largely used in science and industry, in the fields of electricity, metallurgy, electronics, etc.

The whole subject of the discovery of the "rare" gases, first in the Sun, and some years later in the Earth; their extraction from the atmosphere by eminent scientists, and their various uses in industry, etc., makes a fascinating story which deserves to be read in full in the scientific volumes available.

Hydrogen, as we know, is the lightest of all gases, and for that reason has, so far, been used exclusively in European countries for filling balloons. But Hydrogen, owing to its inflammable and, in some conditions of flight, explosive nature, can be very dangerous, particularly in electrical storms. It has been suggested, therefore, that Hydrogen be replaced everywhere by the lightest of the rare gases, the inert, though of double the density, Helium.

Balloon-filling, of course, requires very large quantities of gas, and Helium costs more than Hydrogen, but is not the extra expense justified in the interests of safety?

In my own specialities for Deep Diving operations, High Altitude ascents, Breathing in Irrespirable Conditions in Mines, at Conflagrations, etc., immense quantities of atmospheric air, pure Oxygen, mixtures of Oxygen and Nitrogen, and mixtures of Helium and Oxygen have been used over the years.

One of my Patents, dated January 1912, is for a device in connection with mixtures of breathing gases for Deep Sea Diving operations.

America possesses in the State of Texas the World's largest natural sources of Helium, and great quantities of the gas are produced there; whereas Europe has to rely on the comparatively small proportion extracted from the air.

The efficacy of mixtures of Helium and Oxygen in place of Nitrogen and Oxygen (atmospheric air) in Deep Sea Diving, I have already dealt with in my book *Deep Diving and Submarine Operations*. The use of Helium in connection with such work has enabled divers to attain much greater depths with safety.

To the U.S.A. Navy must go the credit for being the first to use breathing mixtures of Helium and Oxygen for deep sea divers; and many years ago, when we were carrying out in my works (in 1930–1933) experiments in an extension of deep diving decompression methods, and at a time when its export from America was prohibited, the United States Government very generously granted us leave to import a supply of Helium for our experiments.

Canada also has natural sources of Helium. On 15th December, 1925, Mr. R. T. Elworthy, of the Department of Mines, Ottawa, called to see me with regard to the possibility of our using the gas in connection with our work, and to ask what quantities we should be likely to require. I told him that our requirements at first would be in connection with our deep diving experimental work; after that, considerable quantities might be needed.

The Canadian Government was considering the possibility of laying down plant for the extraction of Helium, and considerable correspondence ensued between Mr. R. T. Elworthy and myself, as will be seen from my files.

The quantities of the gas from Canadian sources was considerably smaller than those from U.S.A. fields. In the end, the Canadian Government failed to agree to the expenditure for the necessary plant, and the project fell through.

Of further great importance would be the more general use of Helium, because of its lightness and neutrality, by the Medical profession. In the treatment of pulmonary complaints, a mixture of 80 per cent Helium, in place of Nitrogen, and 20 per cent Oxygen would be invaluable in cases of congestion of the lungs. The Helium, by reason of its lightness, would carry the Oxygen with greater facility to the more remote areas of the lungs' cavities and their secretions.

Scientific research in the fields of Atomic Energy, Nuclear-fission and Radio-activity goes on continuously, and further discoveries, founded on the long and arduous original work of the famous men I have named, have already been made. Today, far more men of scientific knowledge and experience are tackling problems of all kinds yet to be solved, and that they will be solved there is no doubt. R. H. D.