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Use of Pneumatic Tools and Explosives Under Water

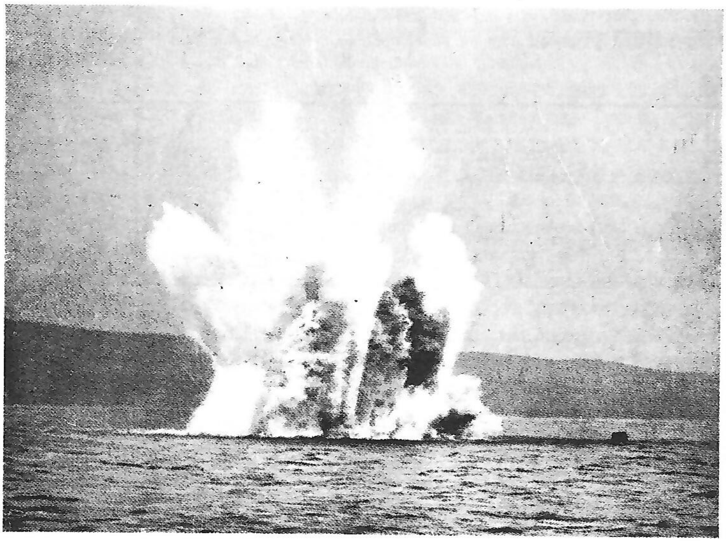


Fig. 225. A submerged rock blast

THE REMOVAL OF SUBMERGED ROCK*

So much depends upon the varying conditions under which work of this description is conducted that it is impossible to lay down any hard and fast rule for the carrying out of submarine blasting operations. When making enquiries as to the best method to employ, the following particulars should be given, viz.: depth of water at high and low tide, nature of rock to be removed, its situation and approximate depth and area.

The following notes as to preparation of explosive charges and general mode of procedure, and particulars of some methods employed, may prove useful.

If the rock is heavily creviced a start can be made by thrusting blasting charges deep into the cracks, but in most cases it is necessary to drill boreholes into the solid rock by either:

Compressed-air drills operated from a floating vessel or raft, or from staging.
Hand drills which the divers take under water with them.
Tripod drills which are heavily weighted and lowered under water and are controlled by divers.

Hand-worked Jumper Drills. Where the quantity of work to be done is so small as not to warrant the purchase of pneumatic tools, the old-fashioned jumper drill, operated by men pulling on ropes carried over sheaves, can be recommended for efficiency and simplicity.

Where the boring is conducted from the water surface, the drill rods should be carried through iron piping resting on the sea-bed, and reaching up to the craft or

* A useful pamphlet on the subject is "Underwater Blasting" by R. Westwater, B.SC., and R. Haslam, B.SC., Imperial Chemical Industries Ltd., Nobel Division, obtainable from Siebe, Gorman & Co. Ltd.

staging. This arrangement gives lateral support to the drill rods, and, on completion of the hole, the pipe acts as a conduit for the placing of the explosive charge in the hole. In many cases, however, the charges are placed by divers.

APPROXIMATE AMOUNT OF WORK THAT CAN BE DONE WITH PNEUMATIC ROCK DRILLS

Pneumatic Hand Drills. The choice of a rock drill is governed by the direction of the hole and the nature of the rock to be drilled. The power of the drill should be such that it will chip the rock, not crush it, and maintain a speed of penetration of approximately 12 inches per minute. The drilling capacities of the various sizes of rock drills working in medium granite are as follows:

Hand Drills

Diameter of hole	Rock drill bore and stroke	Economical drilling depth	Average rate per minute
2 to $2\frac{1}{4}$ inches	$2\frac{3}{8}$ by $1\frac{5}{8}$ inches	6 to 8 feet	5 to 6 inches
$2\frac{1}{2}$ inches	$2\frac{5}{8}$ by 2 inches	12 to 14 feet	6 to 8 inches
$2\frac{3}{4}$ inches	$2\frac{5}{8}$ by $2\frac{9}{16}$ inches	14 to 16 feet	8 to 9 inches

Tripod Drills

$3\frac{1}{8}$ inches up	$3\frac{1}{2}$ inches	20 feet	10 to 12 inches

Tripod Pneumatic Drill Worked Under Water by Diver. It has been found in some cases that if the rock is of a precipitous nature the best method is to commence drilling a row of holes parallel to the edge, and at such a distance from it as gives the best results so far as fragmentation of the rock is concerned. For holes up to 20 feet we suggest that the distance from the edge should be one-third of the depth of the hole. Holes should be drilled 2 or 3 feet below the required level. After blasting out these holes, a fresh series is drilled parallel to the former ones, or to the face left by the blasts, and these also blasted out—a third line—and so on, progressing regularly across the rock, continually blasting it off in parallel blocks extending downward a little below the depth required.

The advantage of this mode of operating is that it enables the blasts to act laterally, and the rock is left after each series of blasts with a nearly vertical side or face, in which the presence of seams can be detected and the character of the strata observed, so that the most favourable positions for the next blasts to produce the greatest effect can be selected.

Sometimes the craters following the strata run under or leave an overhanging face, in which case a large charge usually has the effect of throwing off the overhanging portion, and often dislodges large masses of rock.

With a rock drill of good construction it is possible to do as much work in a few hours as would take several days with hand tools. The diver can easily be taught the use of the drill on land, and when conversant with its working, he will not find the slightest difficulty in carrying out the boring operations under water.

The working vessel (some engineers prefer to work the drill from a raft, or a barge, with a well in the centre, having watertight compartments) having been moored over the rock, the diver descends and selects the exact position for the blast, and then signals to have the drill and stand lowered to him. This being done, he fixes the drill in position by means of its adjustable legs, and then signals to commence supplying the drill with compressed air. Sometimes the drill works uninterruptedly till the hole is drilled to the required depth; at other times its working requires the attendance of the diver, either in replacing drill-heads broken by contact with hard crystals, or in regulating the turn or "hoist" of the drill, or in clearing the holes of cuttings, or "spooning out", as it is termed, and rectifying the direction of the drill by adjusting the legs or guys.

In a rapid current the stoppage of the drill for the purpose of "spooning out" the holes becomes unnecessary, as the motion of the drill works up the powdered cuttings to the mouth of the hole, whence they are sucked out and carried off by the current.

As soon as the hole is drilled to the required depth, the drill is stopped, and, after an examination of the hole and clearing away any cuttings remaining in the bottom, the diver telephones or signals for the charge of explosive (which has previously been carefully prepared with submarine detonators, and with insulated wires extending to, but not yet connected with, the exploder on deck) to be lowered to him, and he inserts it in the drill hole, carefully pressing it to the bottom with a wooden rod. The charges should be of such size as to pass into the boreholes easily, i.e. the diameter of the borehole should be at least ⅛ inch larger in diameter than the diameter of the cartridge. The diver then ascends, and the working vessel is hauled to a safe distance. The wires are then attached to the exploder, a few turns given to the handle, and the operator makes the contact, when a shock, followed instantly by a second shock and the upheaval of the water, announces the explosion of the charges.

The working vessel is then brought back to the position as before, and the same operation repeated.

In cases where the rock is naturally "fissured", it is not necessary to bore holes, as the crevices or fissures themselves form very good receptacles for the explosive charges. As a rule, under these circumstances it is difficult to apply tamping in such a way that the full efficiency is obtained from the explosive. In such a case, a waterproof bag filled with explosive is the best form of charge to use, as it shapes itself to the inequalities of the rock.

Tripod Drills. With a 3½-inch tripod drill, a hole 1½ inches to 1¾ inches diameter by 4 feet deep can be bored in hard rock in from 5 to 8 minutes. Much, of course, depends upon the nature of the rock, and also whether it is solid or fissury. In the case of jointy rock, or rocks of uneven hardness, the time might be slightly increased.*

In determining the depth of holes, spacing apart and the size of explosive charge, the engineer will be guided by the peculiar conditions of the case in hand, and the appliances available. But it should always be borne in mind that the disintegrated rock has to be removed; therefore it should be blasted in pieces of such size as to be easily handled by the ordinary dredging appliances. Regard must also be had to the proximity of buildings on shore, dock walls, river banks, etc.; in many cases it is necessary to proceed with great caution, using only small charges of explosives at a time, so as to avoid risk of damage to such constructions and their foundations.

AIR PRESSURE FOR UNDERWATER TOOLS AND ROCK DRILLS

The normal working pressure used above the surface is from 80 to 100 lbs. per square inch. Pneumatic tools and rock drills (see page 233) will operate satisfactorily with air pressure as low as 60 lbs. per square inch. They can be used to about 50 feet below the surface without fitting a hosepipe to take the exhaust air to the surface. Without the exhaust hose, the air being exhausted will, of course, bubble up through the water to the surface. In comparatively shallow depths of water this is not likely to inconvenience the diver, and it avoids the complication of the additional hosepipe. When used in this way, pneumatic drills for drilling metal and wood are sometimes fitted with a non-return valve on the exhaust outlet to prevent the entry of water when the machine is stopped. In some cases, the action of the machine is controlled by a throttle valve on the exhaust outlet instead of on the compressed air inlet; this also keeps water out of the machine. When working without an exhaust hose, the working pressure at the machine should, if possible, be brought up to normal surface working pressure by increasing the pressure of the air going down to the machine sufficiently

* The above figures represent the amount of dry work at the surface. In the altered conditions of submarine work the quantities would, of course, be somewhat less.

to maintain the exhaust pressure above the hydrostatic pressure. Pneumatic tools and rock drills have been operated at considerable depths without exhaust hoses by increasing the compressed air pressure, but below 50 feet or so most divers prefer the pipe exhaust in order to avoid exhaust air bubbles Most manufacturers are able to supply either machines specially built for underwater use with exhaust hose connections, or standard surface working machines suitably adapted for this purpose. In addition to the air pressure at the machines, there are two very important matters that must be kept in mind when using machines under water, namely, lubrication and cleaning. The best way to lubricate is to use an air-line lubricator fitted either directly to the air inlet on the machine or connected to the air inlet by a short length of hose-pipe. Line oil lubricators are available in various sizes. For rock drills, a pint-size is usual. The line-oiler automatically delivers oil to the ingoing compressed air and thus lubricates all the internal working parts. In view of the destructive effect of water, particularly sea-water, the importance of cleaning cannot be over-estimated. When a machine is brought to the surface, it should be blown through with air to remove as much water as possible. If it is going to be used again within a short period, oil should be blown through and the machine completely immersed in an oil-bath, care being taken to see that the oil penetrates to the interior. If the machine is to remain idle for more than a day, it must be dismantled and every part carefully cleaned and coated with oil before reassembly. Light torpoyl is the best preservative to use. If cleaning is attended to properly, there is no reason why any part of the machine, even parts made of aluminium, should give trouble or deteriorate rapidly.

Tools Supplied

(*a*) *Pneumatic Hammers*. One with piston block weighing 1 lb. and having a stroke of 4 inches, delivering 1,000 blows per minute at maximum output. One with piston block 1 lb. in weight and having a stroke of 3 inches, delivering 1,500 blows per minute at maximum output. Both are fitted with hexagon tool sleeve and supplied with two flat chisels, one cross-cut chisel, one round chisel and two chisel blanks.

(*b*) *Pneumatic Drills*. One capable of drilling a 1-inch hole in a 3-inch mild steel plate in three minutes. One capable of drilling a ½-inch hole in a 3-inch mild steel plate in 4½ minutes. Both are fitted with morse standard shanks and sockets and sets of drills.

Preparations for Use. The supply hose must be connected to the source of supply, care being taken that a pressure of 100 lbs. per square inch is not exceeded at the machine. The exhaust and supply hose are then connected to the machine and stopped together. The tool to be used should be secured with a lanyard or other means to guard against loss. Run the machine on the surface for test.

Sending the Machine to the Diver. The best method is for the diver to receive a light line or wire close to his work to act as a runner. This line is then hauled taut at the surface. The instructions for sending down a wire should now be followed, the length of spunyarn absorbing the turns and preventing the hose winding round the runner.

It is best for the diver to get comfortable and ready to work before pressure is opened up as far as the machine.

EXPLOSIVES FOR UNDERWATER BLASTING

Full details of explosives are given in the Imperial Chemical Industries pamphlet referred to on page 245, and the following is quoted as a guide in the selection of explosives according to the conditions prevailing:

"Explosives for underwater blasting should have a high bulk strength, good water resistance, and should maintain their sensitivity when subjected to hydrostatic pressure. When explosives containing ammonium nitrate or sodium nitrate are subjected to water pressure, the water gradually seeps into the explosive, the rate of penetration being dependent on the pressure. Thus, the diameter of the dry core of the explosive is gradually reduced. Under dry conditions the general performance of an explosive improves with an increase in the cartridge diameter and hence, in underwater work. it is doubly desirable that the cartridge diameter should be as large as possible. The hydrostatic properties, therefore, depend on two factors, namely, the type of explosive and the diameter of the cartridge. On this basis, the properties of a variety of explosives, suitable for underwater operations, can be tabulated as follows:

Type of explosive	Cartridge diameter	Max. depth of water	Max. duration of immersion	Weight strength
Polar ammon gelignite	Less than 3 in.	20 ft.	24 hours	78 per cent
Polar ammon gelatine dynamite	Less than 3 in.	20 ft.	24 hours	90 „ „
Polar ammon gelignite	3 in.–8 in.	30 ft.–100 ft.	7–30 days	78 „ „
Polar ammon gelatine dynamite	3 in.–8 in.	30 ft.–100 ft.	7–30 days	90 „ „
Geophex	All	1200 ft.	24 hours	66 „ „
Submarine blasting gelatine	All	1200 ft. or more	Weeks	95 „ „

"'Geophex' was primarily developed for use in geophysical prospecting, but the feature, which makes it of value in the operations under consideration, is that the cartridges can be readily coupled together in a continuous rigid column by means of special 'Seislok' couplers. With these devices an external thread on the explosive cartridges engages with a thread inside the coupler. The long columns of explosive, which can be built up in this way, form ideal plaster charges, which are particularly suitable for blasting trenches across river beds to accommodate pipe-lines or cables.

"**Detonators.** The modern commercial electric detonator consists of a thin-walled tube, closed at one end, of either aluminium or copper, containing a low tension electric fusehead, a priming charge and a base charge. The open end of the tube is sealed with a neoprene plug, through which the leading wires pass.

"The standard low-tension electric fusehead fitted with double cotton-covered leading wires is not suitable for underwater conditions, as the insulation of the leading wires is not sufficiently waterproof. For underwater work submarine detonators, fitted with plastic-covered leading wires and a neoprene plug seal covered with a layer of red lacquer, are used. These are tested at a pressure equivalent to 120 feet of water for 16 hours, but will normally withstand a head of several hundred feet. For more severe conditions, which rarely arise, it is necessary to obtain special detonators, the construction of which will vary according to the conditions involved.

"It is often essential to arrange for various charges to fire in a definite sequence, and gasless delay detonators incorporating a pyrotechnic delay have been developed to make this possible. These are available in a range of delays – Nos. 0–10 inclusive, the delay interval between successive delays being half-second. As is explained later, water is an excellent transmitter of shock waves, and for this reason many underwater problems may be attended with the further complication of a vibration difficulty, and, hence, a limitation on the maximum charge which can be fired in a single blast. However, short delay detonators are now available which can be employed to reduce this difficulty to a minimum. Short delay detonators are available in a range of delays – Nos. 0–15 inclusive, the delay interval between successive delays varying from 25 milliseconds in the lower delays to 75 milliseconds in the higher delays. Both types of delay detonators have similar hydrostatic properties to the submarine detonators referred to above, but the red lacquer is omitted. The half-second delay detonators have one red and one yellow leading wire, and the short delay detonators have two red leading wires.

"Finally, it should be stated that with 'Geophex' or Submarine Blasting Gelatine, only detonators with aluminium tubes should be used, otherwise the maximum effect will not be obtained. The importance of this aspect cannot be over-emphasised."

Submarine Blasting Gelatine. It has been the custom to recommend Polar Blasting Gelatine for underwater blasting, as it is known that, when used with a waterproof primer, a continuous column of this explosive will detonate at a high velocity under pressures of 1 to 2 tons per square inch. With Submarine Blasting Gelatine, however, no other primer is necessary as it can be initiated to its full velocity with a No. 6 or No. 8 aluminium electric detonator.

Geophex. This explosive can be fired under very high pressures and tests have shown that it is capable of detonation under heads of water as great as 2,750 feet. The explosive has excellent storage properties. In order to obtain the highest blasting efficiency, Geophex should be initiated with aluminium detonators.

Testing Low-Tension Electric Detonators. For underwater work, "submarine electric detonators" must be used. Care must be exercised when testing electric detonators to put the detonator several inches into an iron pot, pipe or other suitable receptacle before connection is made with the galvanometer. When this is done, the detonator wires should be connected with the terminals. If the needle moves the detonator is good; but if it remains stationary the detonator is not to be relied upon. The galvanometer must stand on a firm base, and must not be shaken when in use. Only one detonator should be tested at a time, the rest being kept in some safe place during the operation. Each detonator, after being tested, should be put away in a box or cupboard in order to minimize risk.

When ordering electric detonators for underwater work, it is necessary to ask specifically for submarine electric detonators.

Detonating Fuse. Detonating fuse is invaluable in many sub-aqueous blasting operations for detonating a series of charges simultaneously. An example of this is plastic-covered Cordtex. This can be regarded as a continuous detonator and will detonate explosive which is in contact with it. It consists of a core of high explosive—pentaerythritol tetranitrate—P.E.T.N. for short—contained in an inner textile covering. An outer plastic covering is added to improve its storage and handling properties. This fuse has a velocity of detonation of 7,000 metres per second. Plastic-covered Cordtex can be used in up to 60 feet (18·3 metres) of water but immersion should not exceed 16 hours. However, if the head exceeds 20 feet (6·1 metres) it is recommended that the Cordtex should only be employed in conjunction with primers. To prevent moisture creep at the ends of the Cordtex, it is recommended that an empty detonator tube be crimped firmly on each end and cap-sealing compound applied in the vicinity of the crimp as an added precaution.

Cordtex has another useful property in that it enables the shot-holes to be deck loaded, i.e. the charges may be spaced in different parts of the shot-hole.

Preparing the Borehole. After the borehole is carefully drilled—and for economical reasons it should be as nearly circular as possible—it is cleaned out so that no debris remains.

Charging. The cartridge or cartridges should be of such size as to pass in easily—that is, the diameter of the borehole should be at least $\frac{1}{8}$ inch larger than the diameter of the cartridges—and they should be inserted singly in the borehole. When cartridges of explosives are being ordered, the cartridge diameter should be specified to be given this clearance, e.g. if the borehole finishes at $1\frac{3}{8}$ inches diameter, the cartridge ordered should have $1\frac{1}{4}$ inches diameter.

Fixing Electric Detonator. When the last cartridge (or primer cartridge) comes to be inserted, a hole should be made in it by means of a pointed wooden or aluminium primer peg. The detonator should then be pressed therein until it is completely buried in the cartridge. To prevent the detonator being accidentally withdrawn from the cartridge during charging, a hitch may be made round the cartridge with the detonator lead wires. The primer cartridge is then gently pressed into the borehole by the wooden tamping rod and brought into contact with the main charge.

Connecting the Cable. The ends of the leading wires and cable wires should be stripped for a length of about 2 inches, and made perfectly bright and clean. They should then be carefully joined together by twisting the bare end of the leading wire tightly round the bare end of the cable wire (this precaution will tend to prolong the life of the cable). To ensure perfect insulation of the wire connections of importance, especially in simultaneous or circuit shot-firing, the use of Chatterton's compound, Nobel's joint adaptor or prepared rubber taping is recommended.

Exploders. Details of these will be found in the I.C.I. pamphlet already quoted.

Disconnecting the Cable. Immediately after the shot has been fired the shot-firer should disconnect the cable from the exploder and after locking the case remove the key, which he should keep in his possession. This instruction should be followed, particularly when by defective manipulation a misfire has occurred.

Missed Shot. On no consideration attempt to withdraw any tamping.* A fresh hole should be bored parallel to the old one, and in no case nearer to it than 12 inches.

A missed shot in electric blasting may occur from one of the following causes, namely: (1) Defective exploder. (2) Faulty or imperfect connections, due possibly to the wires twisted together being coated with dirt instead of being bright and clean. (3) Short-circuiting caused by abrasion of the coverings of the electric detonator wires during tamping.* (4) Short-circuiting by injury to the insulation of cable, or by a break in the wires. (5) Leakage of current in the water unless submarine electric detonators and submarine connecting wires are used.

In order to determine where the defect exists, the exploder should be immediately disconnected and its effectiveness tested; then the cable should be tested by means of a galvanometer or pocket ohmmeter.

Simultaneous Electric Blasting. Use low-tension electric detonators and connect the wires in series. If the holes are far apart a connecting wire may be used for joining the fuse wires together. The connecting wire should be of the same class and same diameter as the fuse wires. Special care should be taken that the wires at all joints have the ends clean and bright and free from dirt or grease; they should, if necessary, be scraped with a knife. Wires where connections are formed should be covered with Chatterton's compound or protected by Nobel's joint adaptors or prepared rubber taping as a precaution.

CAUTIONS

Electric Detonators should be stored in a cold, dry place.

Care should be taken not to "kink" or twist the detonator wires in handling or fixing so as to cut the insulation. If the insulation is cut, current leakage will occur and misfires may be experienced.

Care should be taken, under all circumstances, not to cut the insulation of the fuse wire during the process of tamping.*

Exploders. Store carefully when not in use in as cool and dry a place as possible. Make the shot-firer responsible for the care of the exploder, and allow him alone to handle it. Exploders, if taken care of, will last a long time in good condition.

Be careful to use with low-tension electric detonators a low-tension exploder, and connect in series.

Note. There is no economy in purchasing cheap exploders or cheap cables. With regard to the latter, suitably waterproofed cables can be obtained from the manufacturers.

WRECK DISPERSAL AND SALVAGE WORK

If the sunken vessel is of wooden construction or steel construction, not exceeding 200 feet (60·96 metres) long or 1,000 tons displacement, then it can probably be dispersed by firing three heavy charges of explosive simultaneously, one in the forepart, one aft and one amidships, the last-named charge being equal to the other two together. The heavy surge of the water resulting from the explosion assists in levelling down the sides and plates, which have been loosened by the actual explosion. The weights of charges to be used depend on a variety of factors, the chief being the size and construction of the ship, the depth of water and the manner in which the ship is embedded, so that it is impossible to give any definite instruction in this matter. As an approximate figure, however, taking a ship of about 1,000 tons, the following charges of explosive will be required under favourable conditions:

* Tamping is not generally considered necessary in underwater work.

Fore	200 lbs. (90·72 kg.)
Aft	300 lbs. (136·1 kg.)
Amidships	500 lbs. (226·8 kg.)

In addition, further explosive may be required to level down the boilers and for other odd operations. In order to level down a boiler, a 50 lb. (22·68 kg.) case of explosive placed through the firebox, and as near the centre of the boiler as possible, is usually sufficient.

Larger steel wrecks cannot be broken up in such a simple manner. Concentrated charges are of little value, except in breaking out the stern frame and the bows, as they only act locally, blowing holes through the wreck in their immediate vicinity. In this case it is necessary to use long charges of explosive made up in canvas or rubber tubing to cut through the deck. Similar charges should also be placed on the hull of the wreck to cut through the hull plates. The wreck will then be found to bulge out and flatten down considerably.

For heavy shots, hose $3\frac{1}{2}$ inches (8·89 centimetres) diameter should be used and for cutting through the lighter parts of the wreck 2 inches (5·08 centimetres) diameter hose is quite adequate. The explosive used for this work is normally submarine blasting gelatine. Charges 60 feet (18·3 metres) in length are not uncommon and it is necessary to weight the charges at intervals along their length to lower them into position, and any final adjustments in their location can be made by means of divers.

In the case of salvage work it is often necessary to cut holes in the bottom, side or deck plating of a wreck, so that some of the contained cargo can be removed by vertical grabs. Holes up to 30 feet (9·14 metres) square are blasted in this way. In this work it is important to obtain a clean and continuous cut without any excessive bulging of surrounding plates. A continuous charge is again required and this can be made up in various ways, as described later. Submarine blasting gelatine is invariably used and the important factor is the diameter of the charge. This depends on the thickness of the steel plate to be cut and the depth of the water. In shallow water the following will probably give the required result:

Thickness of plate		Diameter of cartridge	
ins.	cms.	ins.	cms.
1	2·54	2	5·08
$\frac{3}{4}$	1·90	$1\frac{3}{4}$	4·44
$\frac{1}{2}$	1·27	$1\frac{1}{2}$	3·81
$\frac{3}{8}$	0·95	$1\frac{1}{4}$	3·18

In heads of water greater than 100 feet (30·48 metres) the corresponding diameters will have to be increased, so that, for example, a steel plate $\frac{1}{2}$ inch (1·27 centimetres) thick will require a charge made up of 2 inches (5·08 centimetres) diameter cartridges.

If the wreck is situated at a depth of the order of 200 feet (60·96 metres), it may be found quicker and more economical to lower the charges from the salvage vessel at the surface on to the wreck without any assistance from divers, although it is essential to have an observer, situated in a submerged observation chamber adjacent to the wreck, directing lowering operations by telephone.

When the charges are to be placed in position by divers, they are usually made up in the hose form previously described. Again these must be weighted, but the divers can ensure that no weights are situated between the charge and the plate to be cut, and that in fact there is continuous and intimate contact between the two. Stooks also can be used when the charges are placed by divers, and these give a very clean cut. Normally 3 feet (·91 metre) lengths with a charge ratio of 2 lbs. per foot (2·98 kg. per metre) are employed. Due to the relatively small demand for these shaped charges, the cost of employing stooks is approximately three times as great as when using a "hose" charge of submarine blasting gelatine. Also, great difficulty is experienced in applying stooks to vertical plates. Various methods of overcoming this have been considered. Magnetic attraction would appear to offer a solution, but this has proved far too costly and, as yet, no suitable cement or adhesive has been found.

When the charges are lowered into position untouched by divers, it is essential that they should be of a more rigid nature, and that it is not possible for any lowering weights to come to rest between the charge and the plates. One method is to use steel tubes up to 10 feet (3·05 metres) in length filled with cartridges of submarine blasting gelatine. The internal diameter of the tubes should be not less than 2¼ inches (5·72 centimetres) to take a 2-inch (5·08 centimetres) diameter cartridge, and the thickness of the tubes should be of the order of ⅛ inch (·32 centimetre). One of the disadvantages of this method is that the plates in the vicinity of the cut are badly bulged and torn, making it very difficult to maintain a continuous cut.

One salvage firm who have experienced this difficulty are experimenting with making up charges weighted with lengths of angle-iron. The cartridges are attached to the underside of the angle-iron and the whole slung by means of two lugs situated on the upper edge of the angle-iron. The angle-iron should be so designed that its two lower edges and the enclosed cartridges should all be in contact with a level surface at the same time; this should eliminate any possibility of the charge rolling over once it is in the required position, thus ensuring intimate contact between the charge and the plates. Two lengths of explosive each 2 feet 6 inches to 3 feet (·76 to ·91 metres) long strapped into position on a 6-foot (1·83 metres) length of angle-iron would make a very convenient charge, and one which can be made up very quickly.

Blasting Cofferdams. Cofferdams are built in cribwork form and filled with broken rock. In removing such a dam, the object of blasting is to scatter its constituent material so that no obstruction will impede the water flow. It has been found that the best results are obtained by placing charges at the crossing of the crib timbers at the front, and back of the dam. The main charges should be laid on the rock foundation and smaller charges should be placed two-thirds of the way up the dam in order to break up and scatter the upper portion of the dam. A charging ratio of 2 lbs. per cubic yard (1·1 kg. per cubic metre) is required to destroy the dam effectively and provided the charges are correctly spaced this should be done without any undue scattering of the material. The main charges should consist of about three-quarters of the total amount. The charges should be spaced out at 15 feet (4·57 metres) intervals along the length of the structure.

In order to place the charges it is necessary to sink shafts along the centre line of the dam or to drive tunnels into the base of the dam and two-thirds of the way up the side. Tunnelling operations of this nature are very difficult and it is advisable, therefore, that pockets to accommodate the explosive charges and connecting tunnels should be built into the dam prior to the insertion of the rock filling. These pockets and tunnels can be temporarily filled with sand and when it is necessary to blast, the sand can be removed, the charges placed in position, and then the sand once more replaced to act as stemming.

Blasting Concrete Dams. Cofferdams made of wood or steel piling are now being replaced in some instances by mass concrete dams. Again it is necessary that these dams should ultimately be removed, and explosives can be used effectively in this work. Dams which have been dealt with in this country in this way have varied in thickness from 5 feet to 16 feet (1·52 to 4·88 metres) and their heights have varied from 33 feet to 50 feet (10·06 to 15·24 metres). So far the tendency in this work has been to use explosive in 1½ inches (3·81 centimetres) diameter cartridges, but there is every reason to believe that 2 inches (5·08 centimetres) diameter cartridges will be more suitable, and in special circumstances the diameter may effectively be increased to 4 inches (10·16 centimetres).

However, this work is often associated with dock areas, where an acute vibration problem may exist and it is primarily for this reason that the diameter of the explosive charge and hence the charge per hole should be kept down to a reasonable figure. The use of a large number of relatively small diameter holes also ensures a higher standard of fragmentation.

Dams up to 6 feet (1·83 metres) thick can be blasted satisfactorily, employing a single row of holes across the centre line of the dam spaced at intervals of 3 feet to 4 feet (·91 to 1·22 metres) and drilled to the base of the structure. In the thicker dams three or even four parallel rows of holes may be required, the holes in each row being staggered. The explosive used in these circumstances would be 1½ inches to 2 inches (3·81 to 5·08 centimetres) diameter. Larger diameter cartridges can be used in the thicker dams with a corresponding reduction in the number of rows of holes required.

The use of small diameter holes at 3 feet to 4 feet centres is attended with one major difficulty due to the fact that the firing of one small group of holes so damages adjacent holes that it becomes difficult, and in some cases impossible, to load these damaged holes with the required charges. One suggested solution is to leave shotholes in the concrete during the construction of the dam by using steel pipes, and raising the pipes as concreting proceeds. If no preformed holes are available, the holes should be lined with mild steel pipes after they have been bored.

The holes are normally full of water and heads up to 50 feet (15·24 metres) will be encountered, and for this reason Polar blasting gelatine is used. As it is necessary to employ a series of deck charges in each hole, Cordtex in conjunction with primers is used to initiate the charges. A loading ratio of 1 lb. of explosive per cubic yard (0·55 kg. per cubic metre) will produce fragmentation sufficiently small for a 1 cubic yard (·76 cubic metre) grab to deal with a very high percentage of the debris.

To facilitate loading operations it has been found advantageous to enclose each section of the charge in a tinned iron 26 S.W.G. (·457 millimetres) container fitted with a conical nose and weighted with lead. These containers are usually made in 3 feet to 6 feet lengths. The external diameter of these containers must be at least $\frac{3}{16}$ inch (·48 centimetres) less than the internal diameter of the lining tubes. These containers can be lowered down the hole on a length of binder twine. Where stemming spacers are required, these also can be made in a similar container form, the filling in this case being sand.

The normal procedure is to fire the initial blast in the centre of the dam with the object of making a complete break-through at this point. The two sides can then be attacked separately. The question of vibration from blasting must be considered and it is interesting to note that in one of these dam-blasting operations a charge of 130 lbs. (59 kg.) in the middle section of the dam caused slight leakage at the glands on the propeller shaft of a warship, which was approximately 500 feet from the blast.

Cutting Piles Underwater (see also Chapter 5). Piles are divided into three main types, namely, wooden piling, tubular steel piling and sheet-steel piling. The method of dealing with the first two types is relatively the same and that is to tie a necklace charge round the pile at the horizon at which it is required to be cut. A necklace charge is a continuous charge of explosive, the cartridges being placed end to end, and can be made up either in a length of hose or by attaching the cartridges to a length of cord. The factor which requires careful consideration is the diameter of the cartridges. In the case of the wooden piles, a circular pile 12 inches (30·48 centimetres) diameter requires 1½ inches (3·81 centimetres) diameter cartridges. The size required to cut tubular steel piles can be determined by applying the rules previously given under wreck-cutting.

Sheet steel piling is similarly cut, employing continuous charges of explosive. Lengths of charge around 10 feet (3·05 metres) should be very suitable and convenient to handle. These long lengths of charge should be applied along one side of the line of piling and, again, the diameter of the cartridges will be governed by the rules mentioned above. Some types of sheet piling are of the interlocking variety and it may be found during blasting operations that a clean cut is not being obtained at the joints, where there may be more than one thickness of steel. If this is the case, a single cartridge should be placed on each joint on the other side of the piling. This cartridge should not be positioned on exactly the same horizon as the main charge, but about 3 inches above or below this level to produce a shearing action on the joint.

There is an alternative method of dealing with wooden piles and that is to bore an inclined hole down into each pile with a wood auger, until it is two-thirds of the way through. This hole should then be charged, and in this connection a pile 12 inches (30·48 centimetres) square will require 12 to 16 ozs. (·34 to ·45 kg.) of explosive. When this charge is fired the pile will be cut off cleanly. Polar blasting gelatine is recommended in general for this type of work.

SALVAGE OF THE WHITE STAR LINER *SUEVIC*

Vessel Cut in Two by Use of Explosives

The forepart of the vessel for a length of about 150 feet from the bow was firmly held, the bottom being badly pierced by rocks. At high water aft of this 150 feet the bottom of the vessel was clear, but rested partially on a ledge of rock at low water. Almost amidship were two high and sharp pinnacles of rock on which the ship's bottom worked heavily at low water, and it was apparent as soon as a careful examination by divers had been made that if the bottom was to be saved from piercing, these pinnacles would have to be removed. It was decided to blast the rocks, and holes were drilled in them by divers using pneumatic tools. The work of levelling the rock was completed two days later. In the meantime it was decided to cut the vessel in two at a point about 180 feet from the bow, or 370 feet from the stern. Forward of the engine space were four holds with three watertight bulkheads separating them, and one bulkhead between the engine space and No. 4 hold, which was in use as a reserve bunker. The next, No. 3 hold, as well as Nos. 2 and 1 farther forward, were for cold storage, and were insulated. The ship had four masts. The position where the severance was made is about the middle of No. 3 hold, forward of the second mast and aft the bridge. When operations were commenced the three forward holds were full of water; No. 4, or the reserve bunker hold, had 12 feet of water in it, and the space under the false bottom was flooded the whole length of the ship. Other parts of the vessel were free from water.

Three powerful centrifugal pumps—two 12-inch and one 10-inch—were placed on board by the Liverpool Salvage Association—but not at any time were all these required, in addition to the ship's pumps, to keep the water under in No. 4 hold. No attempt was made to clear the water from the double bottom, which remained flooded until the vessel was dry-docked.

To strengthen the bulkhead at the forward end of the reserve bunker sufficiently to stand the water pressure after the severance, it was heavily strutted by 12-inch pitch-pine bulks placed horizontally fore and aft up to the level of the orlop deck. Above the orlop deck is the lower deck, then the main deck, and above that again the promenade deck.

The plating of the hull in the neighbourhood of No. 4 hold varied from ¾ inch, to 1 inch in thickness, and the main deck plating was 1 inch thick. The shear strake consisted of two thicknesses of 1-inch plates, and the keel was a flat bar 12½ inches by 3¼ inches. The bottom plating generally was about 1 inch thick. The cutting of these heavy plates was a matter of no little difficulty. Owing to the hold being fully loaded with cargo, the whole of the cutting had to be done from the outside of the hull. No drilling whatever was attempted, the whole of the plates being severed by exploding gelignite cartridges.

The charges varied in size according to the position and thickness of the plates, and were restricted as much as possible to avoid damage to other parts of the hull. The largest charge used in any one explosion was about 10 lbs. The cutting-through of the keel, which, as we have previously remarked, was a steel bar 12½ inches by 3¼ inches, was accomplished by one charge of 8 lbs. The charges were sewn up in canvas covers and laid along the plates in close contact, and fired electrically. All sorts of expedients were adopted for keeping the charges in contact with the plating. On the weather side of the ship the whole of the cutting-down to the level of the bilge keel, about the turn of the bilge, was accomplished without divers and from the deck level. The charges were lowered over the side against the plating, and kept in position by means of sandbags, clusters of chain, etc., hung over them. On the lee side the charges were placed without the aid of divers down to the water level. Below the water level, except for a portion of the weather side, as mentioned, all work was carried out by divers, and every praise must be given the men employed in this dangerous and difficult work. During almost the whole time that the cutting operations were in progress there was a more or less heavy swell, and this, coupled with the strong currents, frequently caused the divers to lose their foothold on the ladders or bottom. As the cutting proceeded the increasing gap in the plating produced additional risks, for the divers were in danger of being forced by the swell and current into the opening. Moreover, the constant exit of sheep's carcases from the hold provided a source of inconvenience to the men, as may well be imagined. As the cutting proceeded and the after and water-borne part of the vessel began to roll independently of the fore part, the danger of approaching the ragged ends of the severed plates was considerable.

It was found impossible to carry on the cutting of the plates under water continuously owing to the heavy sea, which at times rendered a suspension of the diving work necessary. When cutting was impracticable under water it was sometimes found impossible to proceed with the work on the side plating above the water or the severing of the deck plates. A considerable portion of the main deck plates nearly 1 inch thick was left until the remainder of the cutting had been completed, and had to be effected while the partly water-borne hull of the vessel was surging about, racking the plates in all directions. The last plates of the deck were cut by charges placed by men who crawled to the edge of the gap to place the cartridges. At that time the severed ends of the heavy steel frames and beams of the vessel were constantly butting against each other with great violence.

The whole operation of cutting the ship in two occupied less than six days. The length of cut effected by each charge varied greatly, of course; sometimes as much as 2 feet were cut through by a charge, but the average was probably a good deal under 12 inches. Many charges, again, failed to cut through the plates. Towards the completion of the work of cutting, elaborate preparations were made for towing off the severed part of the vessel, and, what was of great importance, also to prevent the water-borne hull being driven end on to the forepart or swung by the seas and current. The engines were kept under steam for 24 hours before the work was completed, and heavy anchors laid out astern, with steel wire hawsers, kept taut by the ship's winches. Five anchors were used, the heavy bower anchor, with 45 fathoms of cable and two wire hawsers, and two pairs of anchors, one backing the other, with two hawsers to each pair. When the time came to attempt the hauling off the vessel, two tugs—the *Herculaneum* and *Blazer* of Liverpool—and one of the two salvage steamers of the Liverpool Salvage Association, the *Ranger*, passed hawsers to the stern of the ship, the engines of the *Suevic* at the same time going astern. The combined efforts of the tugs, engines and winches were successful in dragging the hull clear of the rocks at high water. The tide was one of the best of the springs.

14

Escape from Sunken Submarines

(SEE ALSO APPENDIX C)

The purpose of the present chapter is to show the progress which has been made by the British and other navies in providing means of escape in emergency.*

In order to give some idea of the conditions under which escape has to be made, we reproduce a few examples of escape locks which have been suggested, and, in some cases, adopted in earlier submarines, and will then describe and illustrate arrangements provided or contemplated for later vessels.

It should first be explained that if a vessel is damaged at the top (Fig. 230) the incoming water will gradually replace all the air in the vessel. But if the damage is below the highest point (Fig. 231), then the water, as it enters, will compress the air until the pressure of the latter is equal to that due to the depth of water in which the

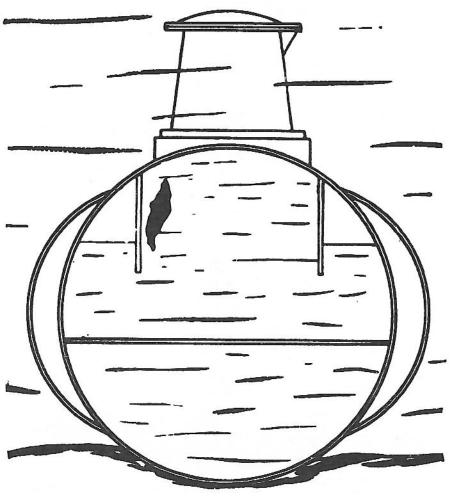


Fig. 230. Vessel holed at top

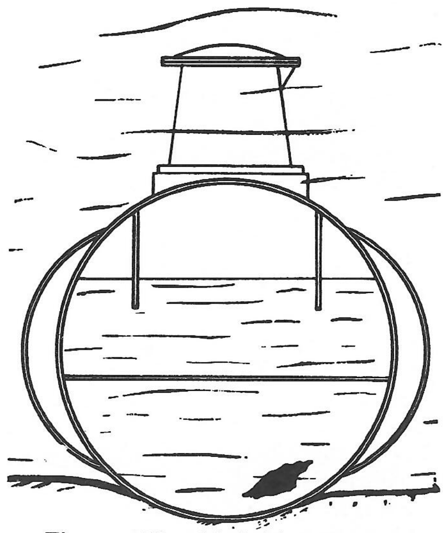


Fig. 231. Vessel holed low down

vessel is sunk. Thus, if the vessel be sunk at a depth of 33 feet = say, 15 lb. per square inch, or + 1 atmosphere, the air will be compressed to one-half its original volume; if at 66 feet = 30 lb. per square inch, or + 2 atmospheres, to one-third; if at 100 feet = 45 lb., or + 3 atmospheres, to one quarter, and so on.

If, through any other cause than the accidents described, the vessel is unable to rise, the compartments will have to be deliberately flooded (unless they are provided with special escape locks), in order to bring about the conditions—i.e. equalization of pressure, etc.—necessary to enable the hatches to be opened, and the crew to make their escape.

* It should be noted that practically all the devices for submarine escape described in this chapter, whether actually adopted or only considered, appeared in a previous edition of this book, published in 1935. The author draws attention to this fact because, when submarine disasters unfortunately occur, it is not unusual for suggestions—of varying degrees of merit—to be offered for the greater safety of lives on these regrettable occasions. But very rarely have these proposals not already been considered. Whilst new ideas must always be encouraged, it should be borne in mind that escape arrangements have to strike the right balance between the fighting efficiency of the submarine and reasonable measures for the safety of her crew.

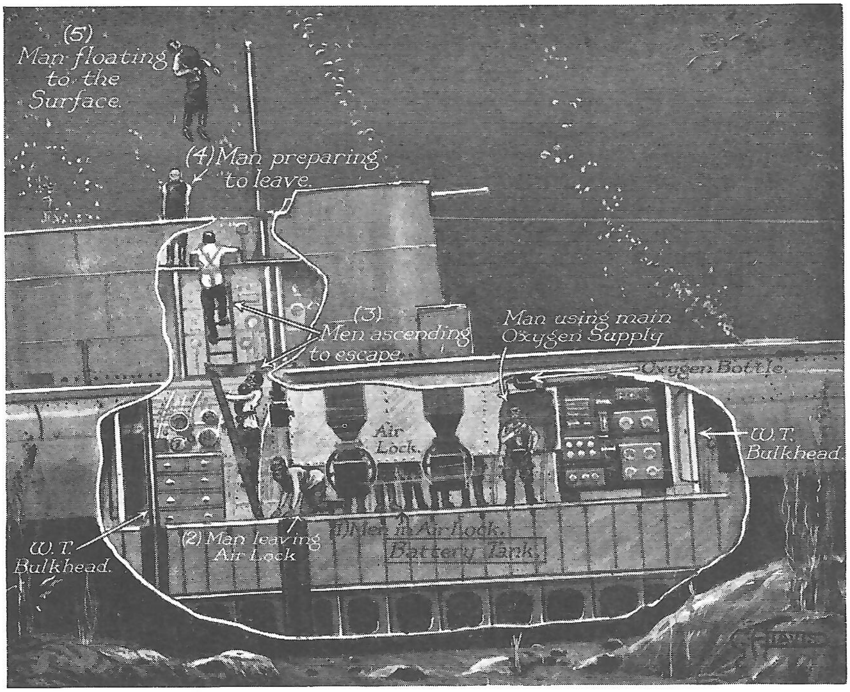


Fig. 232. An early arrangement for escape. Longitudinal section, showing air-lock

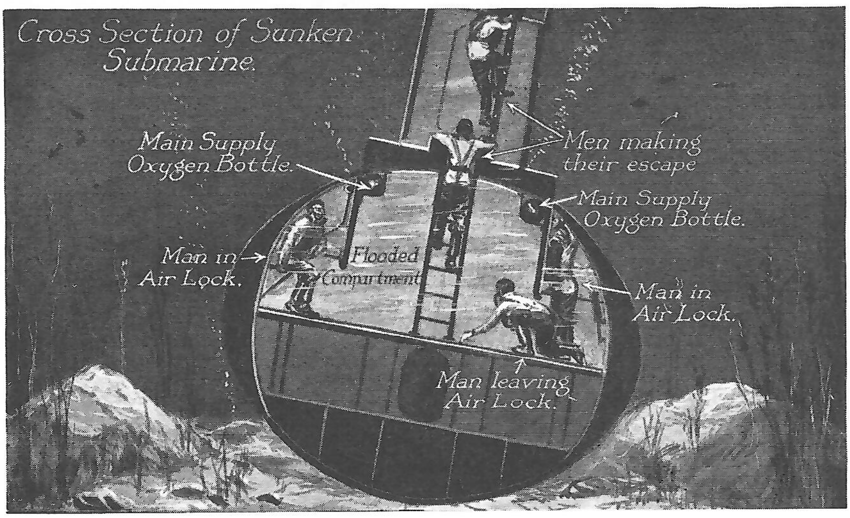


Fig. 233. Cross-section

Figs. 232 and 233 of an early design of vessel show longitudinal and cross-sections of a partial bulkhead forming an air-lock in which the compressed air was trapped, and in which the crew's escape apparatus was hung in readiness. A compressed air supply-main was connected with the air-lock, so that the water flooding the vessel could be kept down to a level which left the men's heads in an air space. Oxygen storage cylinders were also connected to the air-locks to enable the men to charge their apparatus, and so conserve the supply in their individual oxygen cylinders.

When the compartment was completely flooded, and the hatch opened, the men, in turn, ducked under the bulkhead and made their way out.

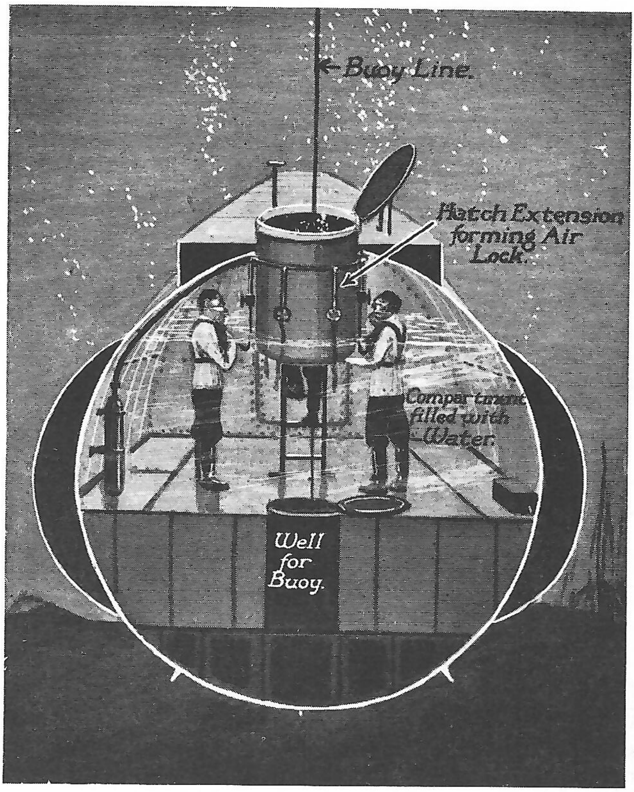


Fig. 234. Another early design of escape lock

Fig. 234 shows another arrangement consisting of a steel tubular extension from a hatchway forming an air-lock, trapping air in the upper part of the compartment, in which are fitted valves and connections for charging the crew's individual escape apparatus from oxygen storage cylinders placed adjacent to the lock. After releasing the hatch-fasteners, water is admitted into the compartment by opening the flood valves. As the water enters, the air in the compartment is compressed, and when the air pressure is about equal to that of the water, the hatch will be practically balanced between the two. Air will be trapped in the top of the compartment by the hatch extension, the depth of this air pocket depending, as already explained, upon the depth of water in which the boat is sunk; the greater the depth of water, the smaller the volume to which the air will be compressed. In this air-pocket the men stand, waiting their turn to leave the vessel. The air in the hatch extension having been released and replaced by water, the hatch can now be opened, and the crew, having already put on

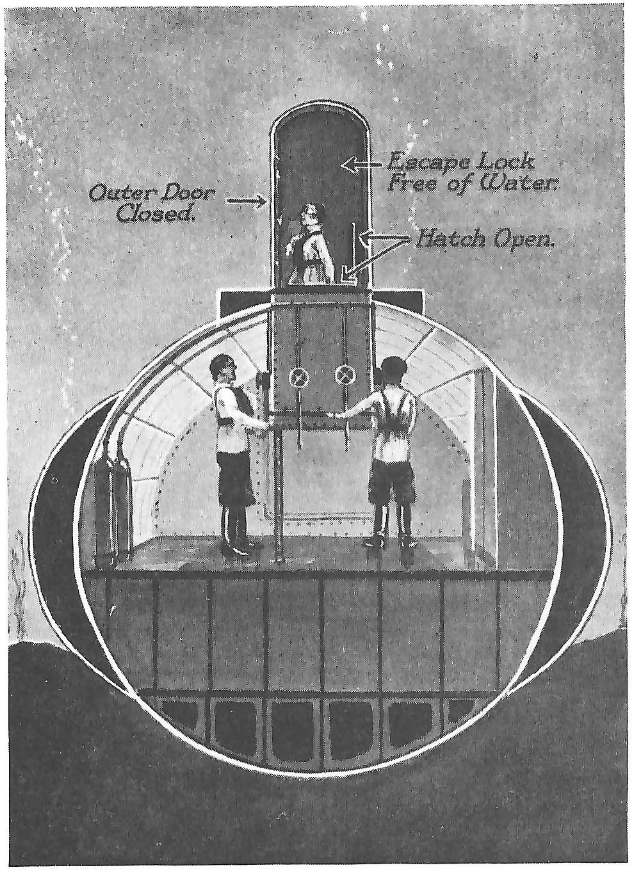


Fig. 235. Another early design. Escaping man has just entered air-lock, which he will flood to equalize pressure

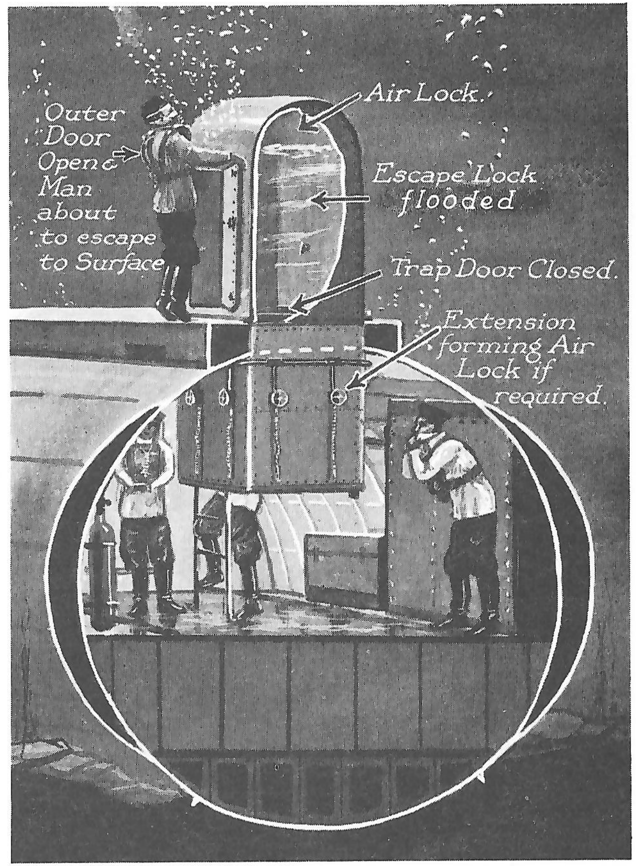


Fig. 236. Lock flooded; man leaving for surface after closing outer door. The lock will now be emptied of water, and the procedure repeated

their apparatus, pass under the skirting and make their way to the hatchway, and so to the surface. It has been suggested that a buoy, with a line attached, might be sent up through the hatch before the men begin to escape; they would then use the line as a guide. In order not to impede normal activities in the submarine, this type was later made telescopic, so that it could be collapsed and secured overhead, out of the way, when not needed for its special purpose. (See Figs. 241-3.)

Another type of escape lock (Figs. 235 and 236) is one built outside the vessel, and with or without an extension, or skirting, into the interior of the vessel, forming an air-lock for men waiting to escape.

Now, in considering the question of submarine escape, we have to remember that a submarine is a vessel of war, and that in designing safety devices one must also have strict regard to available space and limits of weight, so that the vessel shall not be hampered to such an extent as to impair her fighting efficiency.

One point upon which all nations are agreed is that the saving of life, in the event of accident, must be the first and paramount consideration; that the salvage of the vessel is of secondary importance.

Many different devices for the saving of life in submarines have been suggested from time to time—among them detachable steel chambers and the like, which, owing to their size and shape, would have to be carried as superstructures, and so would be very vulnerable, and in the likeliest position to get damaged in case of accident. Indeed, some of the safety devices which have been submitted to us have been so elaborate and so bulky that there would have been room for little else in the vessel.

Most experts are agreed that the greatest measure of safety is provided by making every man independent of the others, by equipping him with a self-contained apparatus which, while amply strong,

1. Is as compact and light as possible consistent with efficiency.
2. Can be instantly and easily put on, without assistance.
3. Has adequate air regenerating devices to ensure the wearer a supply of pure air.
4. Will render him immune against any poisonous gas which may be generated in the vessel.
5. Will allow him to breathe freely under water, no matter what the pressure.
6. Will enable him readily to pass through hatchways.
7. Has means to retard the velocity of his ascent—an important consideration.
8. Will, when he reaches surface, keep him afloat without any effort on his part, face upwards, so that, if exhausted through any cause, his head will not droop forward with his mouth and nose under water.
9. Will not prevent him from moving through the water if he wishes to swim.

The escape apparatus, designed by R. H. Davis, which is used in the British and other navies, is here illustrated (see page 263), every rating in the Submarine Service being taught, theoretically and practically, the use of the apparatus.

He is first instructed in the details and working of the apparatus itself, and is taught to wear it in "the dry", in order to accustom himself to the breathing arrangements. Then, with the assistance of instructors above and below water, he is taught to use the apparatus in a great tank, which is fitted with air-locks to enable actual escape from a submarine to be simulated.

In Fig. 240 we see men undergoing a course of training at Fort Blockhouse, Portsmouth. The steel tank is 16 feet in diameter, and about the same in depth. Should any emergency demand it, the opening of sluice valves would drain the tank completely in 30 seconds. At the bottom of the tank is a steel chamber representing a compartment of a submarine. The chamber is entered through a watertight door in the wall of the tank as shown in Fig. 240. Many thousands of men in the Royal Navy have been trained in the apparatus and very few have failed to become competent to use it.

Filtered water is used in the training tank, in order to ensure good visibility, so that every movement of the men at the bottom can be clearly discerned, and it is warmed in order the better to train the men to breathe correctly under water. Once they are competent to do so, they find no difficulty in breathing when working in cold water.

Requalifying tanks, similar to that at Portsmouth, have been erected in Hong Kong and Malta.

The number of sets of escape apparatus carried in each submarine is one per man (stowed as near as is convenient to his diving station) plus 20 per cent additional sets, which are stowed half at either end of the vessel.

DAVIS SUBMERGED ESCAPE APPARATUS

Description of the Apparatus (Figs. 237, 238 and 239). The apparatus consists of (A) an insertion rubber breathing and buoyancy bag, inside which is arranged a canister containing a chemical for the absorption of the wearer's exhaled carbonic acid gas (CO_2). In a pocket at the lower extremity of the bag is carried a steel cylinder (B) containing about 56 litres of oxygen compressed to 120 atmospheres, the cylinder being provided with a control valve (C) and connected by a tube to the breathing bag. The opening of the cylinder valve admits oxygen to the breathing bag and charges it to a pressure equal to that of the surrounding water at whatever depth the apparatus is being used.

The wearer is thus able to breathe in a normal manner.

The canister of chemical absorbent inside the breathing bag is connected by means of a flexible corrugated tube (E) to a mouthpiece (F); breathing is carried out by the mouth only, the nose being closed by a clip (G). Goggles with splinterless glasses are also provided.

In order to conserve as much as possible the supply of oxygen in the cylinder (B), means are provided whereby oxygen can be admitted to the bag from an external source of supply—for example, a charging manifold connected to a large storage cylinder of oxygen installed in the compartments of the submarine. These consist of a tube (H) connected to the bag and provided at its outer end with a non-return inlet valve (I). This tube is connected to the external source of oxygen and the latter is turned on until the bag is filled sufficiently to enable the wearer to breathe comfortably.

A third and last source of supply is provided in the shape of two small steel capsules of oxygen, called "Oxylets", mounted inside the breathing bag. These capsules are provided with break-off necks and the oxygen is released from them by gripping (one at a time) in the hands (through the breathing bag) and wrenching sharply, so breaking the neck.

The breathing bag is provided with an automatic non-return air release valve (K) which allows air to escape from the bag as the user ascends to the surface and decreasing pressures. A "gag" device is provided so that the wearer can close this valve on reaching the surface, thus retaining the air in the breathing bag, the latter then serving as a lifebelt.

A two-way tap (M) is provided in the mouthpiece. This is kept closed when the apparatus is not in use, in order to prevent access of air to the chemicals in the canister. It should be closed when the wearer reaches the surface, the mouthpiece and noseclip being removed.

Should the main breathing bag become deflated while the wearer is floating on the surface, it may be refilled by taking the mouthpiece into the mouth, opening the cock and blowing into the bag. The cock should be shut again before the mouthpiece is removed from the mouth.

The apparatus is provided with an adjustable neck-strap and with adjustable waist-straps. These straps should be adjusted by the wearer beforehand to suit himself, so that the apparatus is always ready for use in emergency without further adjustment.

The Emergency Buoyancy Bag (N). This is a small additional bag formed on the front of the main breathing bag. Its object is to ensure that the wearer of the apparatus shall remain afloat on reaching the surface—even if he has lost all the air from the breathing bag.

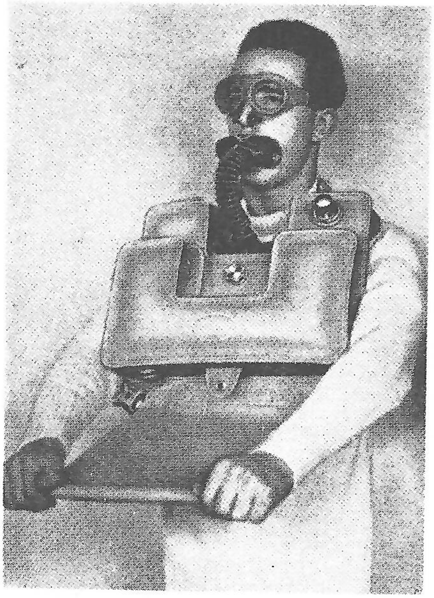


Fig. 237. Check-vane used with both hands

Fig. 239. Check-vane used with one hand, leaving other hand free

A modified valve "K" is now being fitted on the left shoulder of the breathing bag (Fig. 238) with a gag device to retain oxygen on reaching the surface. This, in fact, is a modified version by Siebe, Gorman & Co., of a valve which was tried experimentally by the firm some years ago. Another modification under consideration is the reversion to a cylindrical type of absorbent canister as made when the apparatus was first introduced (see Part II, Chapter 4).

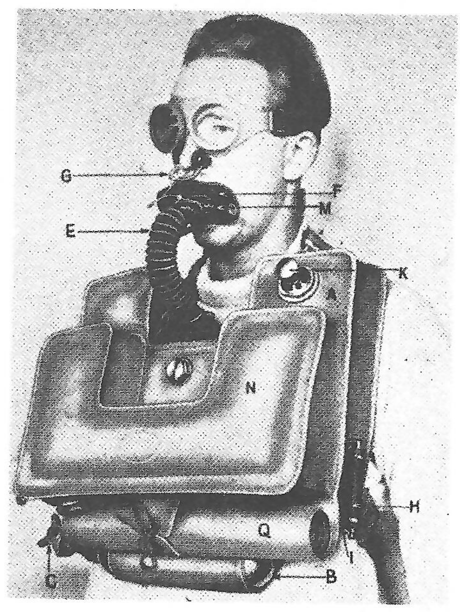


Fig. 238

The emergency bag is inflated by means of an "Oxylet" situated inside it, and broken by grasping the metal holder (situated at the bottom right-hand side) and bending this until the copper seal is broken.

The emergency bag should be inflated before leaving the submarine.

The Speed-Retarding Vane (Q). This is a rubber extension, similar to an apron, which should be unrolled and held out by the wearer in the horizontal position when he is ascending through the water. The vane sets up a considerable resistance to the wearer's passage through the water and greatly retards the speed of his ascent.

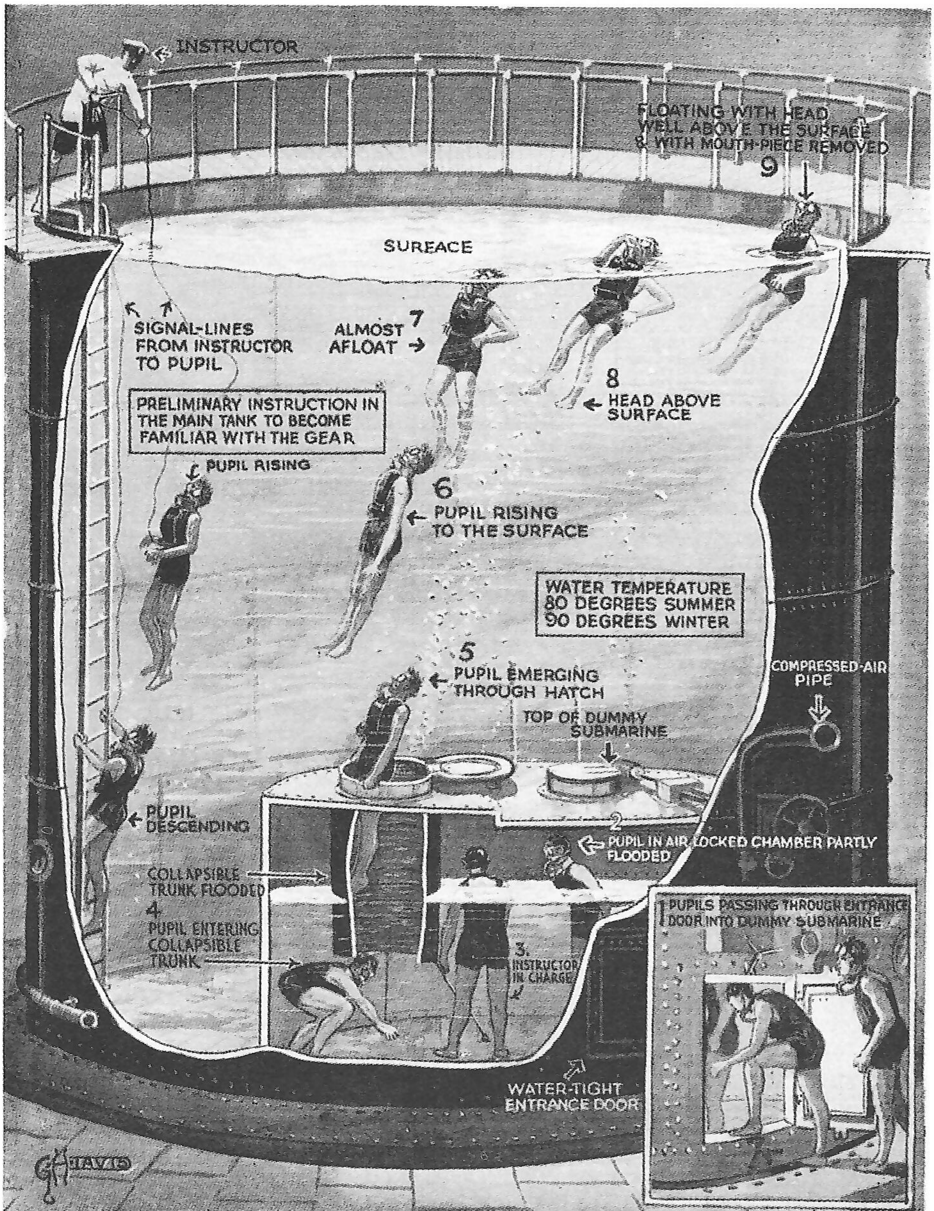


Fig. 240. Training men in submarine escape at Portsmouth

COLLAPSIBLE TRUNKS FORMING ESCAPE LOCKS WHEN SUBMARINE'S COMPARTMENTS ARE FLOODED

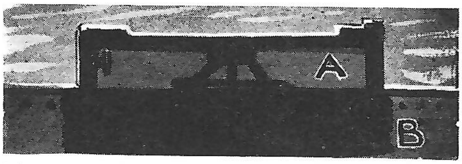


Fig. 241. Showing how trunk is stowed when not in use

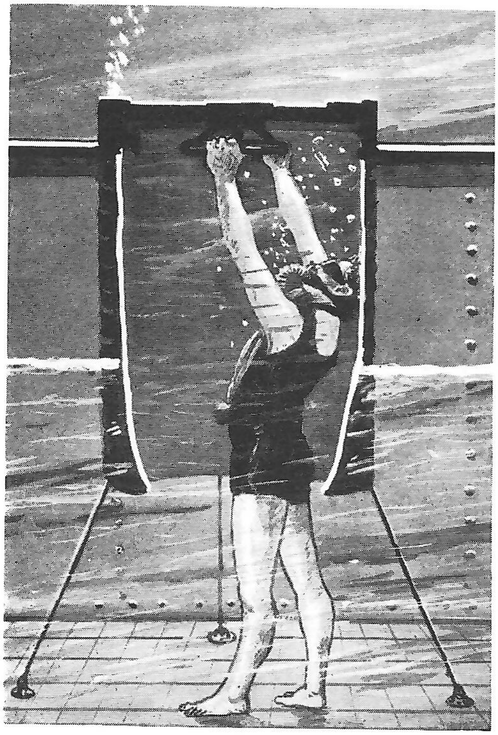


Fig. 242

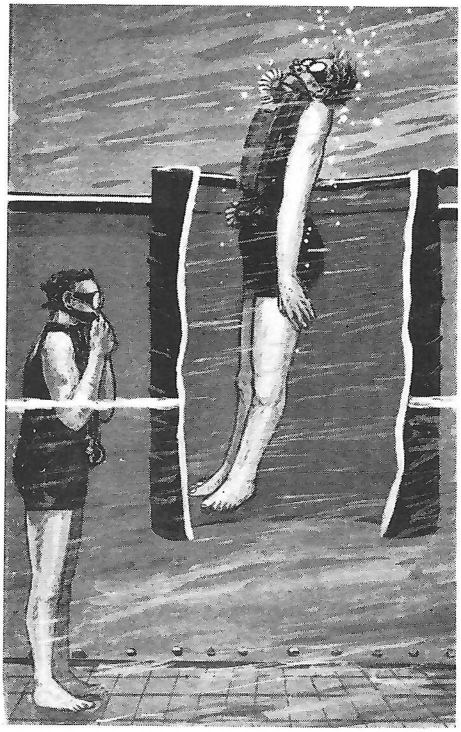


Fig. 243

Men being trained to escape by way of collapsible trunk

Some of the submarines of the Royal Navy are provided with collapsible twill trunks fitted watertightly to certain hatches. They are conveniently stowed, ready for instant use, and take up very little space in the compartments. Fig. 241 shows a trunk in the collapsed position. When required for use in emergency, it is pulled down and secured (Fig. 242), the submarine compartment is flooded, air trapped in the trunk is released by the opening of a valve, and the hatch is then opened. In Fig. 243 the air locked in the trunk has been released, the trunk is completely flooded, the hatch has been opened and a man is escaping to the surface. When he has left the trunk, the next man, who, with his comrades, has been standing round the trunk in the air compressed in the upper part of the compartment, will duck under the trunk and follow, this procedure being repeated every few seconds.

In Fig. 240 a trunk of this description is shown in use in the training tank at H.M. Submarine Depot, Portsmouth.

In certain British submarines completed immediately prior to the Second World War were two specially designed escape locks built into the vessels. These are steel chambers built against the main bulkheads, fore and aft, as shown in Figs. 244 and 245, and having watertight doors giving access to adjacent compartments in the vessel. The controls of the escape locks are arranged so that they can be operated from either of the compartments or from the interior of the locks themselves. With these locks there will be no need to flood the compartment before the men can make their escape; they can be used immediately. The procedure in case of emergency would be for two men to enter the locks wearing the Davis apparatus, close the watertight doors, flood the locks and release the trapped air, and, when equalization had thus taken place, to open the upper hatches and, floating through them, escape to the surface. The hatches would then be closed and the locks emptied by draining the water into the bilges; the next two men would enter the lock, and the procedure would be repeated.

A training tank with this form of escape chamber is illustrated in Figs. 246, 247, 248 and 249.

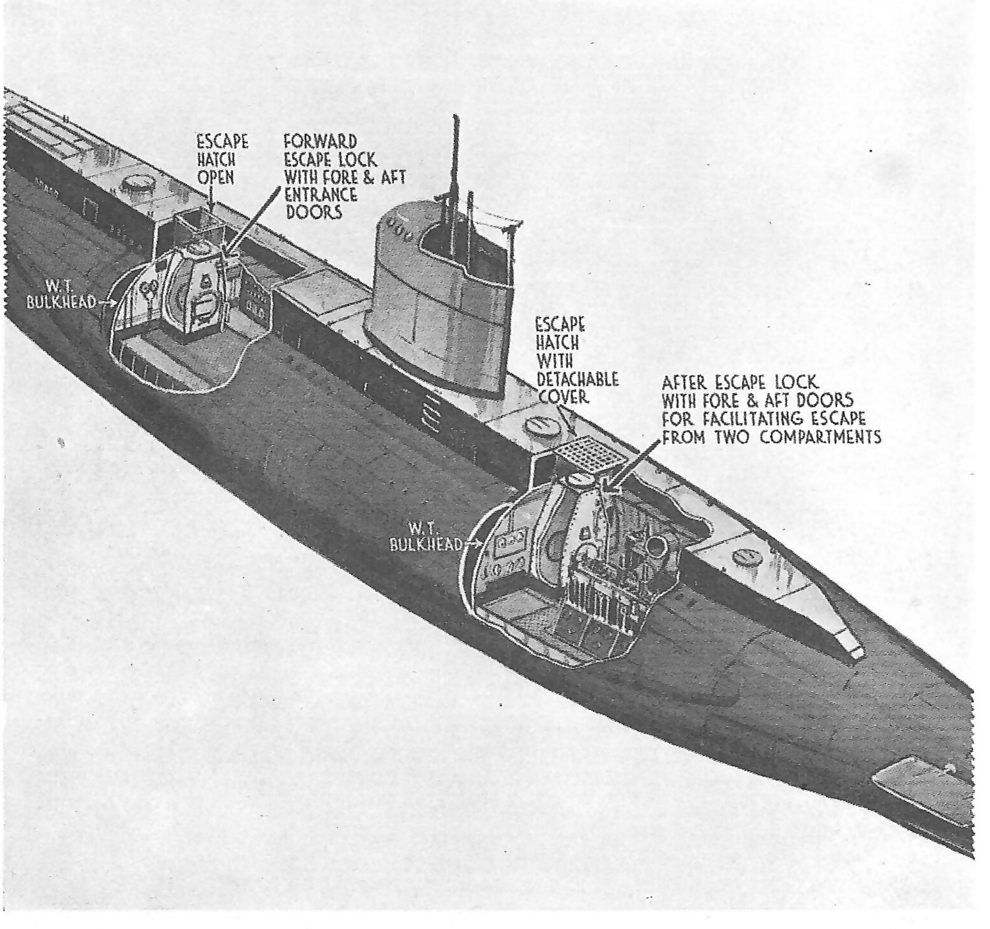


Fig. 244. Showing Davis escape locks for immediate use, without necessity for flooding compartments

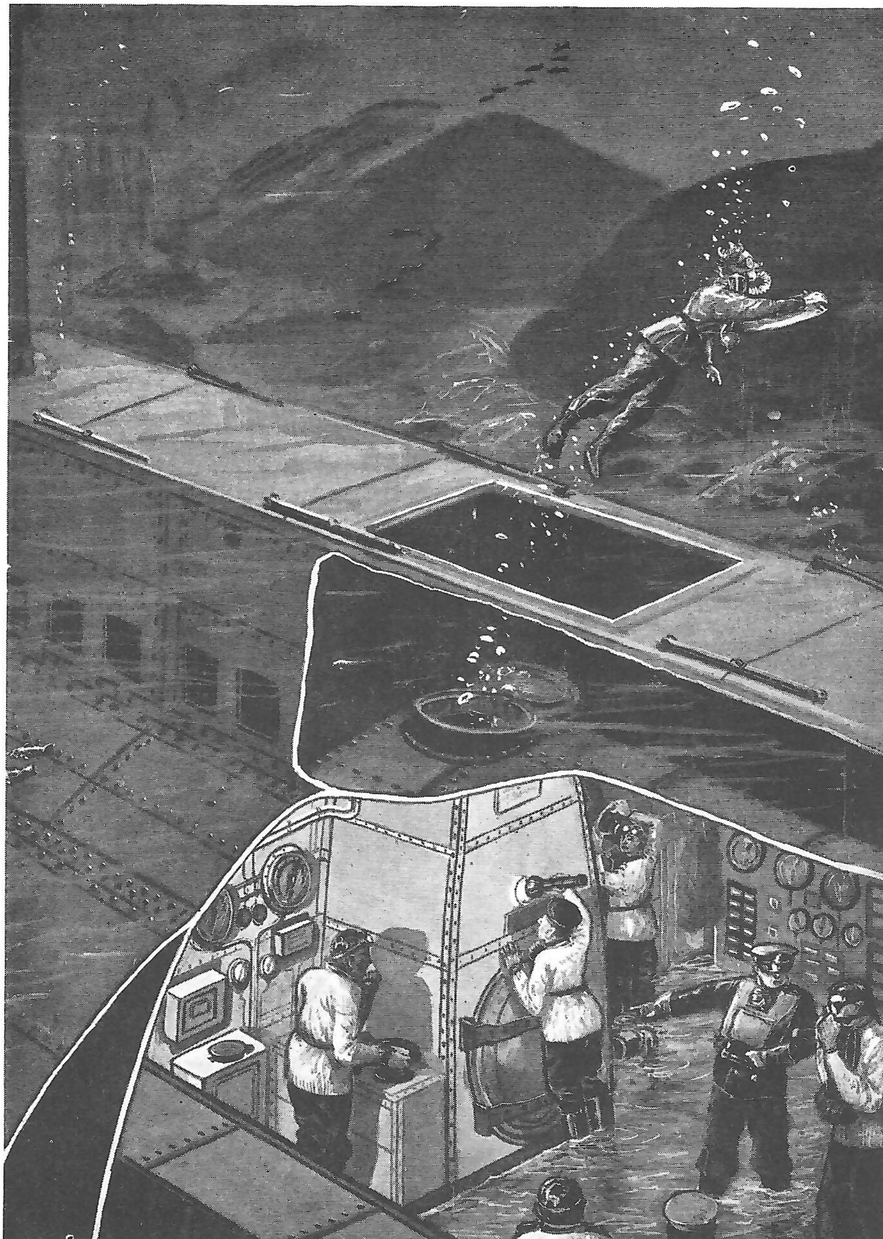
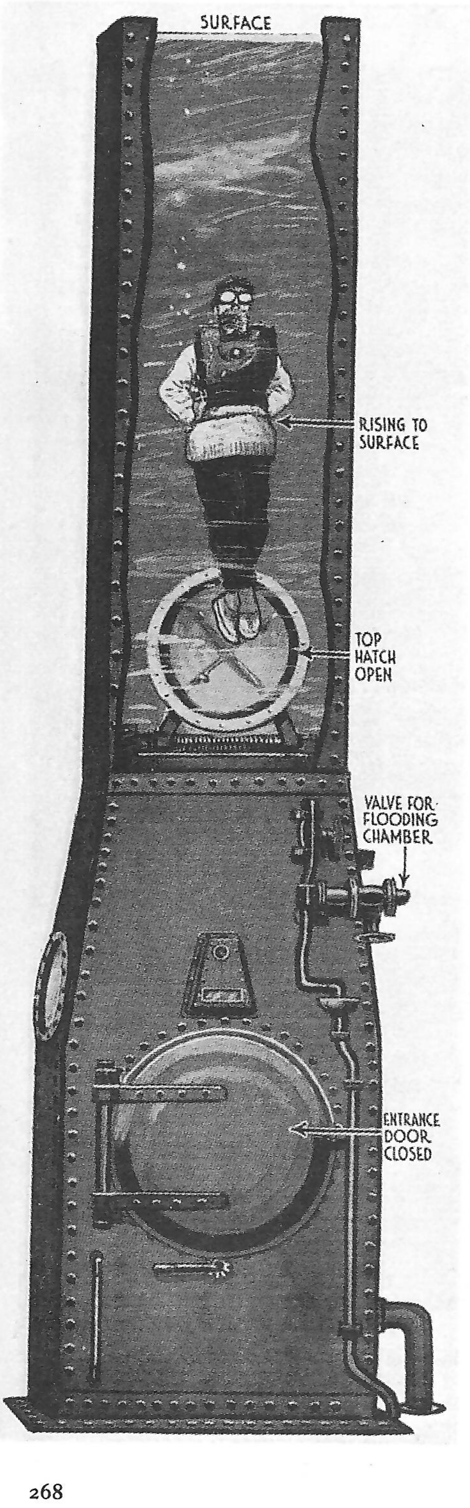


Fig. 245. Leaving for surface by way of Davis escape chamber

TRAINING IN SUBMERGED ESCAPE



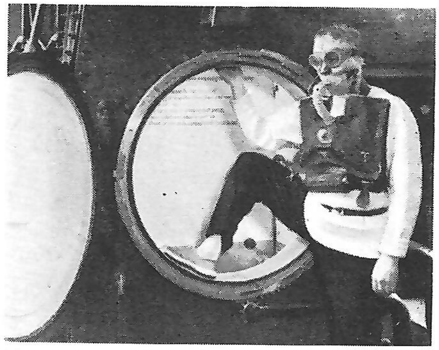


Fig. 247. Man under instruction entering escape chamber

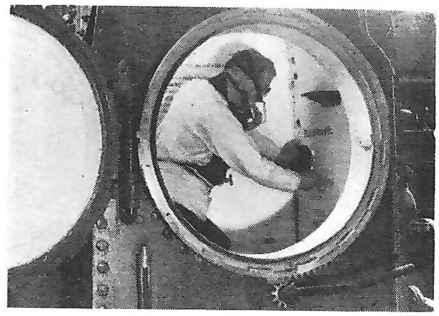


Fig. 248. Opening valve to flood chamber (door left open to show procedure)

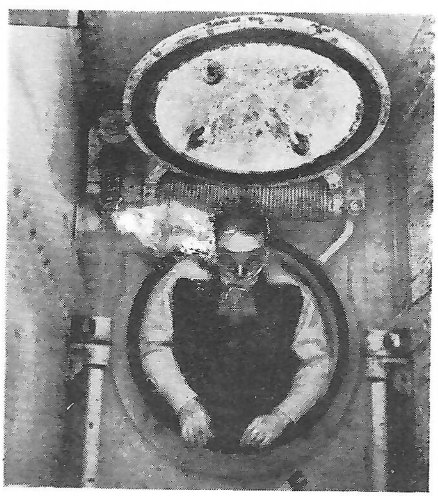


Fig. 249. Man rising through open hatchway

◀Fig. 246. The training tank is divided into two parts, the upper (open) from the lower by a steel hatch. Men wearing the Davis escape apparatus having entered the lower chamber, the door is closed; the flooding valve is then opened, the trapped air in the lower chamber vented, and both chambers are then filled with water. The hatch is then opened, and the men make their escape to the surface, thus simulating escape from a disabled submarine

DAVIS PORTABLE CHAMBER DESIGNED FOR TRAINING MEN IN SIMULATING ESCAPE FROM SUBMERGED VESSELS (Fig. 250)

The chamber, with its occupants standing in the space surrounding the escape trunk, is lowered to the desired depth. Since the chamber is open at the bottom (a grid being provided for the men to stand on), the water rises within to a height varying with the depth of submersion. When ready to escape, the first man dips under the trunk, and the air trapped therein is released, so that the water rises and completely floods it. The pressure of water now being equal to that of the open sea, the hatch can be opened and the escaper float out, his apparatus carrying him to the surface.

Meantime, the men who are to follow have been standing with the upper part of their bodies in the compressed air trapped in the annular space, and; since the escape-hatch is already open, they have merely to dip under the trunk and float through to the surface.

PORTABLE INSTRUCTIONAL ESCAPE DIVING BELL

This portable diving bell (Fig. 251) of steel, was introduced some years ago by the author for the preliminary training of men in the use of submarine escape apparatus,

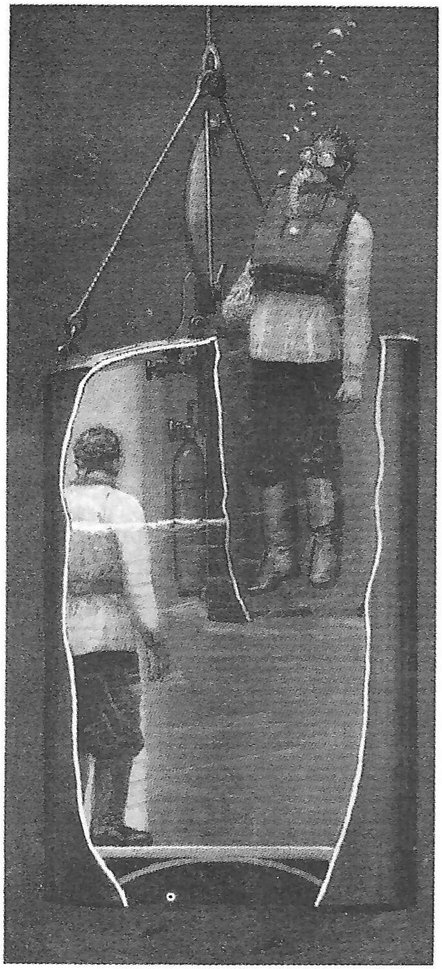


Fig. 250

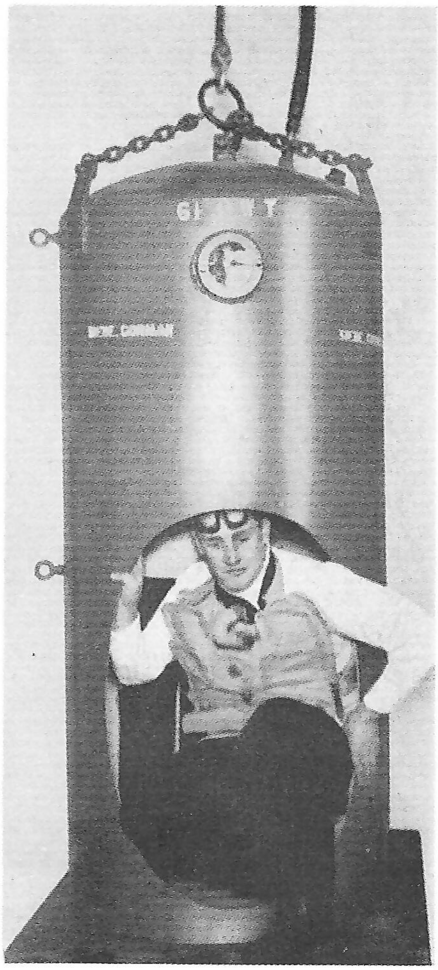


Fig. 251

Fig. 252. Man with Davis apparatus ascending—with check-vane extended in order to retard speed

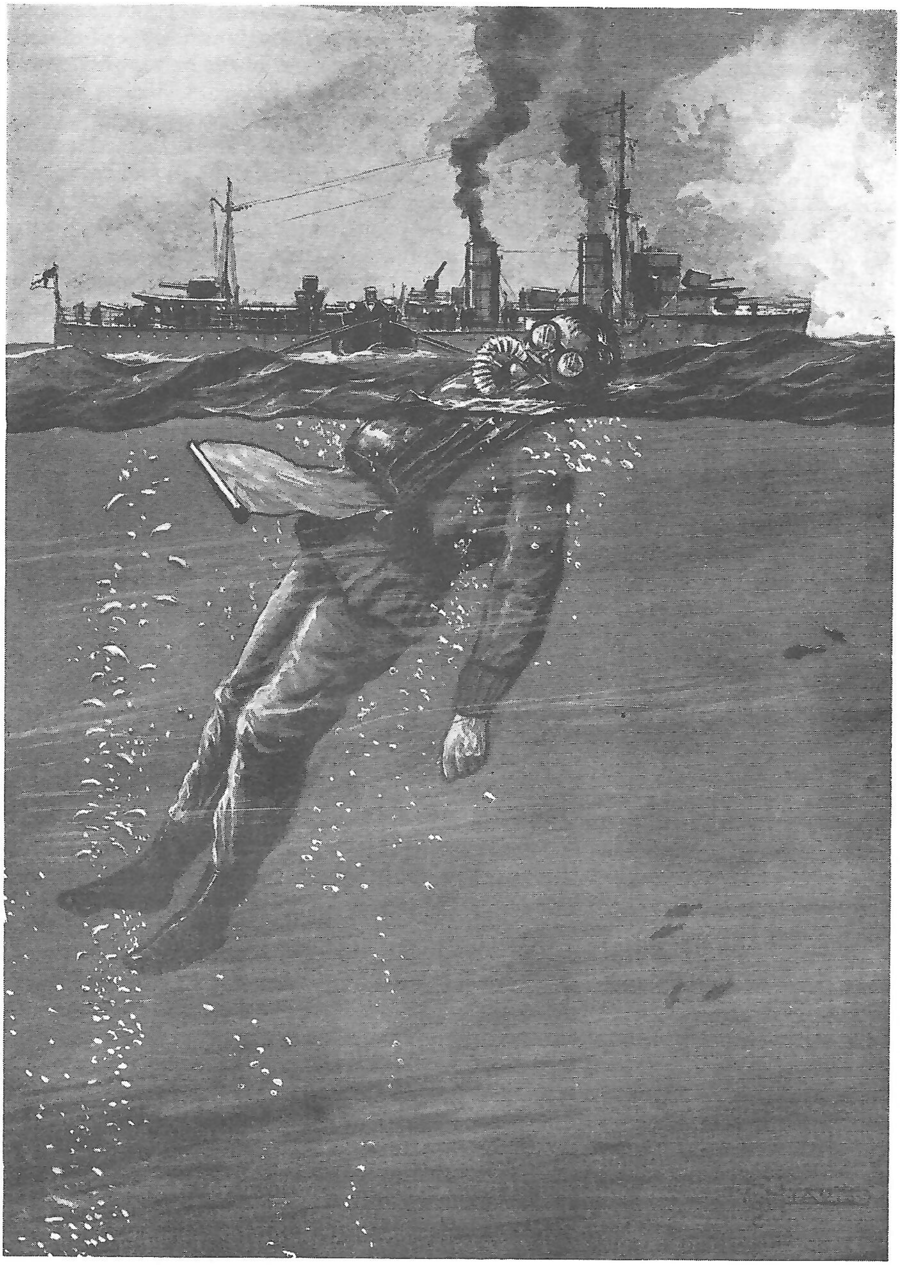


Fig. 253. Having reached surface, the man, wearing Davis apparatus, turns automatically with his face upwards and clear of the water

and as a simple means of simulating escape from submarine to the surface. Two men—usually a novice and an instructor—wearing the escape apparatus, seat themselves in the bell which is supplied with air (either by tube connected to a pump or to compressed air storage cylinders at the surface, or from storage cylinders attached to the bell itself, thus making it self-contained) at a pressure slightly in excess of that at the depth to which the bell is lowered. Thus the water is kept down to the edge of the bell. The necessary sinking weight to overcome the displacement of the bell is provided by the heavy iron platform on which the men stand.

When the bell reaches bottom, the occupants adjust their noseclips, put in their mouthpieces, and start to breathe in the apparatus; then a valve is opened, and the contained air released, so that the water rises gradually inside the bell and completely fills it. Having accustomed themselves to underwater breathing in the apparatus, the men "dip under" the edge of the bell and rise to the surface, using their check-vanes to retard the speed of ascent. It will be found that the ascent is in a diagonal direction, which is a physiological advantage in that it takes the wearer somewhat longer to reach surface than by a direct vertical ascent. Telephonic communication with the surface is provided, as also is electric light. After a little practice in the lighted bell, the lamp is switched off and the men go through the same procedure in darkness, in case they have to do so later in an actual emergency escape from a disabled submarine.

SOME RECENT DEVELOPMENTS

In 1939 a committee was formed under the chairmanship of Admiral Sir Martin Dunbar-Nasmith, V.C., K.C.B., R.N., to investigate the purification of the air in submarines, and also matters connected with emergency escape, including watertight buoyant suits for protection of the crew during prolonged immersion.

Siebe, Gorman & Co. Ltd. collaborated with Surgeon Commander S. G. Rainsford,* R.N., and Mr. R. C. Frederick, of the R.N. College, Greenwich, in the production of CO_2 absorbent devices and immersion suits. The Second World War stopped the committee's work which, however, led the way to later developments and improvements in the purification devices and suits originally investigated by the committee.

Experiences of the war, and the intensive research on pressure problems have defined the problem of submarine escape even more clearly than before.

There are at present in use in the Royal Navy two methods of escape:

1. The collapsible trunk attached to an escape hatch (Figs. 241, 242 and 243), in the use of which the whole compartment of the submarine is flooded.
2. The Davis escape chamber (Figs. 244 and 245) which the escapers enter, one or two at a time, and which is then flooded to enable them to emerge by an escape hatch.

In both systems, the Davis escape apparatus is worn by the men.

THE COLLAPSIBLE TRUNK ESCAPE METHOD

In considering the Trunk method, we have to remember that in the flooding-up process any carbon-dioxide in the air of the compartment will be increased to a pressure equivalent to the depth at which the submarine is sunk. Since the adverse effects of CO_2 increase with the pressure, if there happens to be an appreciable percentage, or the depth of submergence is considerable, the concentration of CO_2 may call for speedy action on the part of the officer-in-charge in releasing his men. Fortunately, air purification in submarines is approaching a more efficient level; therefore, the risk is becoming increasingly less.

Other methods that have been used include a separate CO_2 absorbent canister to be worn by each member of the crew, the canister being thrown aside when he is ready to use his D.S.E.A. for escaping.

The effects of CO_2 concentration can, of course, be avoided by using the D.S.E.A., but we have also to consider the effect of breathing oxygen at high pressure; if the submarine is sunk at a considerable depth, it becomes necessary to delay breathing

* Now Surgeon Captain, D.S.C., M.D., B.CH., D.PH.

oxygen as long as possible, and to get away from the vessel as quickly as possible after starting to breathe it.

Another problem is the avoidance of "bends" if the submarine lies at a depth much greater than, say, 200 feet. In such a case, the personnel might absorb sufficient nitrogen during the period of flooding to render their return to normal pressures risky. It might be suggested that they breathe oxygen to avoid this, but, as already stated, at these high pressures oxygen can only be breathed safely for a limited time while the men are actually escaping. It is obviously advantageous, therefore, to increase the speed of flooding the compartment, and this has been done successfully in a number of cases.

DAVIS CHAMBER METHOD OF ESCAPE

The Chamber method of escape has advantages over the Trunk method in that all the crew in the submarine's compartment breathe air at atmospheric pressure until it is their turn to escape. Thus the risk of CO_2 and oxygen poisoning and of "bends" are avoided, and the escaper is only breathing oxygen at high pressure for a minute or so—that is, during the flooding of the chamber.

For constructional reasons it has not always been possible to install escape chambers in submarines, and in these cases the Trunk is used.

Clearing the Ears. Inability to "clear the ears" is sometimes a source of trouble, but the rupture of an eardrum by pressure is of little importance when escaping. It causes practically no permanent damage, and is a minor consideration in such circumstances.

Training. Further, it is advisable that, in training, chamber escape should be practised frequently until the submarine personnel are relatively unaffected by the procedure. The use of cold water in the training tanks, and the exclusion of light from them are also advocated in the later stages of training.

AVOIDANCE OF BREATH-HOLDING

There is a natural tendency in men escaping from submarines to hold their breath, whether they are wearing apparatus or not. This is a fundamental protective reflex under water. However, with the rapidly diminishing pressure of an ascent, the danger is not of inhaling water from the apparatus, but of the rapid expansion of gas in the lungs. If this is not allowed to vent naturally from the mouth, then the man will damage his lungs, or force gas into his blood-stream. The act of venting easily, and suppressing the desire to hold one's breath is acquired by training practice.

It has always been part of the inventor's instructions to men wearing the D.S.E.A. that they must follow the rules, and not hold their breath when escaping or ascending through the water to the surface, but exhale freely.

The points to be considered in submarine escape are:

(a) The necessity for keeping the air in the submarine as free from carbon dioxide as possible.

(b) The serious effects which may ensue from breathing pure oxygen at a high pressure for longer than can be helped.

(c) That the greater the depth at which the submarine is sunk, the greater is the danger both from excessive carbon dioxide and from high-pressure oxygen.

(d) The importance of quick decision on the part of the officer in charge, so that men ordered to escape may do so in as fresh a condition as possible.

SUGGESTED FREE ASCENT METHOD*

In the last few years, the possibility of a free ascent method, without breathing apparatus, has been investigated in the United States Navy for use in *very deep* escapes where oxygen poisoning might be a menace. This was one of the matters considered by the Admiralty Submarine Escape Committee appointed in 1946 and

* See also Appendix C.

presided over by Rear-Admiral P. Ruck-Keene, C.B.E., D.S.O. It has been shown that chamber escape, with an air-lock to allow air breathing, is feasible to considerable depths, and that "bends" can be avoided if the procedure is carried out very promptly.* It has also been shown experimentally that, owing to the expansion of the gas in the lungs, and washing out of carbon-dioxide, there is no necessity to breathe in during the ascent. A small face mask to increase confidence has been suggested.

A possible adjunct to the free ascent method is a Davis escape chamber of smaller size to accommodate one man at a time, who would be assisted through the escape-hatch either by a moving platform, operated from the submarine compartment, or by the bubble caused by the trapped air escaping from the chamber.

Some authorities consider that the escape apparatus should be worn for all ascents, but that in the case of "free" ascent, the mouthpiece should not be used lest it should hamper the free escape of air from the lungs.

Keystone Press Agency photograph

Fig. 254

Immersion suit (deflated) with D.S.E.A.

Keystone Press Agency photograph

Fig. 255

Immersion suit (inflated) with D.S.E.A.

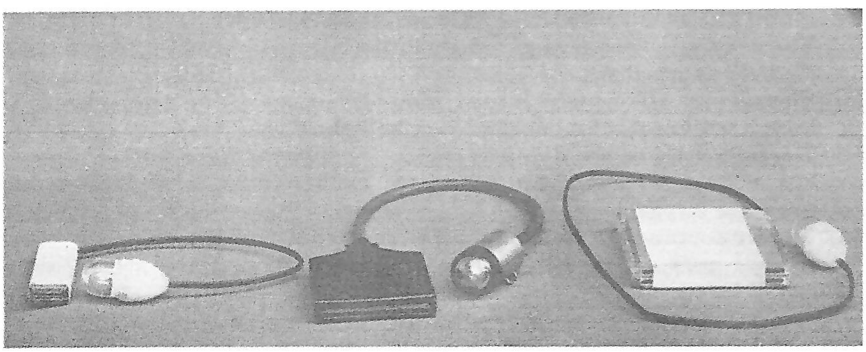


Fig. 256. Types of electric lights for use with immersion suits

* "Submarine Escape Breathing Air", K. W. Donald, W. M. Davidson and W. O. Shelford, *J. Hyg. Vol.* 46, 176, 1948

The Davis Submerged Escape Apparatus is not only a submerged escape apparatus; it is also a buoyancy means to keep the wearer afloat in the right position, with his head thrown back, face clear of the water, when he breaks surface. Further, it is an efficient apparatus for use in poisonous atmosphere.

IMMERSION SUITS FOR PROLONGED EXPOSURE

Special immersion suits can be worn, primarily to protect the escaper from cold, and also to keep him afloat on the surface. They aim at keeping warm those parts of the body that are most susceptible to cold, viz. the extremities, belly, etc. At the same time, and similarly to the D.S.E.A., they maintain the body in an upright position with more tendency to float backwards than forwards. This suit (see Figs. 254 and 255), which is provided with an electric light operated automatically on contact with sea-water, is now a part of the equipment of submarines' crews, and is worn in addition to the D.S.E.A. The free ascent method is not yet fully developed.

The escape chamber and the collapsible twill trunk, using the D.S.E.A., are still the accepted methods down to 200 feet, the escape chambers offering special advantages when the depth exceeds 150 feet or when the air inside the submarine is foul.

U.S. NAVY'S DEEP TANK FOR EXPERIMENTS AND TRAINING IN SUBMARINE ESCAPE

Some years before the Second World War the United States Navy Department erected at the Submarine Base, New London, Connecticut, an open diving tank about 130 feet deep = 5 atmospheres absolute pressure, for training men in the use of submarine escape apparatus, etc. (Fig. 256A). The advantage of this deep open tank is that men under training can be watched, through windows fitted at intervals in its sides, on their passage to the surface, thus enabling their behaviour during the ascent, and their physical and mental condition on arrival at the surface to be carefully noted.

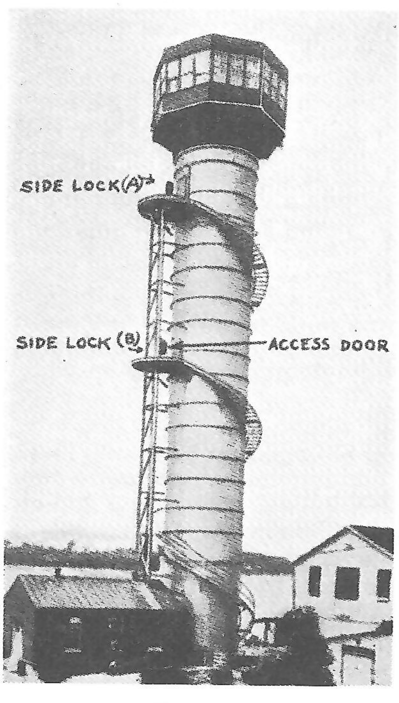


Fig. 256A
United States Navy Department submarine escape training tank

A similar tank, 100 feet in depth = 4 atmospheres absolute pressure, is in process of erection by the Royal Navy at H.M.S. *Dolphin*, Fort Blockhouse, Gosport, in which all forms of submarine escape, including the "free ascent" method, will be carried out.

The deepest open tank erected in the author's works, and which was installed before the war, has a depth of about 30 feet = about 2 atmospheres absolute pressure, but experiments at depths up to more than 200 feet are carried out in the specially designed high pressure water and air chamber described and illustrated in Chapter 1, pages 20, 21 and 24. A similar chamber has since been installed by the Admiralty at Portsmouth (see page 661).

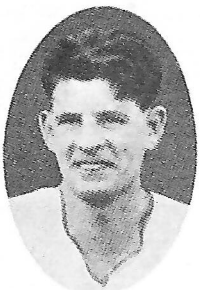
THE FIRST ESCAPES WITH DAVIS APPARATUS

Since the introduction of the D.S.E.A. a considerable number of men have escaped from sunken submarines both during the recent war and in peacetime. It is not the purpose of this chapter to enumerate these various occasions, but because the successful escapes from H.M. submarine *Poseidon,* sunk at a depth of 125 feet in the China Sea in 1931, were the first to take place with the apparatus and thus form a landmark in the history of submarine escape, we record below statements by the First Lord of the Admiralty at the time. Six men trapped in the vessel escaped, of whom one unfortunately died from injuries received by striking his head against the casing of the submarine during his escape. (See story by E. G. Holt, one of the survivors, on page 665.)

P.O. Reginald T. Clarke

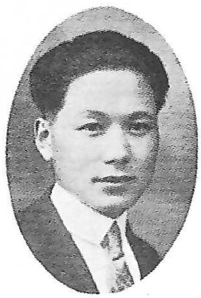
L. S. Vincent Nagle

L. S. Edmund G. Holt



A.B. Lovock

C.P.O. Patrick H. Willis



Ah Hai

Fig. 257

House of Commons, June 10th, 1931.

The First Lord of the Admiralty (Mr. A. V. Alexander):

" . . . All survivors were picked up by the steamship *Yuta* shortly after the collision with the exception of six ratings who escaped from the wreck by means of the Davis submarine escape apparatus between two and four hours later, and were rescued by boats from British warships."

House of Commons, July 7th, 1931.

The First Lord of the Admiralty:

"I rise to inform the House that the Admiralty have received the following report from the Commander-in-Chief China, respecting the recent loss of His Majesty's submarine *Posiedon:*

"On the conclusion of the various inquiries into the loss of His Majesty's Ship *Poseidon* some interesting facts have become available about the magnificent behaviour of the men who were cut off from their fellows in the forepart of the ship, most of whom eventually were saved. When the collision occurred and the order 'Close watertight doors' was given, Petty Officer Willis, the torpedo gunner's mate, took charge of those in the forepart, calling on them to close the door of the compartment with themselves inside, as this might mean saving the ship. The operation was difficult, as the bulkhead had buckled, but by their united efforts the door was eventually closed, leaving only a slight leak. Whilst this work was in progress the ship lurched to starboard and sank with heavy inclination by the bows. At the moment of the collision the electric light leads were all cut and from that time until the final evacuation the imprisoned men were working with the occasional illumination of an electric torch.

"Willis first said prayers for himself and his companions and then ordered them to put on their escape apparatus, making sure they all knew how to use it. He then explained he was going to flood the compartment in order to equalize the pressure with that outside the submarine, and how it was to be done, telling off each man to his station. He also rigged wire hawser across the hatchway to form a support for men to stand on whilst the compartment was flooding. While the compartment was slowly filling, Willis kept his companions in good heart, while one able seaman, Nagle, passed the time in instructing the Chinese boy in the use of his apparatus, and was undoubtedly instrumental in saving his life. The other men worked cheerfully at the various valves for flooding and rigging the platform. During this time oxygen was running low in some of the escape apparatus; one able seaman told Petty Officer Willis that his oxygen flask was exhausted, as he could no longer hear it bubbling. Willis then tested his own and found it also was empty, and told the man, 'That is all right, you can't hear anything in mine, and there is plenty left.' This statement reassured the man and maintained the atmosphere of coolness among the party, which was essential to success.

"After two hours and ten minutes the water was about up to the men's knees, and Willis considered the pressure might be sufficient to open the hatch. With considerable difficulty the hatch opened sufficiently for two men to shoot up, but the pressure then reclosed the hatch, and it was necessary to await further flooding to make the pressure more equal before a second attempt could be made. The two men who first escaped were Able Seaman Lovock and Able Seaman Holt. The former came to the surface unconscious and died immediately, but his body was supported by Able Seaman Holt, himself in a state of great exhaustion, until both were picked up by boats waiting on the scene. After a further hour, by which time the men in the compartment were nearly up to their necks in water and the air-lock was becoming very small, a second effort was made. This was successful and the hatch opened, and four other men came to the surface, Petty Officer Willis, Leading Seaman Clarke, Able Seaman Nagle, and Officer's Steward Ah Hai,* all of whom were picked up by boats. From evidence it is abundantly clear that the courage and fortitude with which all these men in the practical darkness of the slowly flooding compartment faced a situation more than desperate was in accordance with the very highest traditions of the Service. The coolness, confidence, ability and power of command shown by Petty Officer Willis, which no doubt was principally responsible for the saving of so many valuable lives, is deserving of the very highest praise."

House of Commons, July 15th, 1931.

Mr. Alexander: "I am informed by my right hon. friend the Secretary of State for the Home Department, that His Majesty the King has been pleased to award to Chief Petty Officer Patrick Henry Willis, the Albert Medal in Gold. The King has also been pleased to award the Medal of the Order of the British Empire, Military Division, for Meritorious Service, to Able Seaman Vincent Nagle, and to Able Seaman Edmund G. Holt. Promotions have been approved of for Leading Seaman Reginald T. Clarke to be Petty Officer, and Able Seaman Vincent Nagle and Able Seaman E. G. Holt to be Leading Seamen."

* Ah Hai, who had, of course, never used the D.S.E.A. – indeed it is doubtful if he had ever seen it before – was shown, during the flooding-up of the compartment preparatory to the escapes, how to use the apparatus. He came up quite safely.

UNDERWATER PHOTOGRAPHS OF MEN IN DAVIS SUBMERGED ESCAPE APPARATUS ESCAPING FROM GUN TOWER OF A T-CLASS SUBMARINE

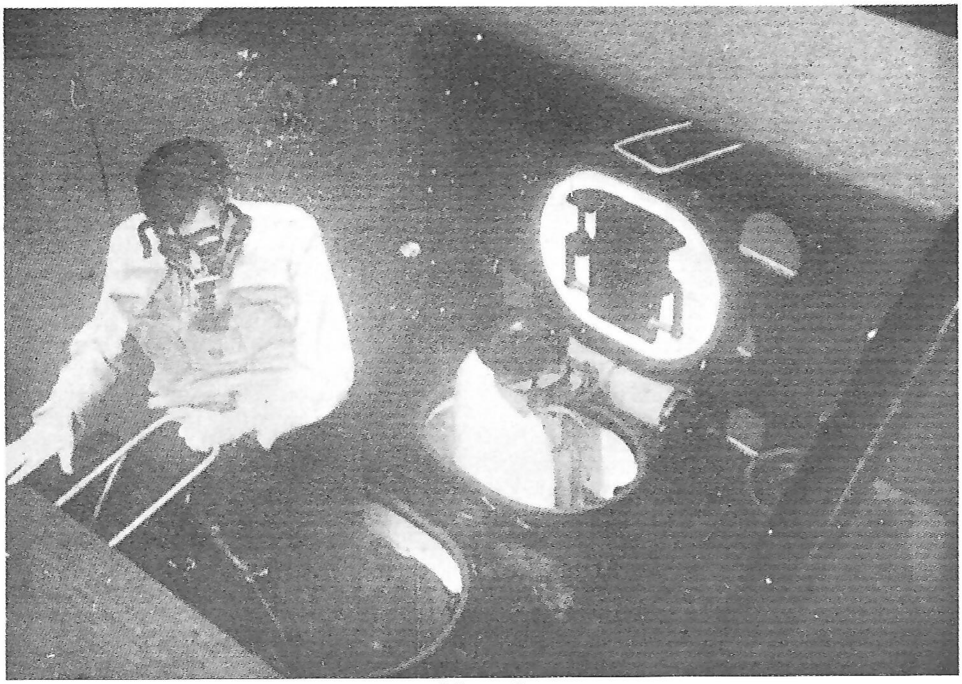


Fig. 258

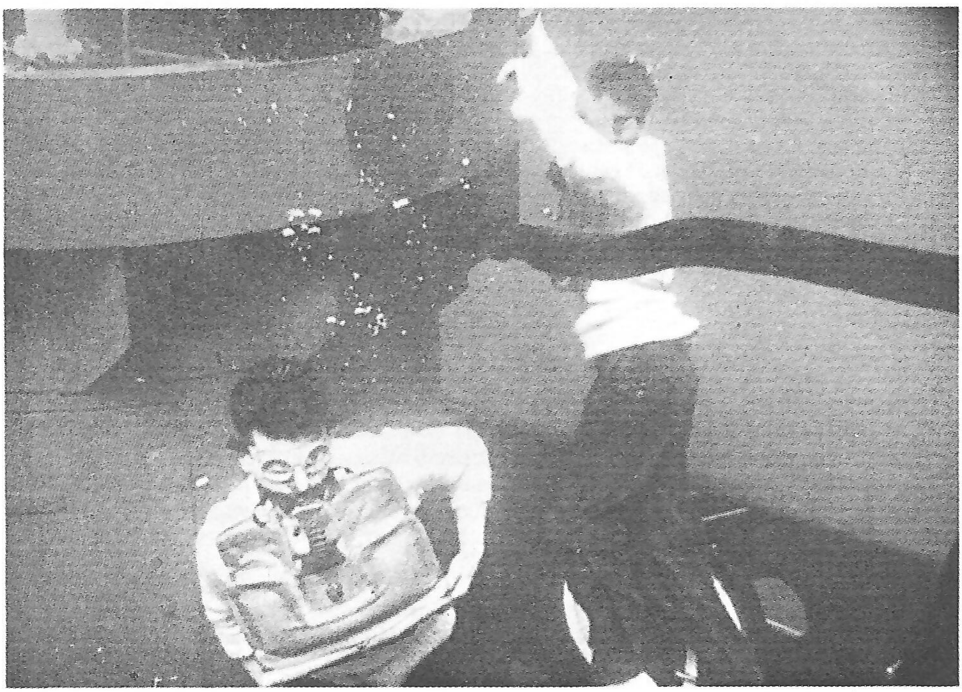
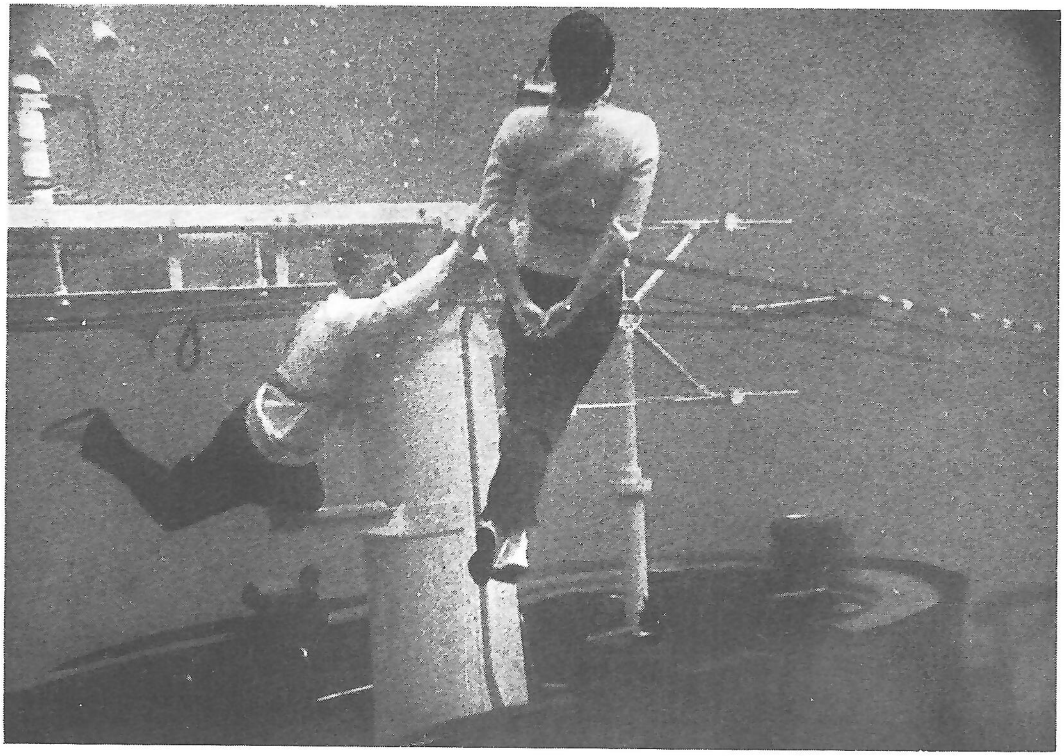


Fig. 259 *Photographs from the film "Morning Departure"*



Photograph from film "Morning Departure"

Fig. 260. Underwater photograph of men in D.S.E.A. escaping from conning tower of a T-class submarine

SOME OTHER METHODS OF ESCAPE

Figs. 261, 262, 263 and 264 illustrate another system of escape designed by A. Belloni, and described by him as the "Tube (or trunk) and tub method, on the Torricelli barometric principle." This system, however, entails for its proper functioning the raising, by means of the vessel's compressed air service, of the air pressure in the submarine's compartment to equality with the outside water pressure due to the depth at which the vessel is sunk. The apparatus consists of a trunk attached watertightly to a hatchway and extending into a tub. The tub and trunk are filled with water and the hatch is opened, but the increased air pressure in the submarine's compartment, acting on the surface of the water in the tub, holds the water back and prevents it from overflowing. Men wearing escape apparatus enter the tub and duck under the edge of the trunk and escape through the hatchway.

Dispensing with the tub and retaining the trunk, we come to the same principle as the collapsible trunk described and illustrated in earlier pages. But in that case the pressure of air in the vessel is raised by flooding the compartment. In either case, of course, the men would be subjected to the same pressure and would be breathing air at corresponding pressure, but in the one case the surrounding pressure would be water pressure, while in the other case it would be air pressure.

Belloni also suggested that escaping men might make their way, by means of a cable stretched between the escape hatches of the vessels, from a disabled submarine to another submarine (not disabled) lying alongside on the bottom. His proposal was that the rescuing submarine should have her escape-hatch open and the tube and tub flooded, so that any men who reached this vessel would (reversing the process of

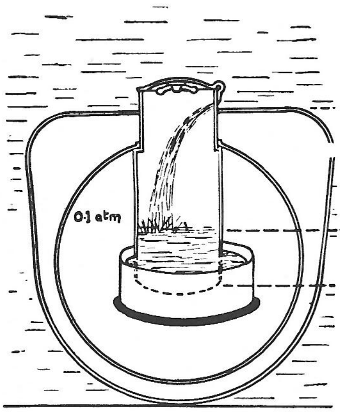


Fig. 261

Flooding the tube

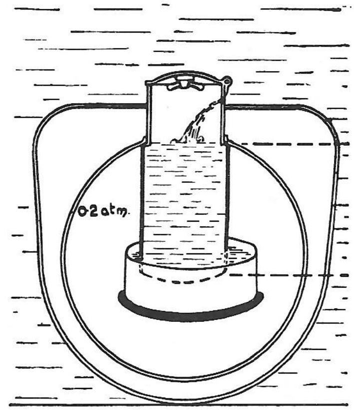


Fig. 262

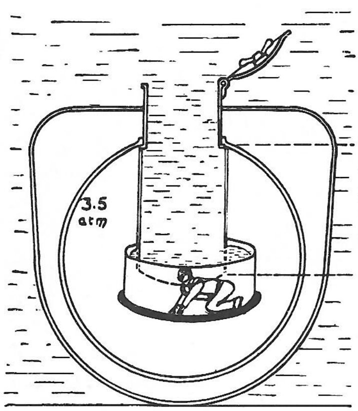


Fig. 263

Tube flooded; man escaping. It is assumed that the vessel is sunk at a depth of 124 feet; =3·5 atmospheres

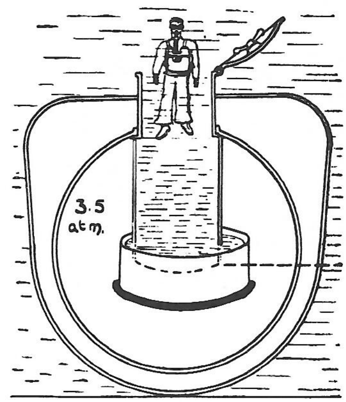


Fig. 264

escape from the disabled vessel) enter the tube through the open hatchway, land in the tub, duck under the edge of the tube, and so enter the submarine compartment.

If such a method were applied to submarines with escape chambers such as those described on page 266, the upper hatch would be opened, the escaped man would enter the chamber, the hatch would be closed, the chamber emptied by drawing the water into the bilges, and the lower door then opened, giving the man access to the submarine compartment, this procedure being repeated as required.

One of the difficulties in either case, however, would be to establish the line of communication between the respective escape hatches.

Other escape devices that have been designed include chambers fitted detachably to the submarine (Fig. 265). At the bottom

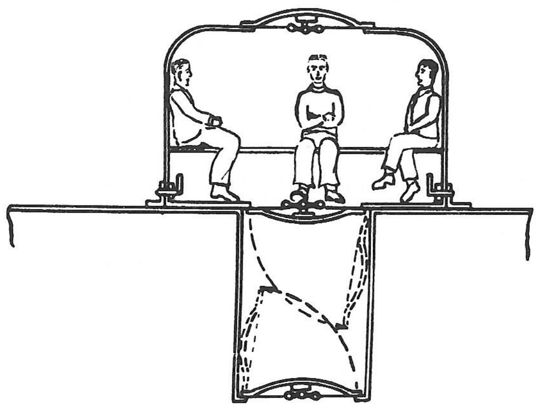


Fig. 265

of the chamber is a watertight door which corresponds to a hatch in the submarine, over which hatch the chamber is connected. In emergency, the hatch of the submarine and the door of the chamber would be opened to give the crew access to the chamber; both doors would then be closed, and, by a special arrangement, the chamber would be released from the boat and rise to the surface.

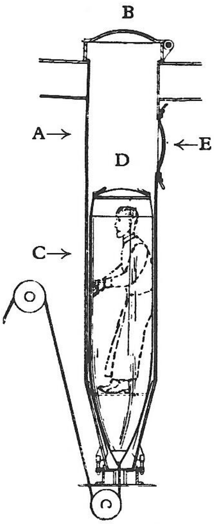


Fig. 266

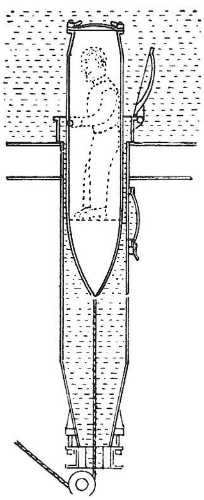


Fig. 266a

Another design for escape, built into a submarine, is that of Gerolami and Arata (Fig. 266). It consists of a cylindrical chamber (A) with a closed lower end formed conically, and with a watertight hatch (B) at its upper end. Inside this chamber is another chamber (C) similar in form, capable of holding a man standing, and fitted with a watertight door (D) at its upper end. On one side at the upper end of the outer chamber is a door (E) giving access to the door of the inner chamber. At the lower end of the inner chamber is connected a wire rope which passes through a stuffing box in the outer chamber and over a train of pulleys in the submarine compartment.

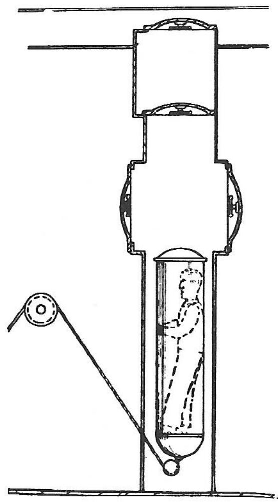


Fig. 267

A man having entered the inner chamber by way of doors (E) and (D), both doors are closed tightly, chamber (A) is flooded by opening a valve, door (B) is opened and the inner chamber (C) floats out of its housing. Having reached surface, the occupant, wearing a lifebelt, leaves the chamber, and the latter is hauled down again, hatch (B) is closed, the chambers are emptied of water, and the procedure of escape is repeated by the next man, and so on.

Means, Fig. 266A, operated in case of need by hand or power from within the submarine, had already been devised for facilitating the ejection by movement, in an outward direction, of the man-carrying chamber.

An apparatus on a somewhat similar principle was also devised by Arturo Genova (see Fig. 267), but in this case the outer—the flooding—chamber had two superposed hatches.

SUGGESTED ARRANGEMENT FOR SAVING MEN FROM SUBMARINES NOT EQUIPPED WITH INDIVIDUAL ESCAPE APPARATUS

In 1917 arrangements, which we here illustrate and describe briefly, were designed for saving the crews of disabled submarines which were not provided with individual escape apparatus. They consisted of a combination of air-lock and diving bell worked by bell divers, alone or, preferably, in conjunction with dress divers. In some of their forms these devices involved slight additions to the submarine to enable the air-lock chamber to be connected to the hull.

Fig. 268. In this case, men in the diving bell would secure the air-lock chamber to a seating already formed on the conning tower. This done, a member of the crew of the submarine would enter the lock and close the lower door, pressure in the chamber would be equalized with that in the diving bell, the upper door would be opened, the man would pass into the bell and the door would be closed again. The procedure would then be repeated by the next man to leave the submarine.

Fig. 269 is a similar arrangement to Fig. 268, but with the air-lock chamber attached within the submarine.

Fig. 270 shows an air-lock formed in the conning tower itself.

Fig. 271 is a view similar to Fig. 268, but showing the air-lock as part of the diving bell.

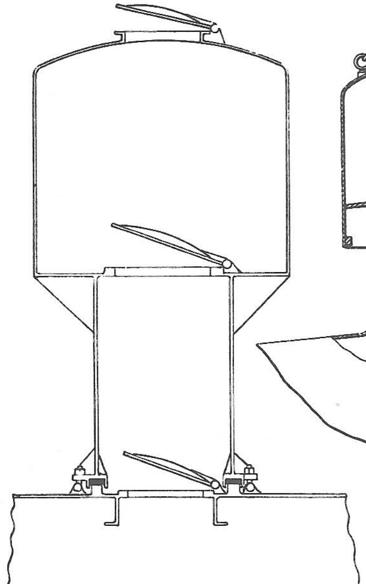


Fig. 268

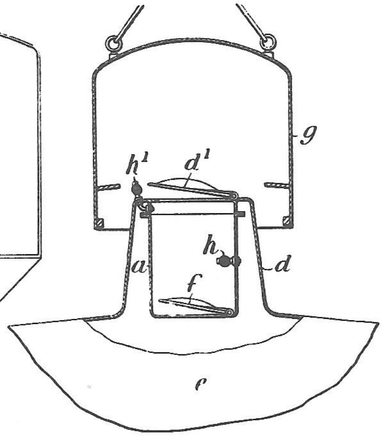


Fig. 269

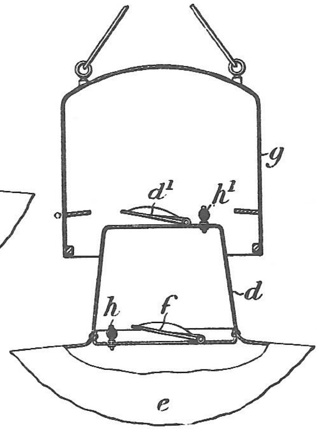


Fig. 270

Fig. 272 is a modification wherein the air-lock is attached to the hull of a submarine instead of to the conning tower, a seating with a door on the hull having previously been fitted.

Fig. 273 is an arrangement by which the air-lock chamber may be connected to vessels which are not already fitted with devices to which the chamber could be attached.

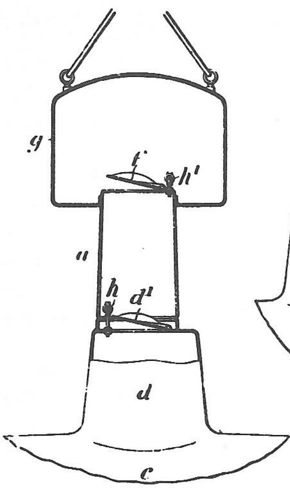


Fig. 271

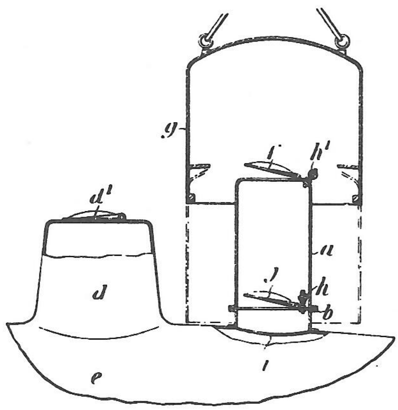


Fig. 272

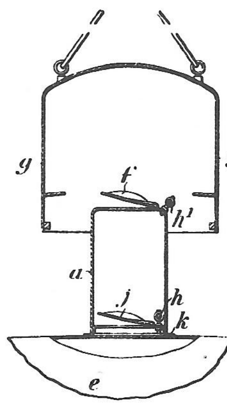


Fig. 273

The United States Navy has since adopted a broadly similar system, but has installed, inside the chamber, an electric hoist operating a wire rope which divers attach to the escape-hatch to which the chamber is to be secured watertightly; the hoist is then started and the chamber is drawn down to its seating on the submarine where the divers secure its attachment.

RELEASE BUOYS, TELEPHONIC COMMUNICATION AND AIR SUPPLY FROM SURFACE

An early type of apparatus supplied to a foreign government is illustrated in Figs. 274 and 275. It consisted of a steel buoy, with quick-opening door secured by swivel bolts, and contained a watertight box in which 200 feet or more of non-kinkable flexible tube, with insulated telephone wires passing through the bore; one end of the

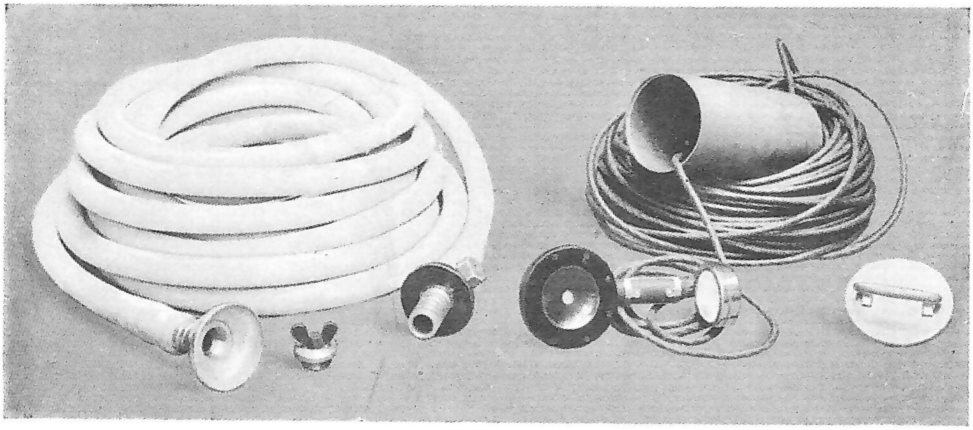


Fig. 274. Telephone instruments, as carried in buoy, and hose and connections to the buoy

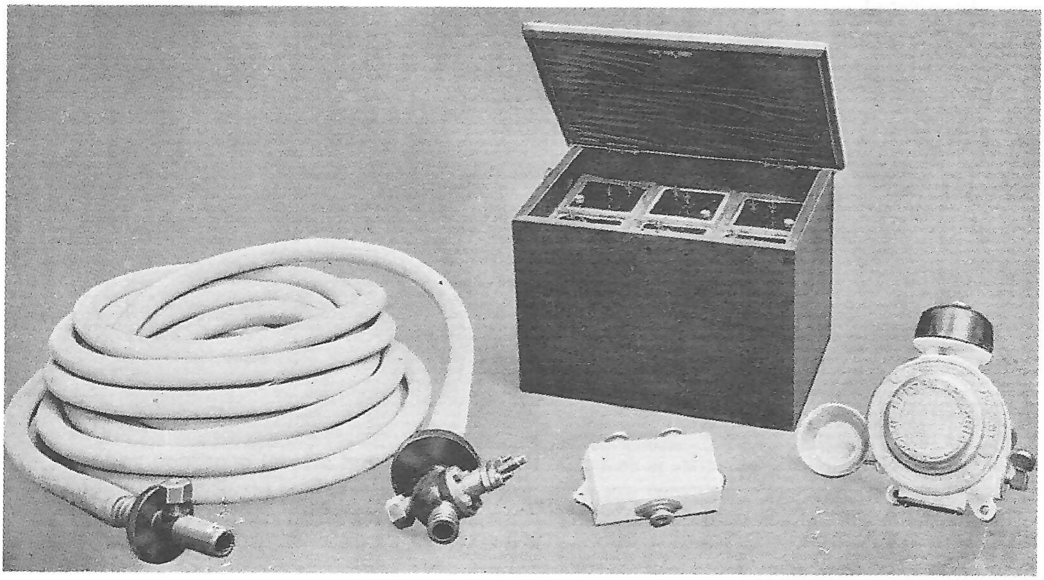


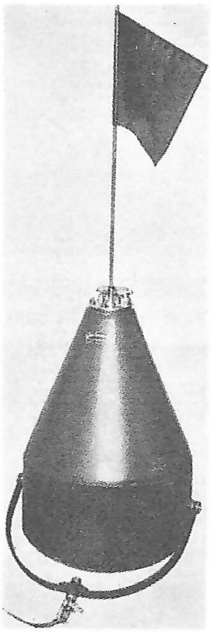
Fig. 275. Telephone instruments and battery as carried in the submarine, and hose and connections to the vessel

tube being connected by a gunmetal watertight fitting through the lower part of the buoy, the other end through the skin of the submarine. Battery, receiver, transmitter and bell were fitted in the boat. A short length of flexible hose, with a screwed funnel closed by a cap, is connected to the main hose and housed in the buoy, so that, when the latter is opened, not only can telephonic communication be established, but fresh air and, if need be, water, can be delivered through the tube to the submerged vessel. The necessary gear for securing the buoy to the submarine and releasing it therefrom, and for housing the tube are also included.

When, subsequently, the crew escape with the D.S.E.A., the tube attached to the buoy floating at the surface serves as a guide and steadier to the escaping men.

Other types of release buoys are shown in Figs. 276, 277 and 278. These are fitted with a flag which assumes a perpendicular position when the buoy is released. Some are fitted with telephonic apparatus and an electric light. The cover, with lamp attached, can be quickly removed to allow access to the telephone.

Recent investigations into means for accelerating the location and rescue of survivors in submarines have been in the field of radar transmitting indicator-buoys, special "seamarkers" for release from submarines and supersonic telephonic communications.



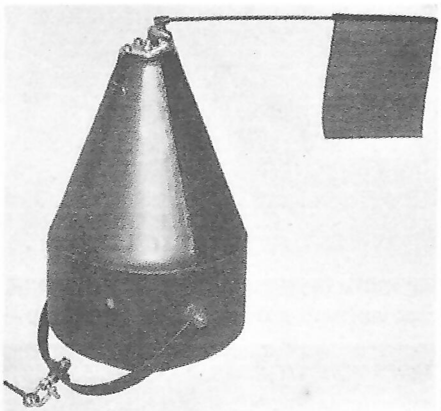


Fig. 276

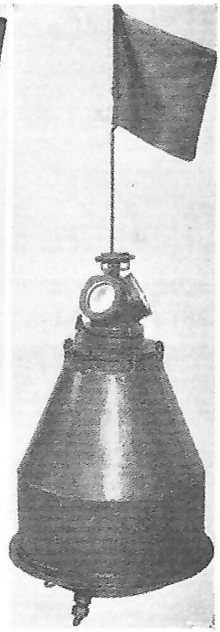


Fig. 277

Fig. 278

PURIFICATION OF THE AIR IN SUBMARINES

Purification of the air in submarines which might, for military or other reasons, be submerged for long periods, is essential if the physical and mental condition and the fighting efficiency of their crews are to be maintained. The desired result is attained by the prevention of accumulation of CO_2 and the maintenance of an adequate percentage of oxygen in the various compartments of the vessels.

The amount of CO_2 expired per man/minute, averaged over periods of work and rest, may be put at 0·5 litres = 30 litres per hour, and the quantity of oxygen consumed per man/minute, averaged over the same period, at 0·5 litres = 30 litres per hour. From

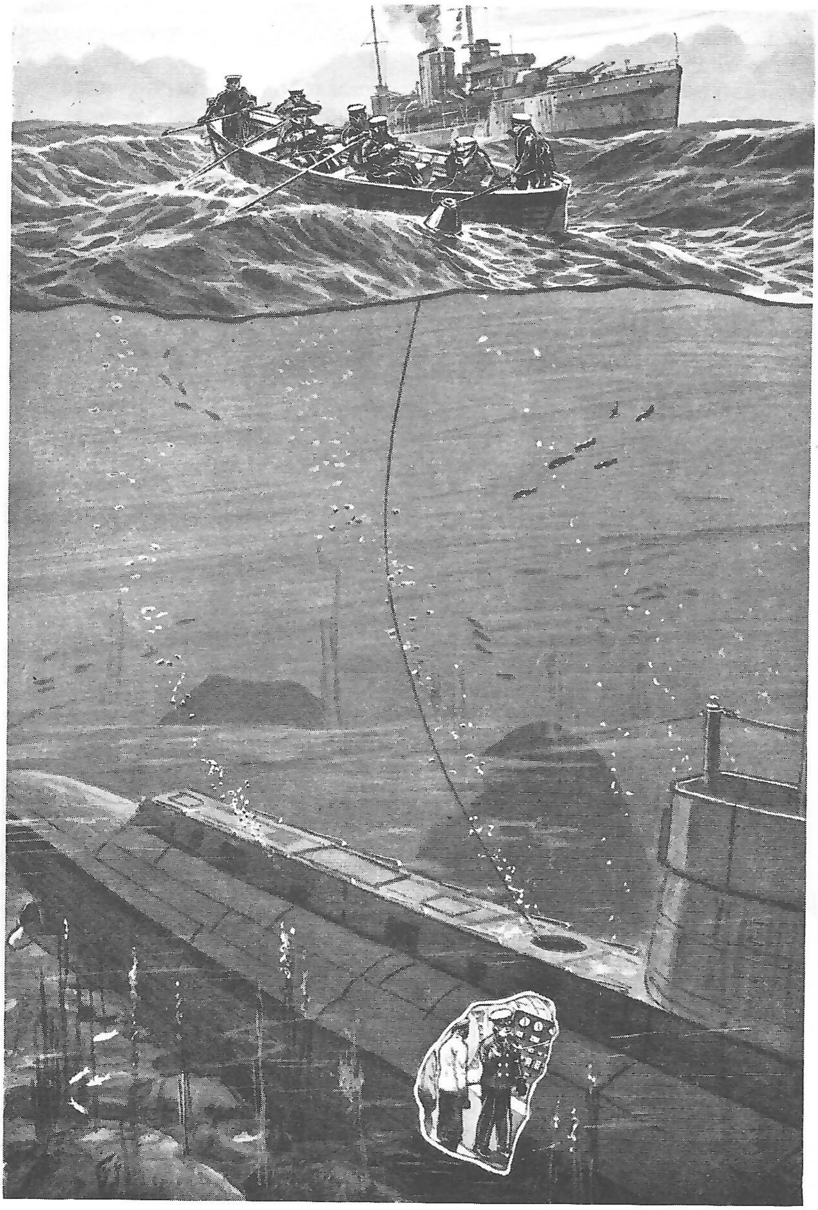


Fig. 279. Communication between submarine and surface by means of telephone-buoy

these figures it is easy to calculate the quantity of oxygen and CO_2 absorbent required for the number of men carried, and the period of submergence.

Each CO_2 absorbent cartridge as illustrated in Fig. 280, will absorb about 400 litres of CO_2 in four hours. One type of regenerator consists of manifolds, each carrying three, four, six or eight cartridges, according to the number of men. The manifolds are connected to the submarine's air circulating trunk, the air in the boat being drawn through the cartridges.

Example of apparatus of this type necessary for a submarine carrying a crew of, say, 40 men, for a submergence of, say, 36 hours:

OXYGEN

1 man consumes 30 litres of oxygen per hour
40 men consume 1,200 litres of oxygen per hour

Thus, in 36 hours, the 40 men will consume 43,200 litres of oxygen. It is usual to allow for about 10 per cent in excess of this supply of oxygen for any possible leakage.

CARBONIC ACID ABSORPTION CARTRIDGES

1 man exhales 30 litres of CO_2 per hour
40 men exhale 1,200 litres of CO_2 per hour

So that every four hours the 40 men will exhale 4,800 litres of CO_2.

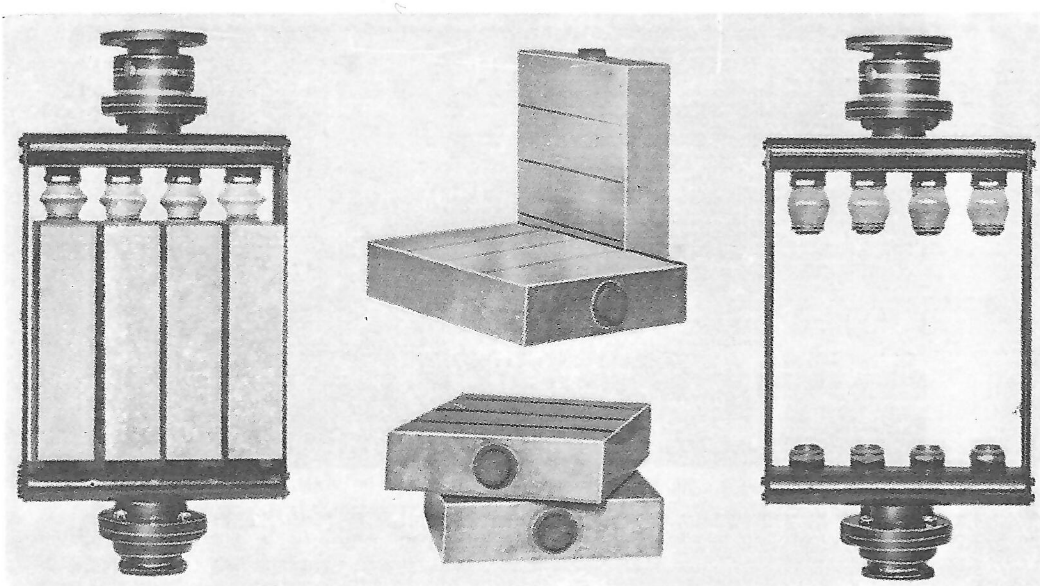
Assuming that three manifolds, each of four cartridges, are distributed over the vessel's three main compartments, the number of cartridges required every four hours would be 12, and for the 36 hours, 108.

It will be understood that the distribution of the oxygen and CO_2 absorbent cartridges, as well as the design of the latter, can be varied according to the number and size of compartments in the vessel.

Analysis apparatus for testing the oxygen and CO_2 content of the air in the submarine and hygrometers for testing the humidity of the air form part of the equipment.

The following alternative methods have either been used already or proposed:

(1) Circulators (fan type). The circulation, by means of fans, of the air in the vessel through CO_2 absorbent containers connected to air trunks, and the automatic



[*Copyright*

Fig. 280

release, through reducing valves, of oxygen in the correct quantity according to the number of crew. Fig. 280 illustrates one form of CO_2 absorbent container, and Fig. 281 oxygen cylinders with reducing valves, pressure gauges, etc.

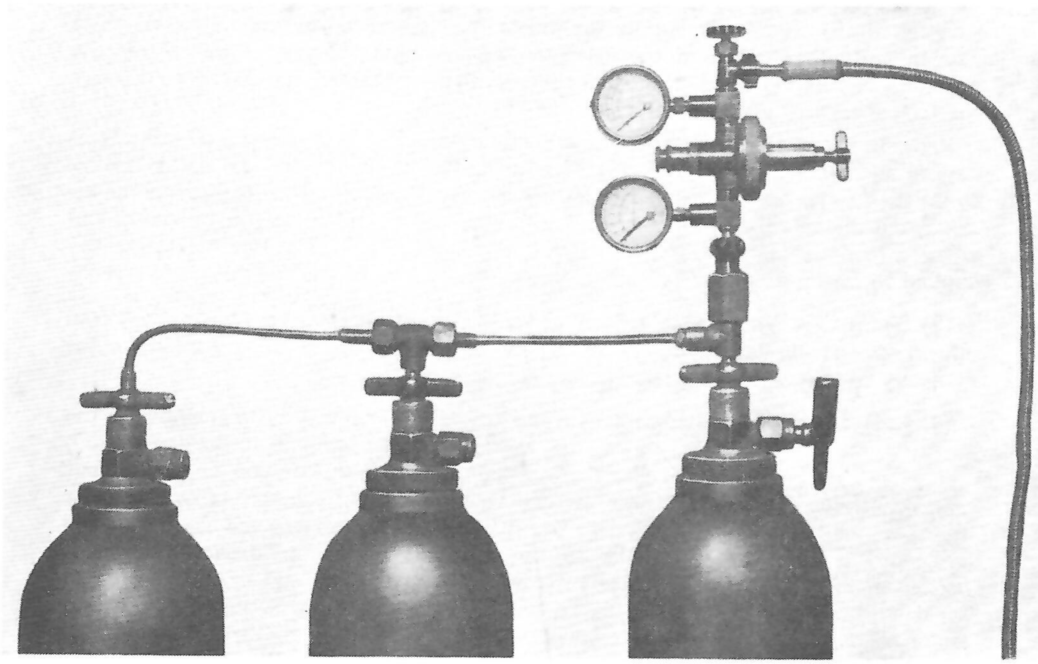


Fig. 281. Oxygen cylinders with reducing valve, pressure gauges, etc.

(2) Circulators (Reducer-Injector type). The circulation of air in the vessel through CO_2 absorbent containers, by means of a specially-designed compound reducing valve and injector connected to oxygen cylinders. With this design, the aim is to circulate as much air as possible, keeping the basic flow through the reducing

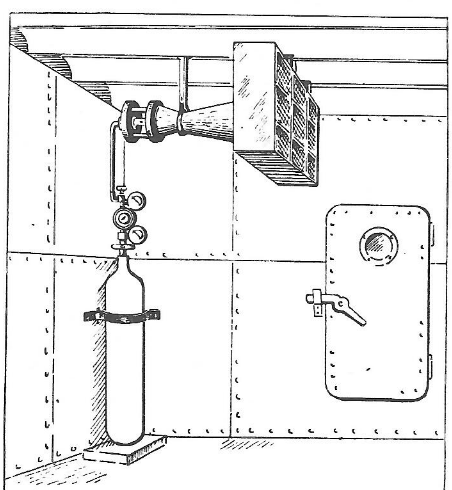


Fig. 282

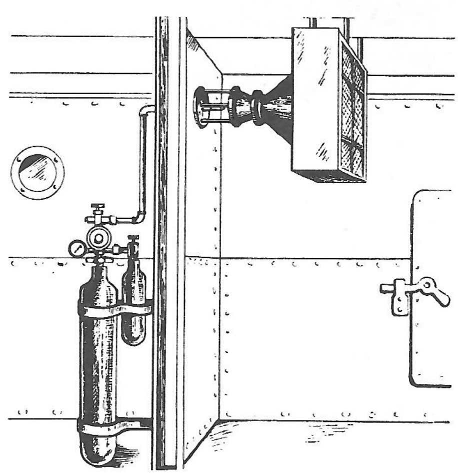


Fig. 283

valve as low as practicable. Shortly before the outbreak of the last war, Siebe, Gorman & Co. designed and made and submitted for test to the Royal Naval College, Greenwich, alternative combinations as illustrated in Figs. 282 and 283. Connected to a CO_2 absorbent container of the type used in the Royal Navy, is a venturi tube with a compound injector. To maintain a constant pressure, a reducing valve is interposed between the source of air supply (cylinders of compressed oxygen or mixtures of oxygen and other gas) and the injector. With a basic flow of 2 cubic feet per minute, a circulation of 100 cubic feet per minute was obtained, the discharge through the CO_2 absorbent giving an efficiency of 88 per cent.

Fig. 282 shows the apparatus with a single cylinder of pure oxygen or mixture of oxygen and other gas; and Fig. 283 with a cylinder of air or other gas and a smaller cylinder of oxygen proportioned to ensure a correct percentage of oxygen in the air circulated in the submarine compartment. The two cylinders being connected and charged to the same pressure, the proportions, by the law of communicating tubes applied to elastic fluids, will be maintained throughout the discharge.

(3) Open CO_2 Absorbent Trays. In some cases, CO_2 absorbent has been spread out on open shallow trays, and fresh oxygen in the requisite quantity supplied automatically from oxygen cylinders via reducing valves.

(4) Individual CO_2 Absorbent Canisters. In other cases, every member of the crew has been provided with a canister of CO_2 absorbent, fitted with an ori-nasal mask or mouthpiece and noseclip (Fig. 284), the necessary oxygen content of the vessel's air being maintained by a supply delivered automatically into the submarine's compartments, as described in (1), (2) and (3). If it became necessary to leave the vessel while submerged, the men discarded the canister and put on their escape apparatus.

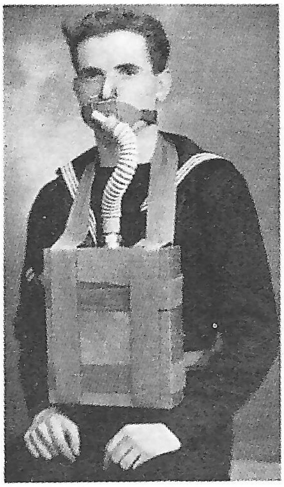


Fig. 284

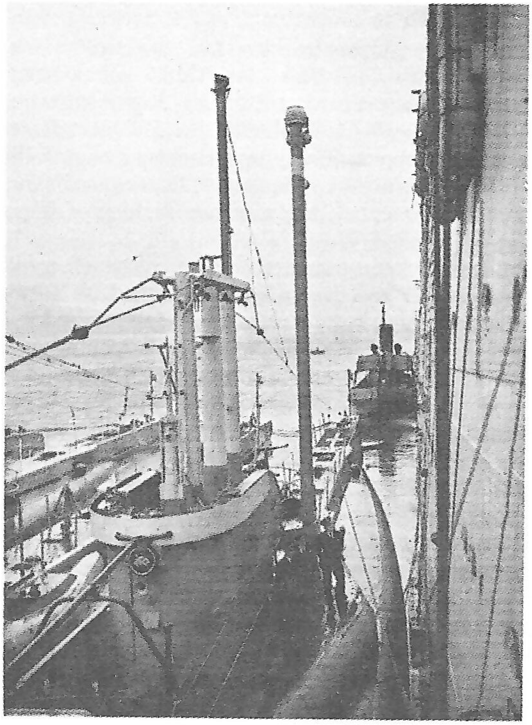
(5) Oxygen-producing Peroxides of Potassium and Sodium. In a few earlier foreign submarines, a special compound of the peroxides of potassium and sodium (named "Oxylithe") spread out on open trays, was employed. This chemical on contact with the water vapour of the surrounding air, liberates oxygen, and its alkaline residue absorbs CO_2. It was found, however, that any organic matter that came in contact with it was liable to spontaneous combustion; its use was therefore discontinued. Individual escape apparatus Hall-Rees-Davis (see Part II, Chapter 4) using the same chemical, worn by members of the crew, was also designed and used for a time, but was ultimately discarded, partly because of the space occupied by the apparatus and partly because it took too long for the water vapour of the wearer's expired air to liberate the oxygen in sufficient quantity for respiration. Experiments are proceeding with a view to overcoming this objection.

(6) Oxygen-producing Potassium Chlorate. Another oxygen-producing device employed is in the form of a candle made of potassium chlorate which, when ignited, releases oxygen. This is a revival of the old method of producing oxygen which Siebe, Gorman & Co. employed many years ago in connection with their original Siebe, Gorman-Fleuss self-contained diving and breathing apparatus.*

* *See the author's "Breathing in Irrespirable Atmospheres".*

THE "SCHNORKEL" OR "SNORT" APPARATUS

The "Snort" mast (Fig. 285) is a British development of the "Schnorkel" device used by the Germans on their submarines during the Second World War. The mast, which is lowered horizontally along the hull when not in use, has an air-intake and exhaust-port at the top and enables a submarine to take in fresh air and charge its batteries when submerged at periscope depth, about 40 feet. The vessel is thereby enabled to remain submerged for very long periods.*



(Associated Press photo)

Fig. 285

H.M. Submarine *Ambush* equipped with "Snort" mast; shown in the vertical position to the right of the conning tower

* About 1576 a gunner named William Bourne, who had served with distinction under Sir William Monson, designed a three-compartment submarine one of the features of which was a hollow mast running from the keel to well above water, for air supply to the vessel when submerged. May not this be regarded as the genesis of the "Schnorkel" device of today? (See Part II, Chapter 4.) *Author.*