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Deep Diving with the Davis Submerged Decompression Chamber

FIVE HUNDRED AND FORTY FEET REACHED BY DIVERS OF THE ROYAL NAVY

We have seen that, after working in shallow water up to 33 feet, a diver may ascend as rapidly as he pleases, but that at greater depths his decompression has to be controlled by a time-table of increasing slowness, till at 204 feet (the limit of the late J. S. Haldane's Tables, pages 100-108) the ascent lasts far longer than the useful working period spent on the bottom. Thus, after spending ten minutes at 34 fathoms, a diver has to spend another 32 minutes coming up his shot rope by stages, and if he stayed half an hour on the bottom, his ascent would be prolonged to one hour.

Though in favourable conditions it does not harm divers to spend an hour or more decompressing in mid-water, it is nevertheless tedious and exhausting. The average sea temperature and tidal conditions round the British Isles and many other countries render such drawn-out ascents impracticable and in consequence the time on the bottom is curtailed (see page 95), while at the greatest depths it is so short as to be of little or no practical value. For this reason, although there was no difficulty in making apparatus suitable for depths beyond 204 feet, it appeared that divers could do no useful work there unless means could be found for improving the conditions of their ascent and so, indirectly, enabling them to work on the bottom for a reasonably long time. Furthermore, attempts to dive in emergency beyond 204 feet showed that the original Haldane Table could not be extended simply by extrapolation, and that the tables would need recalculation for depths greater than 34 fathoms.

The problem was solved by the invention of the Davis submerged decompression chamber and by the introduction of Siebe, Gorman & Co.'s Deep Diving Tables (pages 160-179), which introduce oxygen breathing as a means of hastening the "washing-out" of nitrogen, and thus shortening the decompression times. The submerged decompression chamber enables the diver, on concluding his work below, to leave the water whilst still under pressure and to undergo his decompression in a dry chamber with the company of his attendant whilst, if necessary, his ship can weigh anchor and proceed into harbour.

The method of using the submerged decompression chamber to the best advantage and the application of the new tables was worked out by a committee appointed by the British Admiralty together with their experimental officers and those of Siebe, Gorman & Co. Ltd. (see Chapter 1). Under the auspices of this committee a great number of dives were carried out successfully at depths between 200 and 340 feet, until the procedure was sufficiently perfected to enable the Admiralty to authorize 300 feet as the safe limit for deep diving in the Royal Navy. This procedure was used for 15 years until the conclusion of the Second World War, when the Admiralty decided to investigate the possibilities of diving even deeper than 340 feet. As a result of further intensive experimental work in 1946-48, British naval divers reached a depth of 540 feet in the open sea off Loch Fyne, Western Scotland, in 1948.

Although, at the time of writing, this record depth has not been authorized by the Admiralty for routine deep diving work, the technique of diving to such depths is well established and the following instructions are based on those in use in the Royal Navy.

The Davis Submerged Decompression Chamber. This chamber (generally known in the British Navy as the "S.D.C.") is of steel, cylindrical in shape, and large enough to hold two men. It is arranged to be slung from a derrick or crane over the side of the diving vessel, so that it can be lowered to the required depth or landed on deck as necessary. There is a door at the bottom large enough to admit a fully-dressed diver and a smaller door at the top. Both open inwards and, together with the chamber as a whole, are tested to an internal pressure of 130 lbs. per square inch.

Air is supplied from a special "S.D.C. control panel" through a standard diver's air-pipe and a non-return valve on the chamber itself. Two outlet valves are fitted; the "breaking-down valve", operated from inside the chamber, and the emergency outboard vent, operated from outside. Communication is by amplified speaker system, and illumination is by electric light supplied from the surface or from internal batteries. Pressure and depth gauges are fitted, and the equipment includes a "Novus" apparatus for supplying oxygen to the diver, a Davis submerged escape apparatus for use by the attendant in emergency, and a light ladder which can be thrust out from the lower door to assist the diver in climbing into the chamber.

Method of Use. Before the diver is sent down, the attendant prepares the "S.D.C." and its equipment, testing light and telephones, opening up the oxygen supply and checking that the cylinder is adequately charged. He then enters the chamber by the upper door, which he closes and clips behind him, the lower door being open. The chamber is then lowered to just above the water, and the attendant passes the "bowsing-in line" round the shot rope and leaves it fairly slack. This line will eventually bowse the chamber into the shot rope so that the diver, when he comes up, will find the chamber immediately above him.

The chamber is then lowered to the required depth (usually 60 feet), maximum air being supplied from the surface as it goes down. The chamber thus acts as a diving bell, the water, which tends to rise as the pressure increases, being kept down by the air pressure. When the chamber is at its required depth, the air supply is reduced to the amount necessary for ventilation, surplus air escaping through the open lower door.

The diver, who has meantime been dressed and got ready on the ladder, now starts his descent. The "S.D.C." attendant, seeing him going down past the lower door, reports over the telephone: "Diver passing the chamber", hauls taut the "bowsing-in line", puts the ladder out and generally prepares to receive the diver on his ascent. When all is ready, he reports "Chamber ready for the diver." The diving officer thus knows that at any time during the dive he can, if necessary, get the diver into the chamber.

In due course the diver leaves the bottom, and comes up the shot rope. If, as in the greater depths, there are stops to be carried out below 60 feet, these are carried out on the shot rope in the usual way. On completion of these stops, the diver comes up to the chamber, gets on the chamber ladder and climbs up until the upper part of his body is inside the chamber in air and his legs still in the water below the lower door. The attendant passes a safety lanyard round the diver to prevent him slipping, takes off his weights, then removes the helmet, disconnects air-pipe and breast-rope and drops their ends out through the lower door. Before doing so, he must blank the breast-rope to prevent it being flooded, and orders "Up air-pipe and breast-rope" over the telephone, so that they may be hauled inboard. The attendant now assists the diver to get right into the chamber, shuts and clips the lower door and helps the diver to start breathing oxygen from the "Novus" apparatus. He then reports to the surface: "Lower door closed—diver breathing oxygen".

It will be understood that the diver is now at his 60-feet stage, for the "S.D.C." was stopped at that level, and, acting as a diving bell, contained air at that pressure, so that when the diver came out of the water into the chamber and had his helmet taken off he suffered no change of pressure. Both doors being shut, and the chamber airtight, it can be hoisted on deck, still without any change of pressure on the diver, and the ship then becomes free to get under way, or fire explosive charges, while decompression goes on.

It is most important that no accumulation of carbon-dioxide is allowed to build up in the chamber before the diver enters it, otherwise it may affect him seriously when he comes to breathe oxygen under pressure inside. All the time the chamber is under water with the attendant only in it, air must be supplied at the rate for one diver at the depth of the chamber (see Table III, page 38). While the diver is entering the chamber, the air supply must be doubled, as there are now two men breathing inside the chamber and, incidentally, exerting considerable effort until the diver is up in the chamber and settled down.

When, according to the Deep Diving Tables, the time has come for the diver to ascend from the 60-feet to the 50-feet stage, the "S.D.C." panel attendant orders "Break-down to 50 feet". The "S.D.C." attendant opens the "breaking-down valve" and allows the pressure to drop until the order "Check" is given from the panel. This is repeated for each stage until "zero" or surface pressure is reached when the top door of the chamber is opened and diver and attendant emerge. As the decompression proceeds, the diver can get out of his boots, corselet, etc., but care must be taken that oxygen breathing is not interfered with. If ventilation of the chamber is required during the stops, the "breaking-down valve" is "cracked" and a flow of air maintained from the panel, being so adjusted that the pressure in the chamber remains constant.

Breathing Oxygen. It has been found that if a diver be given oxygen to breathe instead of air during decompression, the process of "washing-out" the nitrogen from his body is accelerated and the decompression times are thereby considerably shortened. Oxygen breathing is always used in connection with the "S.D.C." and the Deep Diving Tables are calculated accordingly.

The oxygen supply to the chamber is carried in a 100 cubic feet steel cylinder mounted on brackets on the outside of the chamber. The oxygen is supplied through a reducing valve inside the chamber to the "Novus" apparatus, which consists of breathing bags connected by a CO_2 absorbent canister, in and out of which the diver breathes by means of a mouthpiece. (For details of the apparatus and full instructions see pages 157-158). Oxygen breathing must not begin until the 60-feet stage is reached, otherwise the diver will be in danger of oxygen poisoning through breathing the gas at too high a pressure.

When the diver first begins to breathe in and out of the bag his body is discharging the nitrogen which it absorbed while he was on the bottom, and if steps were not taken to prevent it, the outpouring of nitrogen in his expirations would accumulate in the breathing bag, diluting the oxygen and thus reducing its efficacy. Accordingly, for the first eight minutes (when the discharge of nitrogen is greatest) he breathes with the two-way cock on the "Novus" apparatus in the position which allows the exhaled gas to pass direct to the atmosphere without entering the bags. This is known as "Diver breathing oxygen". It is, however, wasteful in oxygen, so that, after eight minutes when the outpouring of nitrogen is reduced, the cock is altered to the "recirculating" position. Even then it is necessary occasionally to empty the bags through the escape valve and flush through with pure oxygen from the cylinder in order to prevent an accumulation of nitrogen.

Procedure in Case of Failure of the Oxygen Supply. The stops from 60 feet onwards have been calculated on the assumption that the diver is breathing oxygen, but he may be prevented from doing so by some defect in the oxygen apparatus, by exhaustion of the oxygen cylinder, or because he himself is feeling unwell. In this case, he must breathe air from inside the "S.D.C." AND THE TIMES ORDERED IN THE TABLES MUST BE MULTIPLIED BY $2\frac{1}{2}$. If he is able to resume oxygen breathing later, the stages are again taken direct from the table.

For example: a diver is decompressing after a dive of 20 minutes at 290 feet. When he has been two minutes at his 30-feet stop, the oxygen cylinder requires to be changed as a leaky valve has caused it to run out prematurely. Over the telephone, the diver is told to breathe air, and the cylinder is changed, taking five minutes. The diver then resumes oxygen breathing; five minutes on air is equivalent to $5 \div 2\frac{1}{2} =$ two minutes on

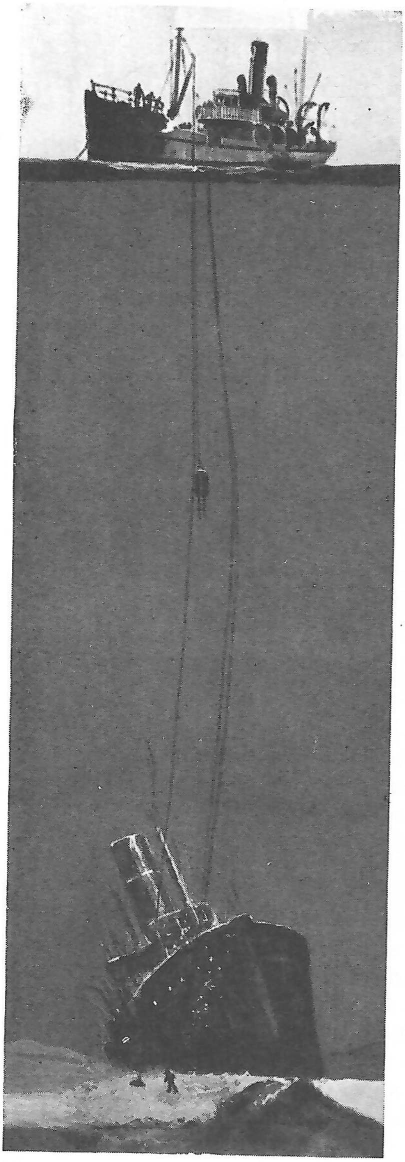


Fig. 125. Chamber lowered, ready for use, to the first stage in the diver's ascent

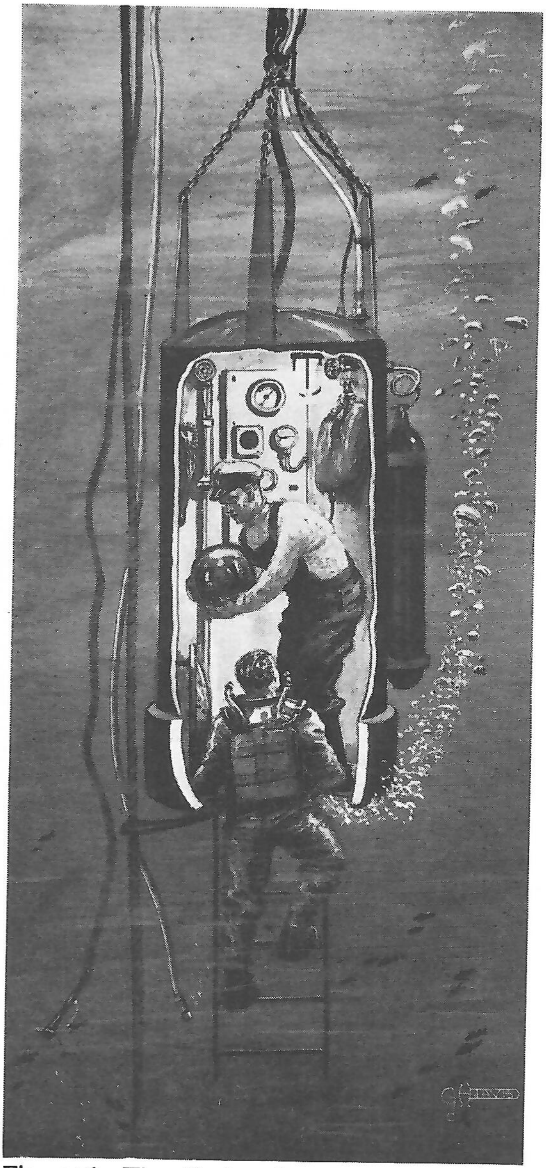


Fig. 126. The Davis submerged decompression chamber. Diver entering by lower door and attendant removing helmet

oxygen. He is therefore considered to have done only four minutes of the ten minutes prescribed by the tables for his 30-feet stop, and he must therefore remain six more minutes at 30 feet before breaking down to 20 feet. If, on the other hand, he has to stop oxygen breathing because of a serious defect in the "Novus" apparatus, the whole of the remaining stops must be done on air, and they will become as follows:

30 feet stop—$10-2=8\times2\frac{1}{2}=20$ minutes
20 feet stop—$16\times2\frac{1}{2}=40$ minutes
10 feet stop—$19\times2\frac{1}{2}=47\frac{1}{2}$ minutes

This example, incidentally, clearly demonstrates the very great saving of time effected by breathing oxygen, especially in the final stages of decompression.

Removing a Diver from the S.D.C. in Emergency. Occasions have occurred when, due to illness or to an accident to the chamber itself, it has been necessary to transfer the diver from the S.D.C. to the main recompression chamber before decompression is completed. In this case the following procedure is recommended:

1. Break down the S.D.C. pressure as rapidly as possible, open up and transfer the diver and attendant to the main chamber without delay.
2. Raise the pressure in the main chamber to the equivalent of that in the S.D.C. at the time of breaking down. Leave the diver at that pressure for five minutes, or, if he has more than five minutes to go at that stop, complete the stop as laid down.
3. Continue decompression in accordance with the tables.
4. If the diver has been removed from the S.D.C. through illness, it may not be possible to resume oxygen breathing after he has been transferred. In this case he must continue to breathe air, stops being multiplied by two-and-a-half, and the first stop in the chamber being a minimum of 12 minutes instead of five.

Prevention of CO_2 Accumulation in the S.D.C. It has been shown that even a very small percentage of carbon dioxide in the S.D.C. atmosphere may cause the diver to be unduly sensitive to oxygen poisoning when he comes to breathe oxygen under pressure. It is therefore of the utmost importance that, whenever the diver is breathing air in the S.D.C., the maximum ventilating air possible must be supplied all the time. The diver may be similarly affected if the "Novus" recirculating system is not functioning at its maximum efficiency. It is essential, therefore, that this apparatus should be serviced and prepared with care before the dive, a new CO_2 absorbent canister used, and no attempt made to use a canister longer than its recommended time.

Use of the S.D.C. in Very Deep Diving. In depths well below 300 feet, the stops must inevitably become very long and tedious. The following method has been found to rest the diver considerably, and avoids the danger of his breathing a foul atmosphere in the chamber before getting on to oxygen breathing. The chamber is lowered to the maximum depth from which the S.D.C. attendant can decompress within the diver's decompression stops, without using oxygen. S.D.C.'s used in very deep work are fitted so that both men can, if need be, breathe oxygen. By using a high altitude type of half-mask instead of a mouthpiece, and wiring the "inter-comm" microphone in parallel with the transreceiver in the chamber, communication with the surface can be maintained, but on the whole it is considered safer to have the attendant on air all the time. It must be remembered, however, that the attendant is also under pressure for a considerable time, and must, therefore, be decompressed as well as the diver.

On coming up, the diver will do perhaps one or two stops on the shot rope in the normal way, and is then called "up and on to the ladder". He climbs on to the S.D.C. ladder high enough to get the upper part of his body into the chamber, and then rests the canister assembly carried on his back, on the floor of the chamber. The attendant passes the safety-lanyard and releases the front weight but, otherwise, does not undress the diver any more, or remove his front glass. "Air for depth" is supplied to the diver, his exhaust air passing out of the outlet valve into the chamber and then out through the lower door. Stops are now carried out by raising the chamber on the crane wire 10 feet at a time, the diver, of course, coming up with it. On reaching the 60-feet stop, the S.D.C. attendant, who, in the meantime, has been loosening the corselet nuts and casting off the air-pipe and breast-rope lanyards, can now take off the front glass and proceed with the normal drill for getting the diver right into the chamber and putting him on oxygen. Thus the S.D.C. is used virtually as a stage for raising the diver, and saves him the fatigue of hanging on the shot rope. His hands are out of water and can be rubbed to restore circulation, and he is generally in a reasonably comfortable position.

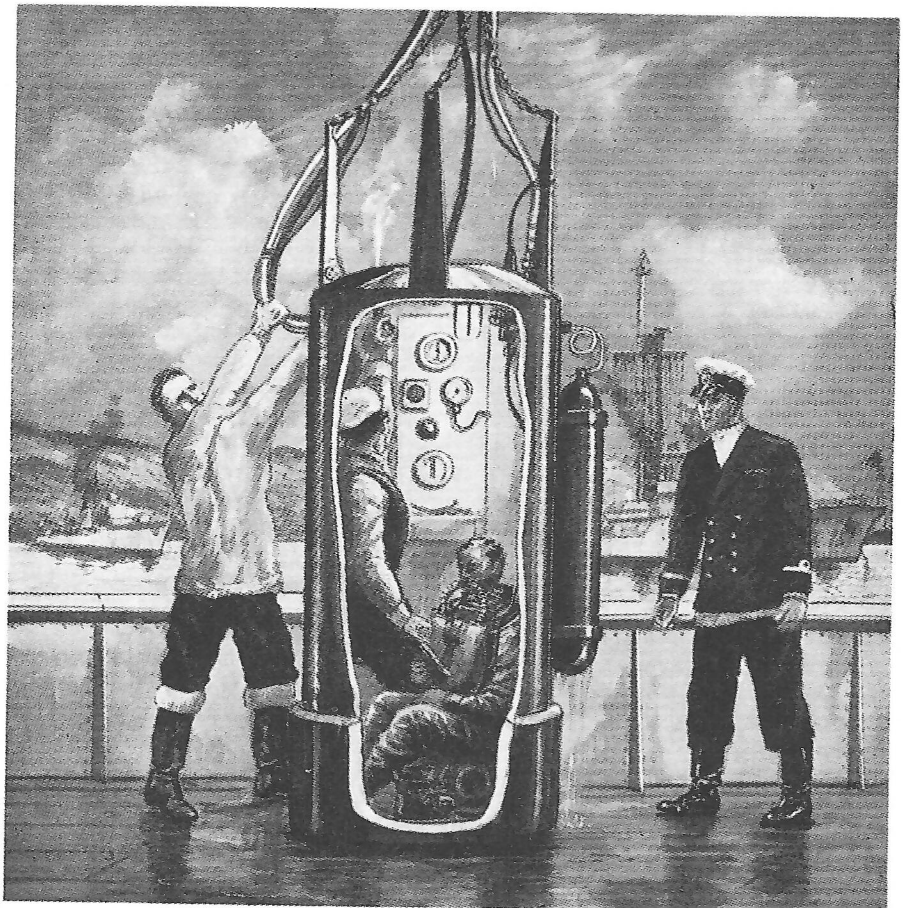


Fig. 127. The Davis submerged decompression chamber. The closed chamber on deck with diver breathing oxygen from "Novus" apparatus during decompression

THE DEEP DIVING DECOMPRESSION TABLES FOR USE WITH THE DAVIS SUBMERGED DECOMPRESSION CHAMBER (see pages 160 to 179)

These are arranged in a similar layout to the Haldane Tables (air only, to 204 feet), but cover depths to 300 feet at 10 feet intervals and include oxygen breathing during decompression. The table for the nearest 10 feet deeper than the diver's actual depth is always used, i.e. if the diver's depth is 282 feet, stops for 290 feet must be given.

If we turn up any depth, say 270 feet, it will be seen that the stages above 60 feet are divided from the rest by a double line, "air-breathing" stages being to the left, and "oxygen breathing" to the right, as oxygen breathing does not begin until the 60 feet stage is reached. Thus, if a diver left the surface at 6 o'clock, went down to 269 feet and left bottom at 6.15, his first stop would be at 100 feet, where he would remain for one minute, and after that he would have stages of one minute at 90 feet, two minutes at 80 feet, and two minutes at 70 feet; during all these stages he has to breathe air, which he may do on the shot rope under water in the usual way, or riding on the ladder of the S.D.C., as already described. In view of the danger of breathing CO_2-laden air before going on to oxygen breathing, the diver should never be allowed to do air stops inside the S.D.C. with his helmet off. The next stage of two minutes at 60 feet and all subsequent stages must be done inside the chamber, breathing oxygen. It follows, therefore, in this case, that the S.D.C. must be lowered to at least 60 feet to await the diver on his ascent, but if for any reason it was thought necessary to get him on the ladder earlier, it could be lowered to meet him at his first stop at 100 feet.

Of course, in shallower depths there may be no stops to be done as deep as 60 feet. If, for instance, the diver has been ten minutes at 160 feet, the S.D.C. need only be lowered to 40 feet, as this is the diver's first stage.

As in the Haldane Tables, a thick black line is drawn across the page under a certain time at each depth: this time being the longest that it is thought advisable for a dive to last. The total time, including decompression, amounts to about one-and-a-half hours, or less at greater depths (e.g. at 160 feet, 45 minutes on the bottom plus 52 minutes decompression = 97 minutes; at 260 feet, 20 minutes on the bottom plus 49 minutes decompression = 69 minutes). These limits were adopted by the British Admiralty as a reasonable working maximum, but the tables have actually been tested and found safe somewhat beyond these limits. It has not been possible to test on human divers whether the tables give complete safety if the limit of the black line is very much exceeded, and it will be noticed that at each depth the tables come to an end at that time which involves a decompression lasting about three-and-a-half to four hours.

While it would be possible to calculate the longer decompressions, no great reliance could be placed on the result, for there is insufficient evidence as to the reactions of the human body to such long exposures to high pressures. Further, unless arrangements can be made, such as are described later in this chapter, to transfer the diver to the Davis three-compartment main decompression chamber on board, the long time which it would be necessary to spend in the cramped quarters of the S.D.C. would be intolerable. The following rule has, therefore, been laid down to cover unexpectedly protracted dives:

"If a diver, from some unavoidable cause, such as getting foul, stays in deep water for a longer time than is allowed for in the tables, he should be given the longest decompression tabled for that depth, and be carefully watched. If symptoms of compressed air illness come on while he is still in the S.D.C. it should be used as a recompression chamber and the man treated as a patient, i.e. the pressure must be increased until the symptoms disappear and, afterwards, pressure must be reduced by the scale given on page 127, and if that proves too rapid, a slower scale must be used."

Practical experience has demonstrated the value of working to the "first stop with safety" in cases of emergency decompression. The "First Stop with Safety" ("F.S.W.S.") is accepted as half the absolute pressure of the maximum depth of the dive, i.e.:

$$\left(\frac{\text{Depth in feet} + 33}{2}\right) - 33 = \text{DEPTH in feet for "First Stop with Safety".}$$

For example, if a man has dived to 283 feet, his

$$\text{"F.S.W.S."} = \left(\frac{283 + 33}{2}\right) - 33 = 125 \text{ feet}$$

This should be calculated as soon as a diver reaches the bottom and his actual depth is known. A diver may sometimes become temporarily foul of his own gear, or the shot rope, light cable or other gear which is being tended from the ship. In this case, it is possible to man the breast-rope or shot rope with as many hands as possible and haul the diver and all to the F.S.W.S. It is accepted that any depth below the F.S.W.S. is treated as time on the bottom, but at the F.S.W.S. or above it, the actual depth only counts for decompression. Thus, the danger of over-running the time on the bottom given in the Deep Tables is avoided, by clearing the diver at a shallower depth. Further, if the diver is unable to clear himself, the "stand-by" diver need only be sent to a depth within the scope of the ordinary tables and can subsequently be decompressed on the shot rope or by "surface decompression". It will be appreciated that if a diver becomes foul of wreckage or other fixed obstruction on the bottom, it may be necessary to send a "stand-by" diver to the maximum depth, and this will involve decompressing two divers simultaneously by the Deep Tables; a long and complicated business.

(Continued on page 144).

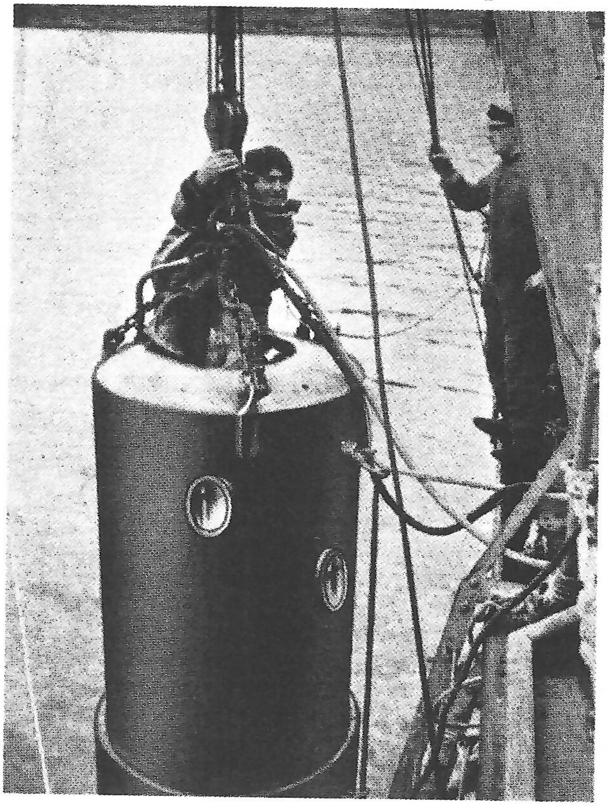


Fig. 128. R. H. Davis's submersible decompression chamber; diver emerging after decompressing

The search for, and recovery of, an object at a depth of 286 feet in bad tidal conditions was recently carried out very successfully. With two divers and two "Novus" sets for oxygen breathing during decompression, the chamber was lowered to visibility distance from the sea-bed, which was fairly flat. The ship was then warped as necessary to carry out the search.

The D.S.D.C. men had the bight of a lamp-lead, and a line with a grapnel in through the bottom door (these were tended from the surface), so that the D.S.D.C. men could manipulate them as required, and then, when the duration of the dive was up, they released them, and the D.S.D.C. was hoisted to the surface and inboard, the lower door having been closed when they reached their first stop. Decompression was then carried out in the normal way.

The advantages were (1) that the Davis Submersible Decompression Chamber could be operated in far stronger tidal conditions than a diver could hope to work in, (2) the maximum permitted time for a dive could be worked, and (3) there was no delay in getting the divers up at the end.

The area searched was much greater than would have been the case had a dress diver been used, and it was possible either to recover any small objects by lowering the D.S.D.C. to enable the operators to reach out through the door and pick them up, or to recover bigger objects by bending the surface line on to them, and having them hauled up from the ship. To make this method even more effective, the D.S.D.C. can be fitted with side glasses, as in the photo, in order to give better side vision, somewhat like the lenses of an observation chamber.

(Continued from page 142).

An important point in normal decompression is that the time spent between the diver entering the chamber and the lower door being closed is considered as "dead time" and does not count towards decompression. Normally, the duration of a stop on the shot rope is counted from the time he leaves the previous stop, so that if a diver has to do five minutes at 60 feet, the five minutes would include the time taken to come up from 70 feet to 60 feet. With the S.D.C. at 60 feet, however, the diver would be called "up and into the chamber" at the end of his 70-feet stop, and some eight minutes or more may elapse while he gets into the chamber, the attendant gets his helmet off, disconnects air-pipe and breast-rope, and closes the lower door. The time for the 60-feet stop in this case does not start until the attendant reports "Diver in the chamber, lower door closed".

Air Supply to Deep Divers. An adequate air supply is an absolute essential to deep divers. All through the deep-diving routine the only real danger to the diver lies in the possible accumulation of carbon-dioxide gas at any point in the system.

Carbon dioxide has a direct effect upon the diver's susceptibility to oxygen poisoning, and upon his mental efficiency and ability to resist the adverse effects of "nitrogen narcosis". These two effects are discussed in Chapter 1 and in a later paragraph in this chapter, but it may be said that both can be kept from becoming serious menaces to the diver by adequate ventilation of the diver's dress and of the S.D.C.

On page 38 will be found a table giving the minimum air supply for divers in ordinary dress in depths up to 321 feet, where it will be seen that he needs at least 16·2 cubic feet of free air per minute, and in actual practice would need considerably more in order to do any useful work. Such large volumes of air are, of course, beyond the capacity of hand pumps and, owing to the pressures involved and the large amount of air which must be stored against a possible failure of the compressor, the ordinary low-pressure power supplied air systems are also inadequate.

A diver wearing Siebe, Gorman & Co.'s "Injector" dress, described later, uses only a small volume of air when on the bottom, although that which he does use must be supplied at an even higher pressure than that required in the normal dress. A full supply of air must, however, always be available to assist his descent and ascent, or in case of an accident to the injector system.

Deep-diving operations must, therefore, be carried out with high-pressure installations, working at 2,000 to 4,000 lb. per square inch and supplying air to the divers through reducing valves and a control valve panel. The control valves are carefully designed and calibrated, so that, not only do the panel operators know how much the diver is receiving at any given time, but also that the rate of increase and decrease is smooth and regular. A sudden change in the volume of air consequent upon a small movement of a badly-designed valve may be embarrassing or even dangerous to the diver.

Filtering and Cleaning the Air. The air supplies must be carefully cleaned and filtered to remove possible impurities. Carbon-dioxide, carbon-monoxide and hydrocarbon vapours are harmful to the diver's health, while moisture and dirt from air-pipes will cause damage and freezing of reducing valves or of the diver's dress. Moist air may also lead to unnecessary "fogging" of the diver's windows. Most impurities can be avoided by the use of properly designed and carefully maintained compressors, but moisture, hydro-carbons and particles of dirt have to be filtered out.

Air System in a Naval Deep Diving Vessel. The following very brief description of the arrangements for air supply as fitted in the latest deep diving vessel in the British Navy, will serve as a guide to the requirements.

Air is supplied at 4,000 lb. per square inch from two electrically-driven compressors into a high pressure ring running through the ship. Reserve air is stored in a large bank of high-pressure steel reservoirs, and four similar reservoirs in the diving flat provide the "ready use" air supply. From the high pressure system the air passes through driers and filters to duplicated reducing valves, which break down the air by stages till the pressure is reduced to that required for diving. The low pressure air is again filtered before it is led to the control panel and thence to the divers through the control valves. Air to the S.D.C. is supplied from a spare diver's panel and to the main recompression chamber through a 1,500 lb. per square inch system supplying the chamber control panel.

The various reducing valves, receivers and reservoirs are all arranged so that they can be isolated or cross-connected in the event of a defect in any one of them. The high-pressure compressors have a charging rate of 80 cubic feet free air per minute each, and the reserve of high-pressure air available totals 24,000 cubic feet of free air.

Such an installation is, of course, intended for diving operations on a big scale, but a system designed on a similar principle is necessary for deep work of any sort.

Equipment—Helmet and Dress. The dress used for deep diving is Siebe, Gorman & Co.'s Injector type, which is fully described below. This dress is a development of the company's standard (i.e. the Davis six-bolt) diving dress, and is specially designed to reduce the carbon-dioxide content of the air breathed by the diver to the minimum. As explained on page 36, the effect of carbon-dioxide varies with the absolute pressure, and when it is realized that the absolute pressure at 300 feet is ten times that at the surface, it will be seen that almost total elimination of this gas at such a depth is absolutely essential to the diver's welfare and safety. The Injector dress is designed so that the diver can either be supplied with sufficient air to sweep the carbon-dioxide out of his helmet, as in the standard dress, or by operation of his by-pass valve he can be supplied with air recirculating through a carbon-dioxide absorbent canister.

This dress has been used successfully in many record deep dives, both on air and oxy-helium mixtures. The only modification necessary to use it with oxy-helium is the changing of the injector jet to allow for the change in density of the mixtures.

Canister and injector are enclosed in a single unit worn on the back of the diver in place of the normal back-weight, and the by-pass valve is led forward on his belt, ready to his right hand.

When the injector system is in operation, only a small amount of air need be supplied from the surface, and this leads, not only to a considerable saving of air or gas supplies, but helps to minimize the danger of a diver "blowing-up" accidentally.

The deep-diving helmet is fitted with a special outlet valve designed to get rid of surplus air as quickly as possible when necessary. If a diver "blows-up" from a great depth, he may be in very real danger from acute "bends" or pulmonary embolisms, and it is therefore essential that he should be able to check immediately any tendency for his dress to over-inflate. The helmet is also fitted with a mouthpiece on a flexible pipe which connects directly into the absorbent canister, so that, if desired, the diver can exhale directly into the CO_2 absorbent.

Amplified telephones, such as Siebe, Gorman & Co.'s thermionic system, are now considered to be essential for deep-diving operations. A small loudspeaker is fitted in the helmet which acts as both transmitter and receiver, and speech is amplified and controlled in volume by the surface attendants. The S.D.C. is fitted with a similar system, and it is possible to switch over so that diver and S.D.C. attendant can communicate with each other through the telephone system. Extra long telephone breast-ropes are necessary for deep diving, and in very deep water a much thinner type of cable than the usual braided type is sometimes used in order to minimize the tide effect on the diver's gear.

The Injector dress is more complicated than the ordinary type; it is bulkier, and for this reason might, in certain circumstances, be found less convenient when working about wreckage. It is also heavier and can be exhausting to the diver when getting on and off the ladder. The fact that, when the injector is open, the back pressure* registers on the gauge, which does not therefore show the diver's true depth, makes it necessary that the diver and panel operators should be thoroughly practised in the use of apparatus of this type.

* 30 lb. per square inch

Injector Canister (Fig. 129). This, as previously stated, contains a cartridge filled with CO_2 absorbent, and, being suitably weighted, is worn in lieu of a back-weight. Its primary function is to keep the air in the diver's helmet circulating, and as free as possible from CO_2. The canister is constructed of metal, with a detachable lid secured by strongbacks, and, besides containing the CO_2 absorbent cartridge, is fitted with an injector, short lengths of air-pipe (B1, B2, B3 and B4), and an injector by-pass valve. The weight of the canister is supported by metal hooks that fit over the two rear studs of the corselet. To prevent it swinging, the canister is secured round the diver's waist by means of a leather harness; this also brings the injector by-pass valve to a position convenient for operating, near the diver's right hand.

The CO_2 absorbent container is secured to the lid of the canister by two connections, through one of which there is direct connection to the helmet, the other being blank. The container is filled from the bottom and, after filling, the absorbent is kept in place by a sliding perforated plate, covered with copper gauze. The plate is held firmly in place by a strong locking-spring which serves to hold the plate always up against the absorbent granules. Thus any movement or "channelling" of the chemical is effectually prevented. Most careful routines for filling, testing and maintaining these canisters have been laid down, and must always be obeyed.

The Deep Diving Helmet (Fig. 129) is slightly larger than the ordinary helmet; it has connections for two air-pipes, as well as an improved type outlet valve. (These air-pipe connections are not fitted with non-return valves.) Air enters the helmet through the connection (B3), and is guided over the front glass by a rubber air chute. A mouthpiece, fitted with non-return valves enabling the diver to inhale air from the helmet and to exhale through the CO_2 absorbent cartridge, is attached to the other connection (B4). Excess air cock and telephone arrangements are similar to those in the ordinary helmet.

Action of the Injector (Fig. 129). Air from the deep diving control panel passes down the diver's air-pipe to the injector by-pass valve; from here air can pass in two directions, either through the injector via pipe (B1), or directly to the helmet via pipe (B2). In the former case the injector is termed "open", and in the latter "closed". When the injector is closed, air enters the helmet via pipe (B2) and leaves via the outlet valve, thus corresponding to a normal air dive. If the injector is open, air passes through the pipe (B1) to the injector, and via the very narrow nozzle to the helmet.

The action of this is to cause a partial vacuum or suction at the injector gap, and to create a depression in the space between the outer canister and the inner container. Air is thus drawn from the helmet, via connection B4, down through the absorbent and, passing through the perforated bottom of the container, returns to the gap in the injector. Thus, having the CO_2 absorbed, the air joins up with the surface supply and re-enters the helmet. This air cycle can be partly obtained with the injector not working, by the diver exhaling through the mouthpiece. This must always be carried out during the descent to keep the helmet clear of CO_2 until bottom is reached and the injector can be opened.

When the injector is in use a back pressure of 30 lbs. per square inch is built up, due to the construction of the nozzle; thus the diver's gauge will show a depth of about 68 feet in excess of his true depth. At the same time a greatly reduced volume of air is being supplied to the diver. A true depth reading of the diver, then, can only be taken when the injector is closed. It has been proved in practice that, with the injector functioning, the air in the helmet is maintained at a high standard of freshness.

Inspection of Fig. 129 will show that air from the surface *can* pass to the injector, whether the injector is "open" or "closed". With the injector closed, however, air takes the easier passage to the helmet via pipes (B2) and (B3), instead of forcing a way through the injector. With the injector open, this easier passage is blanked off, and air must enter the helmet via pipe (B1) and the injector. To prevent any misunderstanding of the terms "open" and "closed", it must be realized that, although the operation is carried out at the by-pass valve, the order refers to the injector itself.

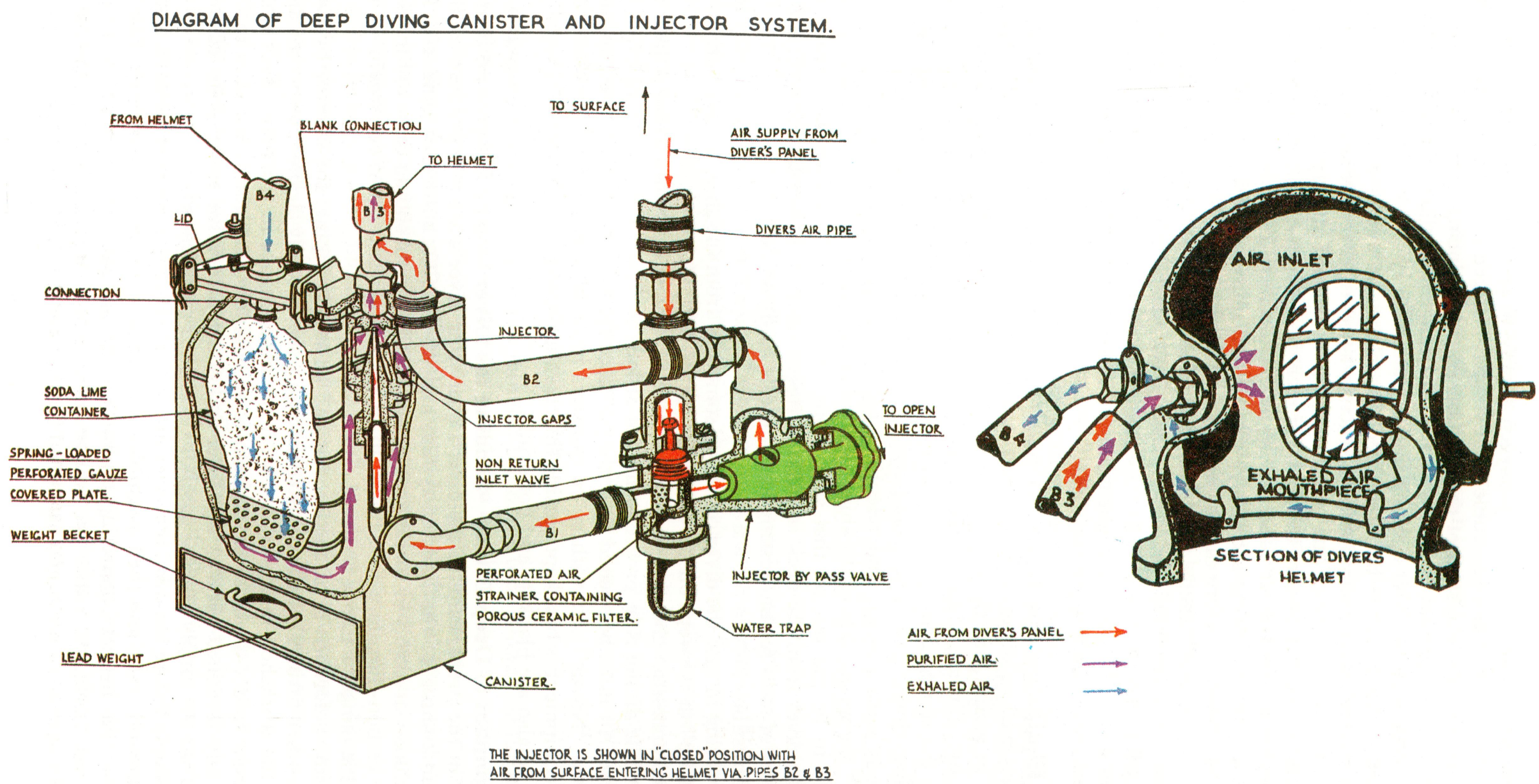


Fig. 129
Siebe, Gorman's air purifying arrangement showing action of the injector

Equipment of the S.D.C. The oxygen supply to the S.D.C. is carried on the outside of the chamber in a 100 cubic feet cylinder, charged to 120 atmospheres. The oxygen is led through the shell of the chamber to two reducing valves inside, which supply the "Novus" oxygen breathing sets. This arrangement allows the cylinder to be renewed if necessary, without opening up the chamber.

A lanyard is fitted outside the upper door for taking the weight while the clips are hove up or slacked off, and another lanyard acts as a preventer for the ladder. These are in addition to the bowsing-in line and diver's safety lanyard already mentioned.

The permanent equipment of the chamber includes a depth-gauge, oxygen pressure gauge, telephone "transceiver" and call-up push and internal illumination.

In addition, the following are always carried and must be prepared and fitted in place by the attendant before the chamber is sent down:

One or two "Novus" sets for the diver during decompression, and for the attendant, should this be considered necessary. One Davis Submerged Escape Apparatus (D.S.E.A.) fully charged and ready for emergency use by the attendant in case of an accident to the S.D.C., a watertight torch for emergency lighting, and spanners and tools necessary for undressing the diver.

Other Equipment for Deep Diving. It is always essential to be prepared for emergencies well in advance as, in the event of an accident to a diver in deep water, any delay in giving him the correct treatment may be extremely serious, if not fatal. A "stand-by" diver is always dressed at the same time as the deep diver himself, usually in the standard suit, as his gear can be got ready more quickly in emergency than the deep diving gear. The "stand-by" diver is dressed except for his helmet which is laid ready with air-pipe and telephone connected up. In case the diver should "blow up" the wrong side of the ship, a second ladder and a "stand-by" shot rope are kept ready to be put out on that side. Long boat-hooks are always kept ready to grapple the diver from the deck, a tackle is rigged ready to hoist him inboard, and a complete set of tools for undressing him must be ready on deck.

A boat must be ready in the water, or, if there is a sea running, it must be ready for instant lowering in case the diver comes up some way from the ship, as may happen if he "blows up" or is swept off his shot rope by the tide.

The recompression chamber must, of course, always be ready to receive a diver at all times while diving is in progress, and for at least 24 hours after the completion of the last dive. Air must be opened up to the panel, oxygen supplies fully topped up, and at least two "Novus" sets with spare canisters must be ready inside the chamber. First-aid equipment is best kept outside the chamber, ready to be "locked through" if required; so also are blankets and hot drinks.

Management of Deep Diving—Sending the Diver Down. The greatest care is necessary in the preparation of the diver's gear. The diver's life is dependent on the correct functioning of the injector system and of the CO_2 absorbent canisters. If, through clumsy assembly or careless maintenance, the system should cease to function correctly, carbon-dioxide would build up in the helmet and the diver would be in considerable danger without warning.

Some time before the dive, the injector and its supply piping, the injector by-pass valve and other fittings on the canister assembly are carefully cleaned, inspected and tested in the workshop in accordance with the maintenance instructions. This work must be done under the close supervision of an engineer, and not be left even to the divers or any unskilled person. The filter and non-return valve at the point of connection of the air supply are also carefully examined and cleaned.

Immediately before the dive, the diver himself charges his absorbent canister, again with the greatest care, and then assembles and closes up the whole apparatus. Blanks are fitted to the helmet connecting pipes, and the air supply is connected up. A pressure not exceeding 2 lbs. per square inch is now applied and the apparatus immersed in a bath of water and examined for the slightest leak. The assembly should then be connected to a test-board which is arranged to show the volume of air or gas passing through the injector and that being circulated through the helmet.

The S.D.C. is prepared, checked, manned and lowered to the correct depth as described on page 137.

While this is going on, the diver and "stand-by" diver are being dressed. Before the diver's front glass is put on, his air supply is tested, both with the injector open and shut. The telephone communications and the "stand-by" diver's air and telephone are also tested.

As soon as the S.D.C. is on its mark, the diver can be got into the water and sent down. He takes up the mouthpiece in his helmet and puts on the nose-clip, the front glass is screwed home and he is hauled on to the shot rope. Before leaving the surface, his dress should be inflated just below the water and his whole equipment inspected for leaks. Any leaks found must be made good before he goes down.

It is important that he should use his mouthpiece continuously from the time his front glass is put on until he arrives at bottom, when he may drop it. This ensures a "CO_2 free" helmet at the time the injector starts to function, and, in order to help him retain the mouthpiece, no reports from the diver are called for during the descent, nor is he allowed to talk before reaching the bottom, except in emergency.

No time is wasted on the descent, as the all-too-short time allowed on the bottom counts from the time he leaves the surface. Most deep divers can go down at 60 to 100 feet per minute, but divers should be encouraged to go down at their own best speed, and not to try to beat someone else. A diver who goes down too fast will "over-run his air", in which case he may not only get an uncomfortable squeeze, but may feel dizzy and ill. Should a diver feel unwell on the descent, he should be checked at once, and, if necessary, ordered to "open injector". This will clear his helmet. When he feels better, the injector can be closed again and the descent continued.

Diver on the Bottom. When the diver arrives on the bottom, he drops his mouth-piece and reports over the telephone: "On the bottom". The surface then orders him to "open injector", at the same time throttling back on the air supply. The opening of the injector is indicated on the surface by the diver's report, "injector open", by the change in the noise of the air-flow on the telephone, and by the creeping upwards of the depth gauge needle. A special "cursor" is fitted on the depth gauge which can be adjusted to the required back pressure of the injector. When the gauge needle has risen the required amount, the panel attendant adjusts the regulating valve to keep the needle steady at that pressure.

The diver may now be sent about his work.

Bringing the Diver Up. A few minutes before the time allowed on the bottom by the tables is due to expire, the diver is called into his shot. The time allowed for this must depend on how far away he is thought to be and the nature of the bottom. It must be remembered that the going is usually pretty heavy at deep depths, and if the diver takes longer than anticipated he may get into another and much longer series of decompression stops.

When he has reported himself "into his shot", the diver is ordered to "close injector" and the air supply is correspondingly increased. The diver must work his outlet valve with care, and watch that he does not get blown up by the extra inrush of air into his helmet and dress.

With the injector closed and normal air supply restored, the diver can now be brought up through his stops to the S.D.C. as has already been described.

In very deep water, and in cases where, as in oxy-helium diving, the rate of ascent has to be controlled at a steady speed, it is usual to haul the diver up rather than let him come up on his own. Coming up the shot rope slowly, by the usual method of working the outlet valve to give a buoyancy lift, can be very fatiguing for the diver, especially as air must be continuously cut back to avoid over-inflating him. This may lead again to CO_2 formation in the helmet, while the manual effort necessary to keep moving on

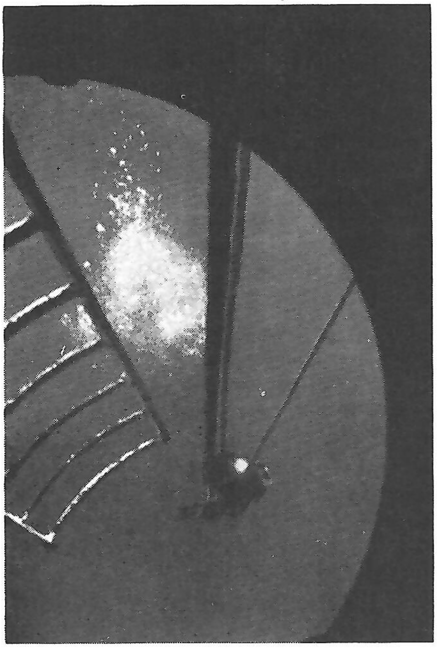


Fig. 130
The diver on the shot rope at his 130 feet stage

Photographs taken from inside a Davis Submerged Decompression Chamber looking through the open lower hatch during a diver's ascent from a deep dive. The chamber is 90 feet below the surface in the Mediterranean Sea and the lighting is natural

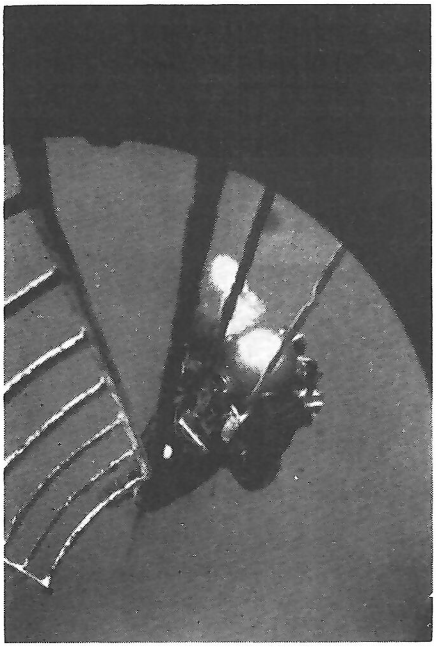


Fig. 131
The diver arriving at his 100 feet stage

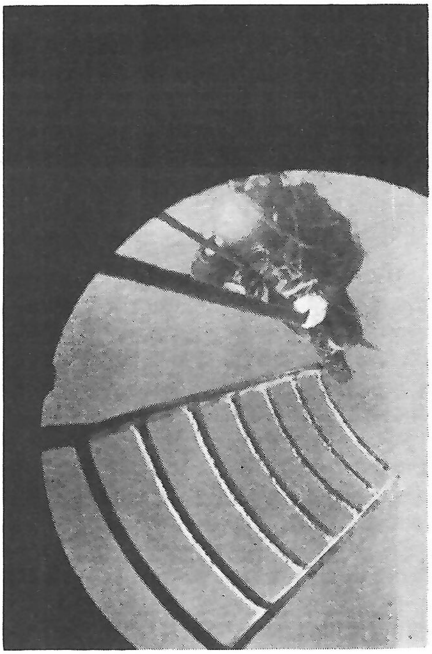


Fig. 132
The diver about to get on to the ladder of the chamber

the shot rope has been known to give rise to "bends" in the diver's arms. If the diver is hauled up, he opens his outlet valve wide and makes no attempt to lighten himself. He simply lies back on the breast-rope, and only keeps himself close in to the shot rope. This allows a much greater flow of air to be maintained from the surface, and therefore effects more efficient ventilation. The breast-rope is led over a sheave on the upper deck, and at least four men must man it and maintain a steady pull. If it is hauled in jerks the diver may be shaken off the shot rope. A timekeeper checks the rate of ascent and adjusts it as necessary.

It would be an advantage for the breast-rope to be led to a small winch which would ensure a steady controlled haul, and would save man-power.

Use of Two S.D.C.'s. When using only a single S.D.C. some delay may be caused by the necessity of waiting for one diver to come out of the chamber before a second man can be sent down. To obviate this, two S.D.C.'s have been worked alternately which enabled diving to proceed continuously throughout the whole period available between tides. A special derrick rig is necessary for this.

Transferring Divers to the Main Chamber. On page 159 is illustrated the Davis method of transferring divers from the S.D.C. to a three-compartment main chamber whilst still under pressure. This method also clears the S.D.C. ready for another diver, and is also useful in long decompressions when the cramped conditions in the S.D.C. become very uncomfortable. In the main chamber the diver can be in reasonable comfort, can get right out of his wet dress, and can start using a new dry oxygen apparatus. In oxy-helium diving, where very long decompressions on oxygen are involved, this method is considered essential.

Precautions after Diving. Decompression illness may occur after the dive has been completed. The most dangerous period is for about four hours after surfacing, but cases have occurred up to 24 hours later. The treatment has already been described in Chapter 6, but the following precautions are rigidly enforced in the British Navy, and any diving organization would be well advised to adopt them.

No diver who has been decompressed by the Deep Tables is allowed to leave the ship until four hours after he has finally surfaced. If he then goes ashore, he must be accompanied by another diver or by a qualified person who knows what to do should the diver get a "bend." Arrangements must be made for his instant return to the ship in case of need for recompression treatment.

The recompression chamber must be kept ready for instant use, with air pressure available, for at least 24 hours after the last dive has been completed. The watch aboard should contain at least one, preferably two qualified divers who have not been deep that day; one to act as diver's attendant in the chamber, the other to operate the control panel.

Similar arrangements must be made for medical assistance to be at immediate call until all divers may be considered "clear".

No diver who has been to any depth exceeding 180 feet should be allowed to dive again for 24 hours, except in cases of great emergency.

*Diving on Oxy-Helium with the S.D.C. and the Three-Compartment Main Chamber**

THE NEED FOR USING SYNTHETIC MIXTURES FOR VERY DEEP DIVES

So far, we have dealt mainly with deep diving on ordinary compressed air. Such a method can be used up to 300 feet (50 fathoms), but maximum efficiency should not be expected from the divers over 240 feet (40 fathoms). As has already been briefly explained in Chapter 1, special mixtures of gases such as oxy-helium and oxy-hydrogen are necessary if 300 feet is to be appreciably exceeded, and they are, in fact, desirable at any depth over 240 feet.

Nitrogen Narcosis. The main reason for using such mixtures is the phenomenon known as "Nitrogen Narcosis" (see Chapter 1). The effect of this varies somewhat with the individual diver concerned, but practically all men are affected to the extent of slowing their reactions and causing a noticeable loss of mental efficiency. The border-line depth for the average man is 240 feet, below which depth no man can be expected to behave quite normally or as efficiently as usual. Many experienced deep divers will deny that they have ever been affected in this way, but it must be remembered that, as with alcoholism, lack of oxygen, or other cause of temporary mental impairment, the man concerned is often the last to be aware of anything wrong. For many years, too, it has been wrongly assumed that a man at depths between 40 and 50 fathoms must inevitably be inefficient and somewhat slow in thought and deed, so that those on the surface have only remarked upon the more exceptional cases.

Some men may be quite seriously affected even to becoming confused and partially incapable. This condition usually manifests itself in the first dive to any great depth, and can be detected on the telephones. If, after a few dives, the man shows no improvement he must be considered as unfit for deep diving work.

Nitrogen under considerable pressure also causes a feeling of general malaise, producing an unpleasant throbbing sensation in the head, and a general inability to concentrate or to do anything definite.

Experiments show that this effect depends upon the weight of the inert gas, which in the case of nitrogen is fairly high. (See Gas Data, Chapter 16.) When subjects breathed oxygen mixed with argon, one of the heaviest gases known, these symptoms were felt severely at 100 feet or so, but, when very light gases such as helium or hydrogen are substituted for the nitrogen, the symptoms are absent to 500 feet or more.†

Thus, to obtain efficient results from the divers at over 240 feet, the use of oxy-helium mixtures has been developed into a practical possibility and has enabled the maximum depth of flexible-suited divers to be extended to 90 fathoms (540 feet).

Oxygen Poisoning. Regardless of the effect of the inert gas, compressed air cannot be used much in excess of 300 feet because of the danger of poisoning from the oxygen content. It has already been explained that diving on pure oxygen cannot be considered safe at any depth in excess of 33 feet of sea water, or at an absolute pressure exceeding two atmospheres. At 300 feet, the absolute pressure of the air has increased to ten atmospheres, and, as oxygen forms one-fifth of atmospheric air, it will be seen that the partial pressure of the oxygen at this depth is approaching the danger limit of two atmospheres, and that any appreciable increase in depth will subject the diver to the dangers of oxygen poisoning if he continues to breathe compressed air. Cases of oxygen poisoning on the sea-bed have actually occurred among deep divers.

It is therefore essential that we should use artificial gas mixtures with a reduced oxygen content for deep diving below 50 fathoms.

* The United States Navy tables and extracts from their instructions for oxy-helium diving will be found in Chapter 8. As explained in the present chapter, the Royal Navy procedure when diving with this mixture, differs in certain respects from that of the United States Navy.

† As stated in the footnote on page 15 some physiologists hold the view that the narcosis is due to excess of CO_2 in the body, basing their opinion on the fact that helium, the lighter gas, allows greater diffusion of the CO_2 from the lungs, while nitrogen obstructs it.

Carbon-Dioxide—Its Effect upon Deep Diving. The effects of CO_2 upon a diver under pressure have already been explained in Chapter 2, from which it will be understood that, in deep diving, the permissible CO_2 content of the helmet gases becomes very small. Moreover, as stated in Chapters 1 and 2, any excess of CO_2 increases the susceptibility of the diver to oxygen poisoning and nitrogen narcosis as well as aggravating the symptoms. For these reasons, removal of CO_2 from the helmet is still more important in deep than in shallow diving. The Siebe, Gorman injector dress is designed to achieve the necessary purity and can be relied upon to do so, if correctly used and maintained, but it is essential that the drill and testing described on page 148 should be conscientiously performed.

Method of Carrying Out Oxy-Helium Diving. The Siebe, Gorman injector dress is used in conjunction with the S.D.C., but the actual size of the injector nozzle has to be smaller than that used for air, owing to the much lower density of helium mixtures. The oxy-helium mixtures are made up in the diving ship (well in advance of the actual dives) in high pressure cylinders which are connected to a manifold to which is attached a special reducing system and control panel. The composition of the mixtures is decided upon so that the oxygen content is low enough to avoid oxygen poisoning, but at the same time the helium content must not be unnecessarily high, since it is the partial pressure of helium which controls the length of decompression. Each cylinder is analysed and its contents carefully recorded after mixing.

Helium is an exceptional conductor of heat, and, since he is surrounded by an envelope of helium inside his dress, the diver is liable to feel extremely cold when he has been under water for some time. To counteract this, the diver must wear a special undersuit heated by electric coils; the electric supply to this suit is controlled from the surface. While extra woollen clothing may be of some assistance, experience has shown that electrically-heated underwear is the only practical method which does not cause undue discomfort and sweating when dressing or at the beginning of the dive.

When using mixtures with an oxygen content of less than 17 per cent it is necessary to start the dive on air, so that the diver does not suffer from anoxia when getting on to the shot rope. The diver is checked on his way down when abreast the S.D.C. and the change-over to oxy-helium mixtures is effected at this stage.

Fig. 133 shows the arrangement of a typical oxy-helium manifold and control panel.

Decompression in Oxy-Helium Diving. It was at first thought that the use of helium instead of nitrogen might well reduce the length of the decompression time, but experience has shown that this is not so, although the actual durations of the stops are quite different from those used for equivalent depths on air.

It has been shown that, while some tissues do not absorb as much helium as they do nitrogen in a given time at a given pressure, others may absorb many times more helium than nitrogen, so that the whole staging process is different.

Also, as helium is a highly diffusible gas, it starts being given off by the bloodstream in considerable quantities somewhat earlier in the ascent than does nitrogen, so that the first stop in helium diving is always much deeper than for an equivalent dive on air. In fact, after a dive to 500 feet the first stop is at 240 feet. During this deep stop, and during some of the subsequent stops, the slower-saturating tissues are still saturating, so that the shallower stops towards the end of the decompression must be correspondingly longer, in order to give the body time to get rid of the extra helium taken up during the deep stops, in addition to that absorbed while on the bottom.

Oxy-helium decompression takes into account the amount of helium given off during the actual ascent, and a table is given showing the rate of ascent from any given depth. This rate of ascent must be strictly adhered to and carefully timed.

Since the proportion of oxygen and helium in the mixture is variable, the oxy-helium decompression tables are given according to the partial pressure of helium (see Chapter 8). Table II, therefore, gives the equivalent partial pressure in feet depth according to the actual depth and the percentage of oxygen in the mixture.

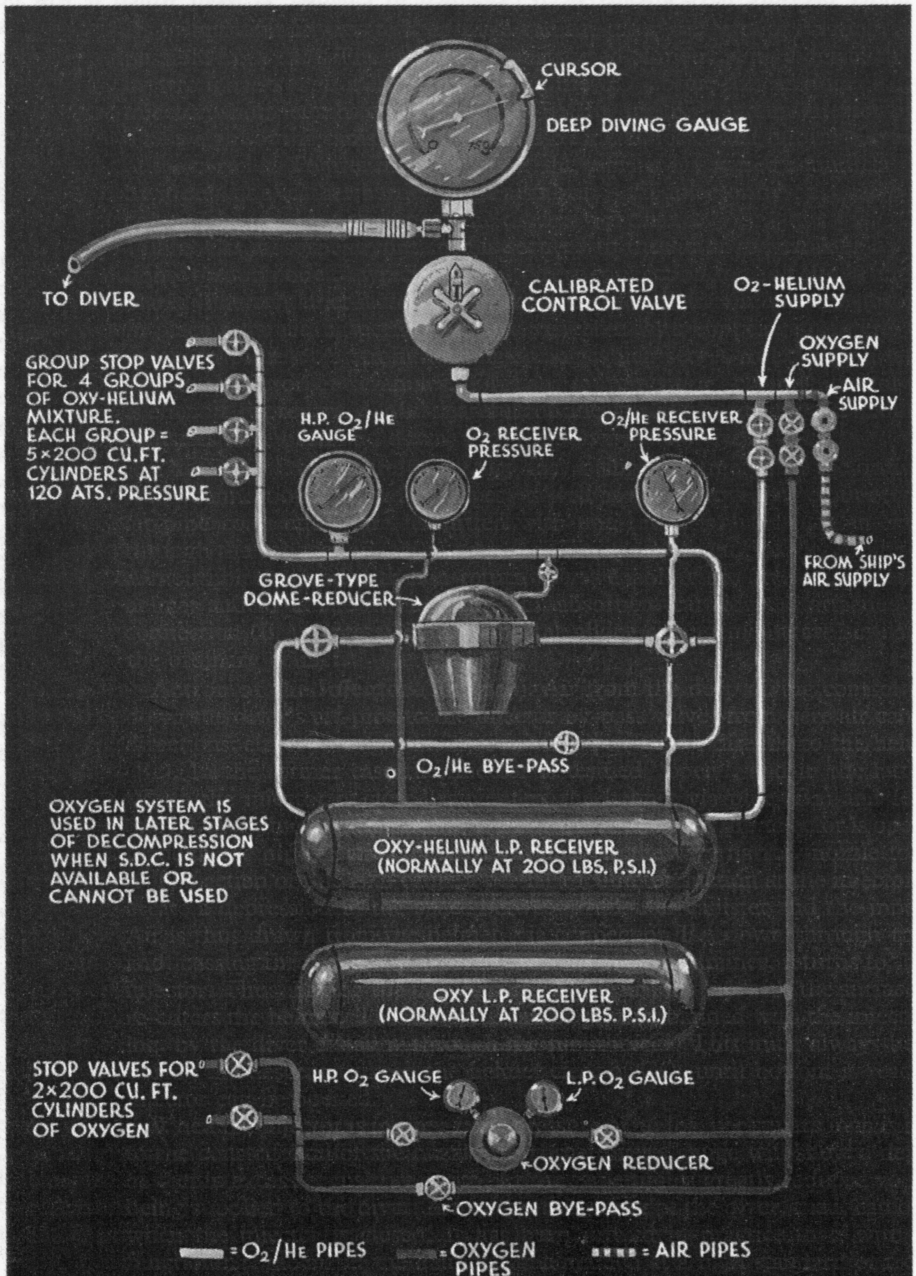


Fig. 133

Diagram of typical layout of oxy-helium supply system and control panel

Having looked up the rate of ascent from the true depth, from Table I, and found out the partial pressure from Table II, the main Decompression Table III can be entered and the decompression stops obtained.

Management of Oxy-Helium Diving. The requisite quantity of mixture having been prepared and the manifold loaded, air pressure and mixture pressure must be opened up to the control panel. The S.D.C. is prepared, hoisted out and sent down as usual, and the diver and "stand-by" diver dressed as for air diving.

Before the front glass is screwed on, oxy-helium is opened up to the diver's air-hose and his injector opened and tested on oxy-helium mixture. The test being completed, the mixture is shut off, and *air* supplied to the diver.

The front glass is screwed home and the diver gets under water on the ladder and is tested for leaks, as before, and then sent down the shot rope. At the level of the S.D.C. the diver is checked, air is shut off and oxy-helium mixture opened up. It will take a little time to get rid of the air in the coil of air-hose on deck, but the arrival of oxy-helium in quantity in the diver's helmet is clearly indicated by the change in tone of his voice. Helium has a strange effect upon the vocal chords, and the diver's voice is transmitted in a peculiarly distorted quality. If, after changing over to "mixture", the diver is told to count or talk out of the corner of his mouth, past the mouthpiece, his voice will be heard to change, and it may then be considered safe to send him down.

He should carry on down as fast as possible, with no further delays, using his mouthpiece all the way and reporting when "on the bottom". Some divers report that it is difficult to get down the last 100 feet or so, when in depths of 400 feet and over. This is probably due to an increase in buoyancy of the dress and air-hose due to their helium content, and an extra 7 lbs. or so of lead on the diver's weights has been found helpful.

Diver on the Bottom. On the bottom the oxy-helium diver's procedure is exactly the same as that of the air diver. On the order from the surface, he opens the injector before proceeding to work and shuts it again before starting his ascent.

The injector makes very little noise when opened, as compared to air diving, and those on the surface must listen carefully to make sure that it is working. High quality thermionic telephones are in fact absolutely essential, especially in view of the distortion of the diver's voice.

The panel attendant must watch his gauges with very great care, as the light density gas (helium) necessitates only the slightest "crack" of the control valve to be open when the injector is open, so that the attendant has very little to "play with" for adjustment purposes.

Bringing the Diver Up. The diver's ascent from the great depths possible with oxy-helium mixtures is a matter of great importance and must always be conducted with scrupulous care. While there is no reason to believe that there is likely to be any greater incidence of "bends" when oxy-helium mixtures are used, there is evidence that a "bend" caused by a helium bubble may be extremely stubborn and difficult to get rid of.

The diver is called "into his shot" in the usual way, and his injector closed by order from the surface. He is then hauled up by the surface attendants, as has been described, his outlet valve being wide open and as great a supply of mixture as possible being fed from the surface. This method of ascent must always be used in this type of diving.

On arrival at his first stop, it is advisable to open the injector again in order to economize in oxy-helium mixture, the consumption of which will be very heavy if the diver remains on "open circuit" at considerable depths. The injector should be closed before hoisting him to the next stop.

It is usually possible to arrange for the S.D.C. to be waiting at the second stop, and for the diver to be got on to the ladder to do the remainder of his stops with his head in the chamber and his front glass on, as has been described earlier in the chapter. This part of the decompression may be a matter of hours, and the utmost consideration of the diver's welfare is necessary. Again, the injector is opened to save consumption of mixture, and it is necessary that the diver be in such a position in the chamber that his injector by-pass is accessible. In oxy-helium diving this method has the additional advantage that all the time the diver's helmet is inside the chamber a certain amount of helium mixture is being discharged from his outlet valve into the chamber atmosphere. Thus, when his front glass is removed, he does not suffer the unpleasant direct change from breathing helium to breathing nitrogen.

British practice is to avoid undue exposure to oxygen under pressure during the decompression stages, and the United States Navy oxy-helium tables have been varied so that the diver never breathes oxygen for more than five minutes at the 60-feet stop. This stop is, therefore, a composite one on air and oxygen. When the chamber arrives at 60 feet, the S.D.C. attendant removes the front glass, canister, helmet and corselet and brings the diver into the chamber.

The S.D.C. panel operator doubles the air supply to the chamber during this period.

As soon as the diver is inside the chamber the S.D.C. attendant reports to the surface: "Ready to close lower door". The time is noted at the surface and is taken as the beginning of the stop on air at 60 feet. The time elapsed to this point since the chamber arrived at 60 feet is counted as "dead time", as in air diving.

At the appropriate time by the modified tables when the *air stop* has been completed, the surface orders: "Close lower door, diver breathe oxygen", and when the S.D.C. attendant reports: "Diver breathing oxygen", the 60-feet oxygen stop is considered to have started.

The remaining oxygen stops are completed as below.

Transferring the Diver to the Main Chamber. The final stages of oxy-helium decompression differ from the routine for air diving in that the process is finished off at one pressure instead of continuing to stage down to "surface" pressure as is normal with air diving. By the United States Navy tables, the whole of the oxygen decompression is finished off at the uniform pressure equivalent to 50 feet, but British authorities prefer to stage down to 30 feet and then finish off at that pressure.

At whatever pressure the final stage is carried out, the time to be spent in the S.D.C. when coming up from very deep dives is bound to be considerable and somewhat exhausting to the diver, and arrangements must be made to transfer him to the main recompression chamber as soon as it is safe to do so.

If the diving ship is fitted with the Davis "Transfer Under Pressure" system, there are no problems involved, and the diver can be transferred to the main chamber at any time after going on to oxygen at 60 feet.

It is possible, however, that diving may have to be carried out without the advantage of this method, and the following procedure has been adopted successfully. Ten minutes after arriving at 30 feet, the S.D.C. is broken down to surface, and the diver and attendant are transferred to the main chamber, being immediately recompressed to 30 feet. The remainder of the 30-feet stop is then completed in the main chamber.

Apart from the relief of getting into the larger chamber, the divers benefit from the break in the monotonous decompression routine. There is no objection to the diver receiving refreshment such as hot tea before resuming oxygen breathing after the change-over, though, of course, no effervescent drinks are permitted. A completely new and dry "Novus" set should be used, and the diver can now rid himself of all wet clothes.

While the change-over need not be unduly rushed, the same interval of five minutes, as in surface decompression, should not be exceeded between "leaving 30 feet" in the S.D.C. and "arriving 30 feet" in the main chamber. No attempt must be made to change attendants at this point, as it must be remembered that, as the S.D.C. has in this case been much deeper than in air diving, the S.D.C. attendant is also being decompressed.

It may happen that the diver complains of a slight "bend" during his transfer. If pain is not completely relieved by the time the diver is back at 30 feet in the main chamber, the pressure should continue to be increased until relief is obtained and 15 lbs. per square inch should be added to the "relief" pressure. The diver must then be surfaced by the "Treatment Table" (see Table on page 127).

Limiting Factors in Oxy-Helium Diving. In the Royal Navy practical trials involving a number of men have been carried out at 60 fathoms, while individual dives have been made in 68, 75 and 90 fathoms.

At 400 feet and over, however, the length of decompression is too long for sustained diving under operational conditions, and there is some evidence that the decompression ratio and other theoretical factors may need to be revised for depths below 500 feet (83 fathoms).

A maximum of 500 feet is, therefore, advisable until further research is completed, while the normal maximum working depth should not exceed 400 feet.

Precautions after Oxy-Helium Diving. The same precautions should be taken after deep diving on oxy-helium mixtures as after deep diving on air. The 24-hour "stand-off" period should be insisted upon, and after very deep dives, say at 400 feet or more, a 48-hour stand-off is advisable, if working conditions permit.

Oxy-Helium Tables. The oxy-helium decompression tables, which are given on pages 182-192, are those developed and used in the U.S. Navy. Experimental work continues in England on this subject, but at the time of writing there is no complete set of British tables available for publication.

In the oxy-helium dives carried out by the Royal Navy, the proportions of oxygen and helium are so adjusted that the partial pressure of oxygen never exceeds 33 feet at any stage of the dive.

Oxygen stops are recalculated so that the diver is staged up in 10-feet stops from 60 feet to 30 feet as in air diving practice and finishes his decompression at the 30-feet stop and not the 50-feet stop as in American usage.

For very deep dives beyond 450 feet, a complete recalculation is necessary, and as such diving is in the experimental stage it is not recommended that it should be carried out except under expert scientific supervision.

THE "NOVUS" OXYGEN BREATHING APPARATUS FOR USE IN THE DAVIS SUBMERGED DECOMPRESSION CHAMBER AND IN THE MAIN DECOMPRESSION CHAMBER (see Fig. 134)

Method of Use. For the first eight minutes, the apparatus is used with the two-way cock (5) in the horizontal position. The diver thus inhales from the inhale bag (7), through the inhaling non-return valve (4) in the mouthpiece, and exhales via the mouthpiece non-return valve (3) straight to atmosphere. He replenishes the bag by using the by-pass valve on the reducing valve in the chamber.

After eight minutes, he turns the cock (5) to the vertical position, and, while still inhaling as before, he now exhales through the exhaling bag (8), through canister (6) and back into the inhale bag. The oxygen supply is maintained by the automatic flow from the reducing valve.

At the end of each stage of the decompression, or whenever the breathing bags become fully distended, the diver empties the exhale bag by pressing on it and squeezing gas out through the pressure release valve (9). He then "tops-up" by working the by-pass again. This gets rid of the nitrogen or helium being given off by the body, and refreshes the oxygen in the system.

Breathing is carried out by the mouth only, the nose being closed by a clip supplied. Alternatively, an ori-nasal mask, to which a small microphone transmitter may be fitted, may be used in place of the mouthpiece and nose-clip.

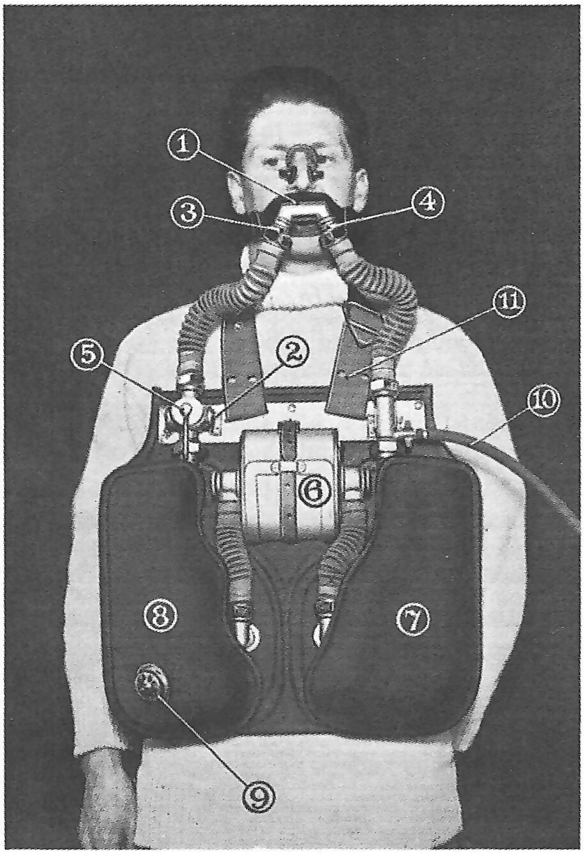


Fig. 134. "Novus" apparatus

1. Mouthpiece 2. Exhaling valve to atmosphere 3. Exhaling non-return valve 4. Inhaling non-return valve 5. Two-way cock 6. Pre-filled CO_2 absorbent canister 7. Inhaling breathing bag 8. Exhaling breathing bag 9. Pressure release valve 10. Flexible connection to oxygen reducing valve 11. Neck strap

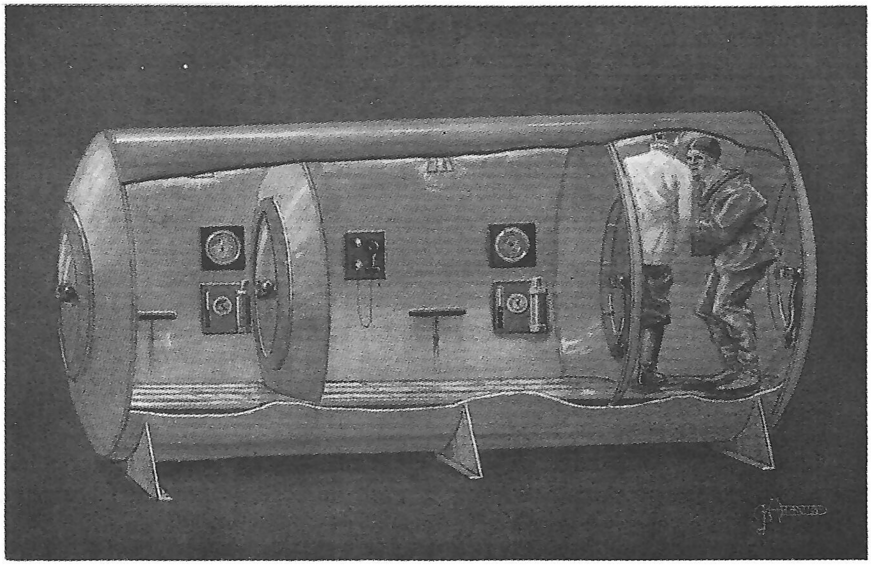


Fig. 135. Davis patent three-compartment decompression chamber without hatch for submersible chamber

ROBERT H. DAVIS'S SUBMERSIBLE DECOMPRESSION CHAMBER FOR DEEP SEA DIVERS

METHOD "A"
(as originally employed)

I designed the Submersible Decompression Chamber, known generally in the submarine world, including H.M. Navy, as the Davis Submersible Decompression Chamber (D.S.D.C.), for the purpose of saving Deep Sea Divers the long, tedious and sometimes risky (due to sudden onset of bad weather or other adverse cause) Decompression stages on the shot-rope during their ascent to the surface after completing their task on the sea-bed – a procedure which had been practised for more than 50 years.

I was influenced in the creation of what I regard as a simple, yet effective, invention by the fact that the divers have in the past few decades been required to descend to much greater depths than formerly.

I made and submitted my first Submersible Decompression Chamber to the Admiralty for trial at my own cost, as in the case of my various designs of Diving Apparatus and other submarine appliances, and the Admiralty agreed to have it tested in Loch Long, Scotland, by divers of H.M. Navy, who were at the time engaged in testing my DIVING APPARATUS on the INJECTOR PRINCIPLE, and using the late Professor John Scott Haldane's "Stage" method of decompression, as invented by him in 1905, the system universally employed in deep diving operations throughout the world today. (See page 6 of this book.)

METHOD "B"
TRANSFER OF THE DIVER, UNDERGOING DECOMPRESSION IN THE D.S.D.C. TO AN ORDINARY DECOMPRESSION CHAMBER INSTALLED IN THE SALVAGE VESSEL

When two or more divers are working and only one D.S.D.C. is available, it may be necessary to free the D.S.D.C. for use by the second diver before the first has finished his decompression. Until I designed the Transfer-under-pressure system, this could only be done by dropping the pressure in the D.S.D.C. to zero, opening its door and decanting, so to speak, the first diver into an ordinary decompression chamber fixed in the diving ship.

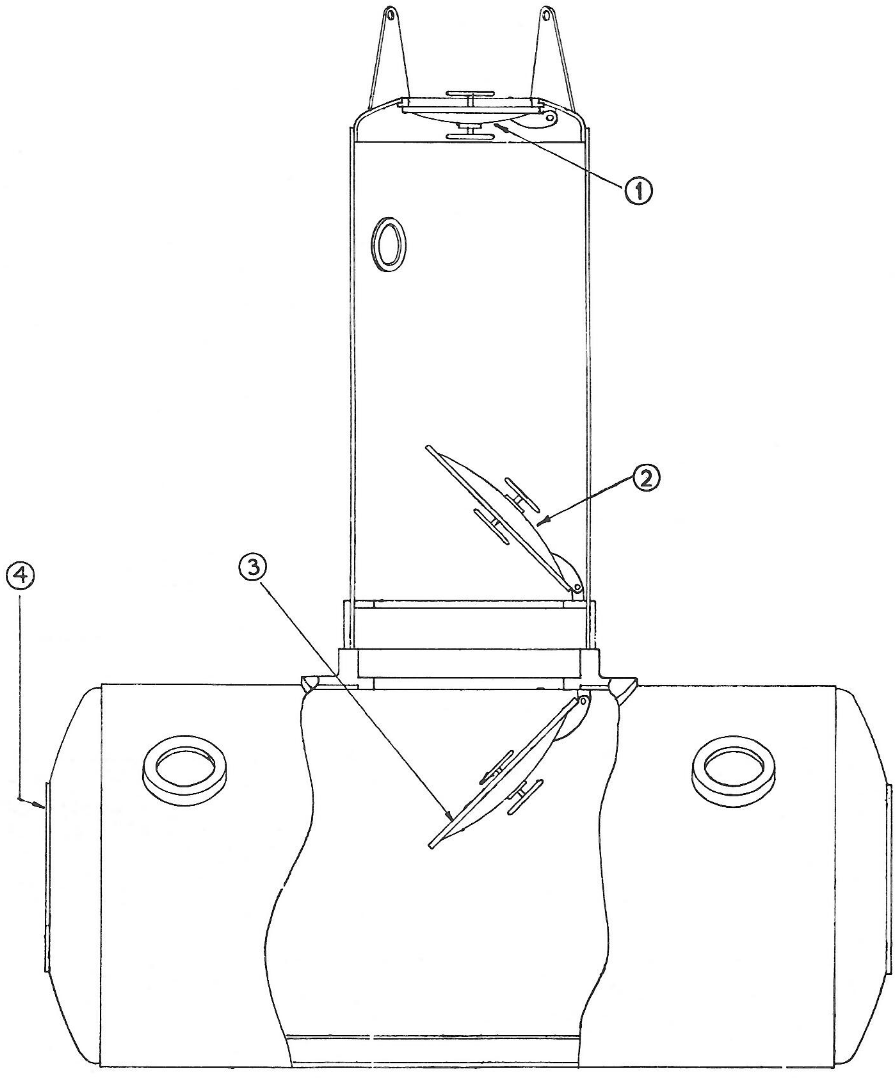
Notwithstanding the speed with which these "change-overs" were made, they sometimes resulted in the first diver suffering an attack of "bends" caused by the above-mentioned drop in pressure. The risk involved in this method of transfer set me thinking of a way by which the "change-over" could be effected without temporarily reducing the air pressure on the first diver and so interfering with the proper sequence of his decompression. The result was the design of

METHOD "C"
THE "DAVIS TRANSFER UNDER PRESSURE" PRINCIPLE

In this design, the Permanent Decompression Chamber installed on board the Diving Ship is a three-compartment type, one compartment with an airtight door, forming the entrance. On either side of this central compartment is a diver's decompression compartment, entrance to which is by an air-lock door.

My original design is briefly described on page 151 and illustrated by Fig. 137 on page 159 of this book. While the lay-out of the D.S.D.C. and fixed decompression chamber follow established practice, the method of forming the airtight pressure joint between the two to allow transference to take place under pressure is a matter requiring careful planning and workmanship. Three practical designs are illustrated by the drawings on the following pages.

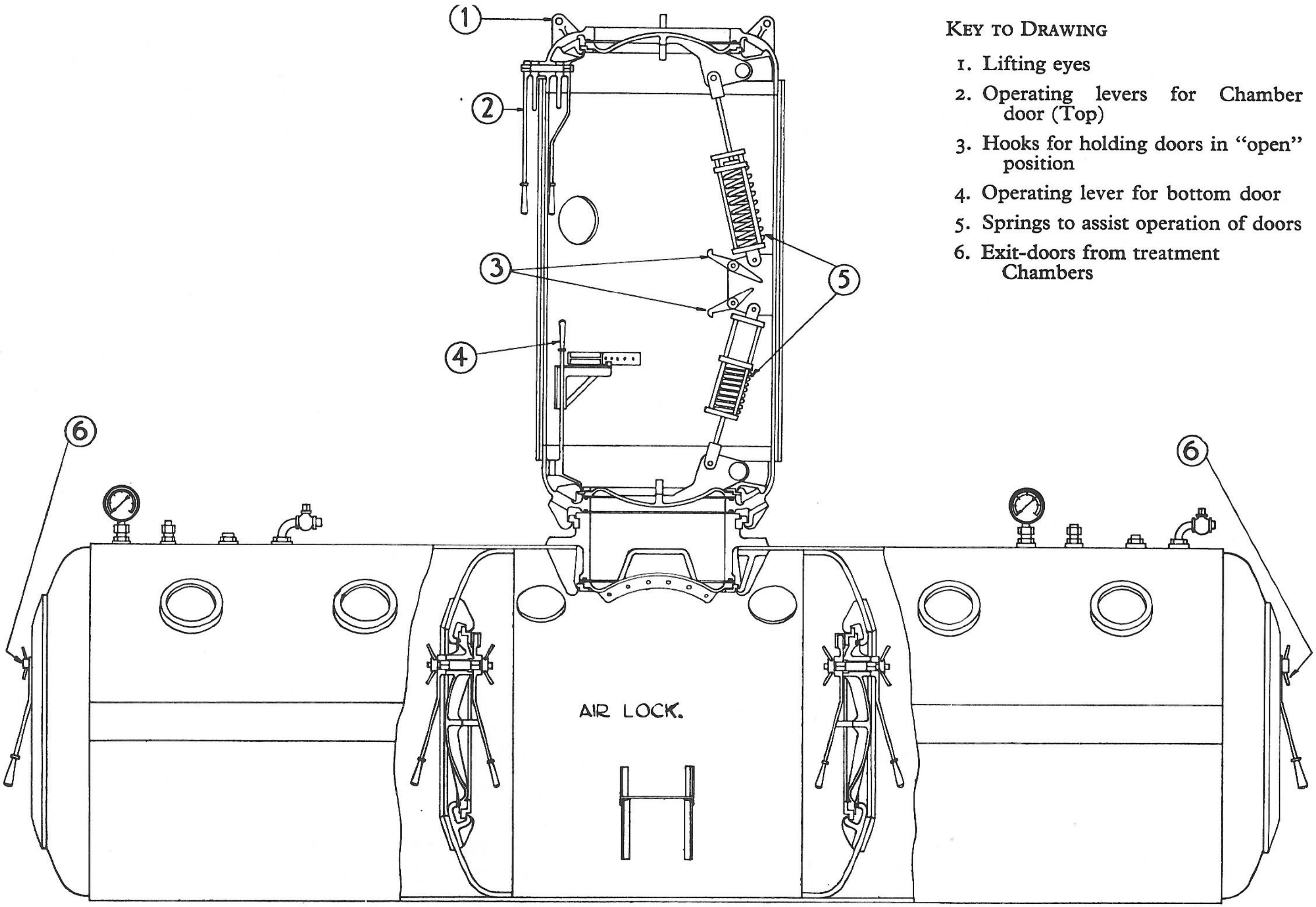
1. Originally designed by Siebe, Gorman & Co. Ltd. In this case the method of connecting the D.S.D.C. to the static decompression chamber is by hooks and swivel bolts, guided into position by horns welded on the chamber.
2. Improved method designed by Vickers-Armstrongs Ltd., for Siebe, Gorman & Co. Ltd., has guides, interrupted notches, and clamping ring operated by lever.
3. Jenkins' "Ivanhoe" Clamping Ring, operated by worm and wheel.



SIEBE, GORMAN & CO's. ORIGINAL DESIGN

KEY TO DRAWING

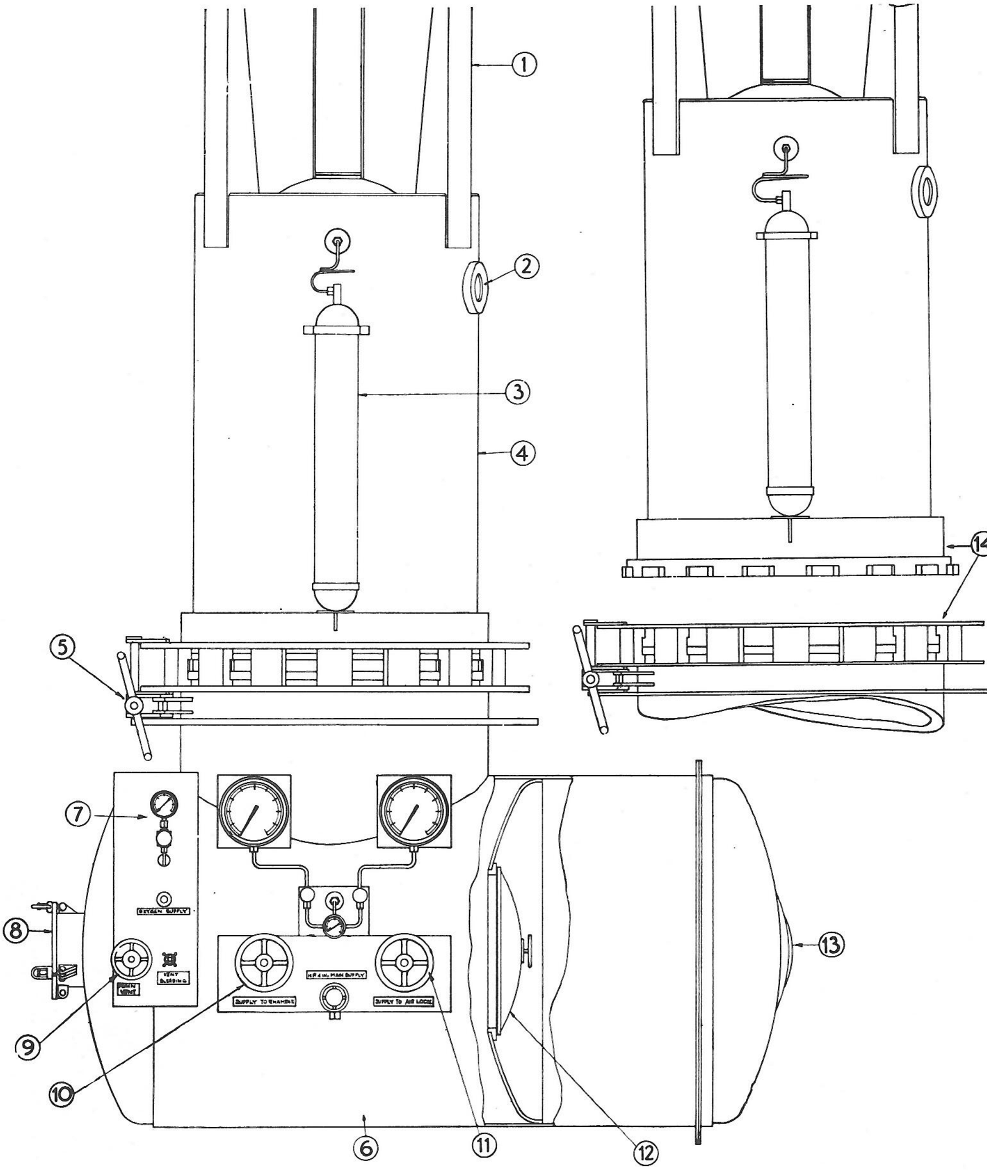
1. Entrance door for attendant at surface
2. Underwater entrance for diver
3. Transfer door to Decompression Chamber
4. Exit-door after treatment



Key to Drawing

1. Lifting eyes
2. Operating levers for Chamber door (Top)
3. Hooks for holding doors in "open" position
4. Operating lever for bottom door
5. Springs to assist operation of doors
6. Exit-doors from treatment Chambers

IMPROVED DESIGN BY VICKERS-ARMSTRONGS LTD., FOR SIEBE, GORMAN & CO. LTD.



JENKINS' "IVANHOE" CLAMPING-RING DESIGN,
as used in H.M. Deep Diving Ship "RECLAIM"

KEY TO DRAWING

1. Lifting Arms
2. Window
3. Oxygen cylinder
4. Davis Submersible Decompression Chamber
5. Mechanism for locking chamber in position
6. Surface Decompression Chamber
7. Oxygen gauge and control valve
8. Medical Lock
9. Valve for exhausting Main Chamber to atmosphere
10. Valve for controlling air supply to Main Chamber
11. Valve controlling air supply to Air Lock
12. Entry door to treatment Chamber
13. Exit door from Surface Decompression Chamber
14. View showing Davis Submersible Decompression Chamber disconnected from Surface Chamber

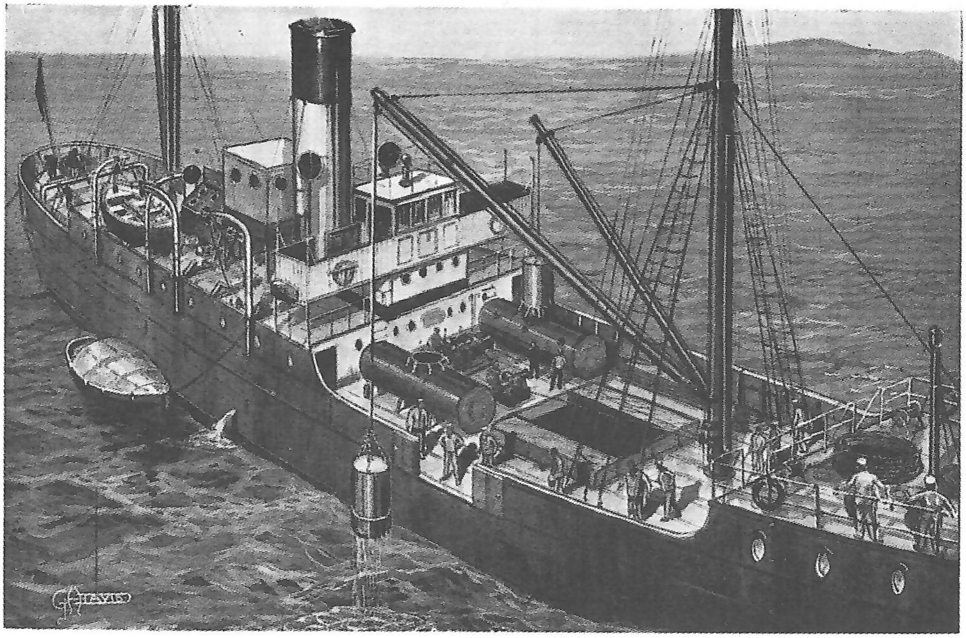


Fig. 136

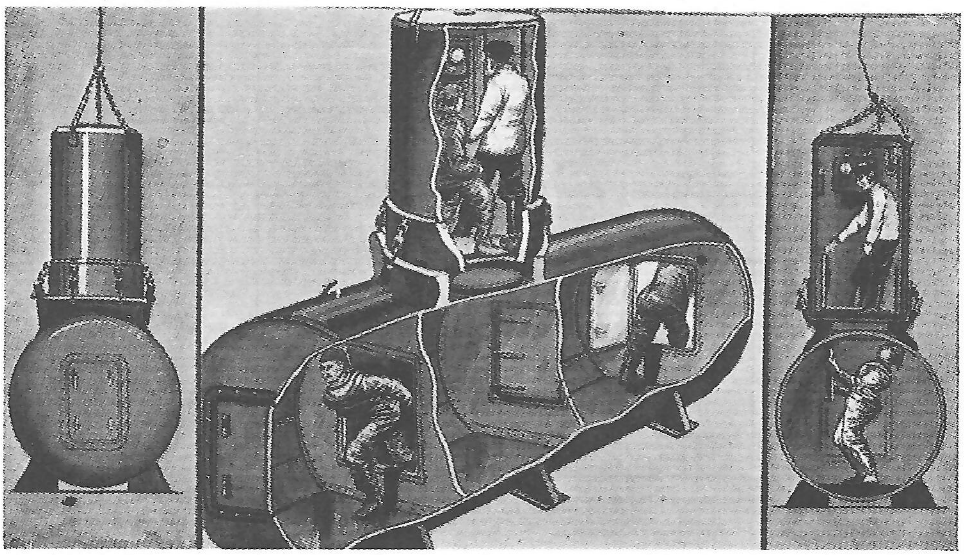


Fig. 137

Davis patent arrangement for transferring divers (where a number are employed) from submersible decompression chamber to large three-compartment decompression chamber on deck of salvage vessel, and so releasing the former chamber for use by other divers

SIEBE, GORMAN & CO.'S DECOMPRESSION TABLES TO 300 FEET

(AIR: BREATHING OXYGEN DURING LATER STAGES OF DECOMPRESSION)

120 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths						Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air	Breathing Oxygen							
	Time for Ascent to First Stop	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	2	—	—	2	2	3	2	7	9
16	2	—	—	2	4	4	2	10	12
20	2	—	1	2	4	4	2	11	13
25	2	—	1	3	4	6	2	14	16
30	2	—	1	4	5	6	2	16	18
35	2	—	2	4	6	7	2	19	21
40	2	—	3	5	7	9	2	24	26
45	2	—	4	6	10	11	2	31	33
50	2	—	5	7	10	13	2	35	37
55	2	—	5	7	12	15	2	39	41
60	2	—	5	9	13	16	2	43	45
80	2	—	8	10	17	20	2	55	57
100	2	—	10	13	20	27	2	70	72
2 hrs.	2	—	11	19	23	31	2	84	86
3 hrs.	2	—	19	22	35	35	2	111	113
5 hrs. and over	2	13	27	30	35	35	2	140	142

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

130 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths									Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air		Breathing Oxygen									
	Time for Ascent to First Stop	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.				
12	2	—	—	—	—	2	3	3		2	8	10
16	2	—	—	—	1	2	4	4		2	11	13
20	2	—	—	—	2	2	4	5		2	13	15
25	2	—	—	—	2	3	5	6		2	16	18
30	2	—	—	—	3	3	6	7		2	19	21
35	2	—	—	1	3	5	7	9		2	25	27
40	2	—	—	2	4	6	8	11		2	31	33
45	2	—	—	2	5	6	10	13		2	36	38
50	2	—	—	2	6	7	11	14		2	40	42
55	2	—	—	3	6	8	12	15		2	44	46
60	2	—	—	3	7	8	14	16		2	48	50
80	2	—	—	6	8	10	18	23		2	65	67
100	2	—	—	7	10	15	21	28		2	81	83
2 hrs.	2	—	—	9	10	18	27	31		2	95	97
3 hrs.	2	—	—	12	17	25	35	35		2	124	126
5 hrs. and over	2	—	7	19	27	30	35	35		2	153	155

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

140 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths							Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air	Breathing Oxygen								
	Time for Ascent to First Stop	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	2	—	—	1	2	3	3	2	9	11
16	2	—	—	1	3	4	4	2	12	14
20	2	—	1	1	3	4	6	2	15	17
25	2	—	1	2	3	6	6	2	18	20
30	2	—	1	3	3	7	7	2	21	23
35	2	—	1	4	5	8	10	2	28	30
40	2	—	3	5	7	9	12	2	36	38
45	2	—	4	5	8	11	13	2	41	43
50	2	—	5	6	8	11	15	2	45	47
55	2	—	5	7	8	13	16	2	49	51
60	2	—	5	7	9	14	16	2	51	53
80	2	—	8	9	12	20	26	2	75	77
100	2	—	10	11	17	24	31	2	93	95
2 hrs.	2	5	10	11	17	32	31	2	106	108
3 hrs.	2	6	14	16	30	35	35	2	136	138
5 hrs. and over	2	12	25	27	31	35	35	2	165	167

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

150 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths								Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air		Breathing Oxygen								
	Time for Ascent to First Stop	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	2	—	—	—	2	2	3	3	2	10	12
16	2	—	—	1	2	2	4	5	2	14	16
20	2	—	—	1	2	3	4	7	2	17	19
25	2	—	—	2	2	4	6	7	2	21	23
30	2	—	—	2	3	4	7	8	2	24	26
35	2	—	1	3	4	6	8	11	2	33	35
40	2	—	2	4	5	8	9	13	2	41	43
45	2	—	3	4	6	8	11	14	2	46	48
50	2	—	3	5	6	9	12	15	2	50	52
55	2	—	3	5	7	9	14	17	2	55	57
60	2	—	3	5	8	10	15	19	2	60	62
80	2	—	5	8	10	14	20	26	2	83	85
100	2	—	7	9	11	16	27	31	2	101	103
2 hrs.	2	—	7	10	13	20	33	33	2	116	118
3 hrs.	2	—	11	15	19	30	35	35	2	145	147
5 hrs. and over	2	5	17	25	27	32	35	35	7	171	178

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

160 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths								Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air		Breathing Oxygen								
	Time for Ascent to First Stop	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	2	—	—	—	2	2	3	4	2	11	13
16	2	—	—	1	2	2	4	6	2	15	17
20	2	—	—	2	2	3	4	8	2	19	21
25	2	—	—	2	3	4	6	8	2	23	25
30	2	—	1	2	3	4	8	8	2	26	28
35	2	—	2	3	4	7	8	11	2	35	37
40	2	—	4	4	5	9	10	14	2	46	48
45	2	—	4	5	6	9	11	15	2	50	52
50	2	—	4	5	7	9	14	15	2	54	56
55	2	—	4	6	7	10	16	18	2	61	63
60	2	—	5	6	8	11	17	21	2	68	70
80	2	—	6	8	10	16	20	29	2	89	91
100	2	—	9	9	13	17	30	31	2	109	111
2 hrs.	2	—	10	11	14	21	35	35	2	126	128
3 hrs.	2	—	14	16	22	31	35	35	2	153	155
5 hrs. and over	2	9	22	26	28	32	35	35	11	178	189

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

170 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths									Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air			Breathing Oxygen								
	Time for Ascent to First Stop	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	2	—	—	—	1	2	2	4	4	2	13	15
16	2	—	—	—	2	2	3	5	5	2	17	19
20	2	—	—	1	2	2	3	6	7	2	21	23
25	2	—	—	1	3	3	4	7	8	2	26	28
30	2	—	—	2	4	4	6	8	10	2	34	36
35	2	—	—	3	5	6	7	10	13	2	44	46
40	2	—	1	4	5	6	9	11	14	3	49	52
45	2	—	1	4	6	6	10	13	15	3	54	57
50	2	—	1	4	6	7	10	15	17	3	59	62
55	2	—	1	5	7	7	11	16	20	3	66	69
60	2	—	2	6	7	9	12	18	22	4	74	78
80	2	—	3	7	9	11	17	24	30	5	98	103
100	2	—	3	9	11	14	18	31	33	5	116	121
2 hrs.	2	1	3	10	12	16	23	35	35	6	131	137
3 hrs.	2	2	5	14	18	24	29	35	35	9	155	164
5 hrs. and over	2	6	14	22	26	28	32	35	35	22	178	200

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

180 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths									Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air			Breathing Oxygen								
	Time for Ascent to First Stop	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	2	—	—	1	1	2	2	4	5	2	15	17
16	2	—	—	1	2	2	3	5	6	2	19	21
20	2	—	—	2	2	2	3	6	7	2	22	24
25	2	—	1	2	2	3	4	7	10	3	28	31
30	2	—	1	3	4	4	6	9	12	3	38	41
35	2	—	1	5	5	6	8	11	13	3	48	51
40	2	—	2	5	5	6	9	12	14	4	51	55
45	2	—	2	5	6	7	10	14	16	4	58	62
50	2	—	2	6	7	7	11	16	17	4	64	68
55	2	1	2	6	8	9	12	17	21	5	73	78
60	2	2	2	7	7	9	14	18	25	6	80	86
80	2	2	4	8	8	12	17	28	33	8	106	114
100	2	2	4	9	12	14	21	34	34	8	124	132
2 hrs.	2	3	5	11	14	17	26	34	34	10	136	146
3 hrs.	2	4	9	14	20	23	32	35	35	15	159	174
5 hrs. and over	2	12	19	22	26	28	32	35	35	33	178	211

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

190 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths									Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air			Breathing Oxygen								
	Time for Ascent to First Stop	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	1	1	2	2	4	5	3	15	18
16	2	—	1	1	2	2	3	5	6	3	19	22
20	2	—	1	2	2	2	3	7	7	3	23	26
25	2	—	1	2	3	3	4	7	11	3	30	33
30	2	—	2	3	4	4	6	9	15	4	41	45
35	2	—	2	5	5	6	8	12	15	4	51	55
40	2	—	3	5	5	7	9	14	16	5	56	61
45	2	—	3	6	6	7	10	16	18	5	63	68
50	2	—	4	6	8	7	11	18	19	6	69	75
55	2	—	4	6	8	8	14	18	24	6	78	84
60	2	2	3	7	8	9	16	19	29	7	88	95
80	2	2	6	9	9	14	17	33	34	10	116	126
100	2	3	6	10	14	16	22	34	34	11	130	141
2 hrs.	2	5	6	12	15	17	28	35	35	13	142	155
3 hrs.	2	6	13	15	22	27	30	35	35	21	164	185
5 hrs. and over	2	18	24	22	25	28	33	35	35	44	178	222

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

200 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths										Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air				Breathing Oxygen								
	Time for Ascent to First Stop	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	1	1	1	2	3	4	5	4	16	20
16	3	—	—	1	1	2	3	3	6	6	4	21	25
20	3	—	—	1	2	2	3	3	7	8	4	25	29
25	3	—	—	2	2	3	4	5	8	10	5	32	37
30	2	—	1	2	4	4	6	7	11	12	5	44	49
35	2	—	1	3	5	6	7	8	14	15	6	55	61
40	2	—	2	3	5	6	8	9	15	17	7	60	67
45	2	—	2	3	6	7	9	11	16	20	7	69	76
50	2	—	2	4	7	8	9	13	17	22	8	76	84
55	2	—	2	5	7	8	10	15	20	26	9	86	95
60	2	—	3	5	7	8	11	16	24	29	10	95	105
80	2	—	5	6	9	11	15	18	34	34	13	121	134
100	2	—	6	6	11	14	16	25	34	34	14	134	148
2 hrs.	2	3	5	8	13	15	21	29	35	35	18	148	166
3 hrs.	2	3	9	12	18	24	28	30	35	35	26	170	196

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

210 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths										Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air				Breathing Oxygen								
	Time for Ascent to First Stop	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	1	1	1	2	3	4	6	4	17	21
16	3	—	—	2	1	2	3	3	6	7	5	22	27
20	3	—	—	2	2	2	3	4	7	9	5	27	32
25	3	—	1	2	2	3	5	5	9	10	6	34	40
30	3	—	2	2	4	4	6	7	11	13	7	45	52
35	3	—	2	3	5	6	8	9	14	16	8	58	66
40	3	—	3	3	6	7	8	9	17	18	9	65	74
45	3	—	3	4	6	8	9	12	17	22	10	74	84
50	3	—	3	4	7	9	9	14	18	27	10	84	94
55	3	—	4	5	7	10	10	16	22	28	12	93	105
60	2	2	3	6	8	10	12	16	26	29	13	101	114
80	2	2	5	6	10	12	16	20	34	34	15	126	141
100	2	3	6	6	11	15	16	24	35	35	17	136	153
2 hrs.	2	5	5	10	14	15	24	30	35	35	22	153	175
3 hrs.	2	5	11	12	20	24	28	32	35	35	30	174	204

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

220 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths											Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air					Breathing Oxygen								
	Time for Ascent to First Stop	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	2	1	1	2	3	4	7	5	18	23
16	3	—	—	1	2	1	2	2	4	6	8	6	23	29
20	3	—	—	1	2	2	2	3	5	7	10	6	29	35
25	3	—	—	2	2	3	3	5	7	10	12	7	40	47
30	3	—	1	2	3	5	5	8	8	14	13	8	53	61
35	3	—	1	2	3	5	6	8	9	16	17	9	61	70
40	3	—	1	3	3	6	8	8	10	18	20	10	70	80
45	3	—	1	3	4	7	8	9	13	18	25	11	80	91
50	3	—	1	3	5	7	8	9	17	18	32	12	91	103
55	3	—	2	3	6	7	8	11	18	24	32	14	100	114
60	3	—	2	3	7	8	9	13	18	29	32	15	109	124
80	3	—	3	5	7	11	12	14	22	35	35	18	129	147
100	3	—	4	6	9	14	15	15	27	35	35	21	141	163

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

230 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths																Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air										Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	—	—	1	2	2	2	2	3	4	7	6	20	26
16	3	—	—	—	—	—	—	—	2	2	2	3	3	4	5	7	7	24	31
20	3	—	—	—	—	—	—	—	2	2	2	3	3	5	8	8	7	29	36
25	3	—	—	—	—	—	—	1	2	3	3	4	5	7	10	12	9	41	50
30	3	—	—	—	—	—	—	1	3	3	4	6	7	9	13	15	10	54	64
35	3	—	—	—	—	—	—	2	3	3	5	7	8	10	16	19	11	65	76
40	3	—	—	—	—	—	—	2	3	3	7	8	9	12	18	24	11	78	89
45	3	—	—	—	—	—	—	2	3	5	7	8	10	15	20	26	13	86	99
50	3	—	—	—	—	—	1	2	3	6	8	8	10	17	20	32	15	95	110
55	3	—	—	—	—	—	1	2	3	7	8	10	13	17	24	32	16	104	120
60	3	—	—	—	—	—	1	2	4	7	9	10	15	17	29	32	17	112	129
80	3	—	—	—	—	—	2	3	5	8	11	12	14	24	35	35	21	131	152

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

240 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths																Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air										Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	—	—	1	2	2	2	2	3	6	7	6	22	28
16	3	—	—	—	—	—	—	—	2	2	2	3	3	4	7	7	7	26	33
20	3	—	—	—	—	—	—	1	2	2	2	3	3	5	8	8	8	29	37
25	3	—	—	—	—	—	—	1	3	3	3	5	5	7	9	13	10	42	52
30	3	—	—	—	—	—	—	2	3	3	4	7	7	9	13	15	11	55	66
35	3	—	—	—	—	—	—	3	3	3	6	8	8	10	15	22	12	69	81
40	3	—	—	—	—	—	—	3	3	3	8	8	8	13	19	28	12	84	96
45	3	—	—	—	—	—	1	3	3	5	8	8	10	15	21	29	15	91	106
50	3	—	—	—	—	—	1	3	3	7	8	8	12	17	24	30	17	99	116
55	3	—	—	—	—	2	3	4	5	7	10	11	13	23	28	35	24	120	144
60	2	—	—	—	2	3	4	6	7	7	12	15	16	28	35	35	31	141	172
65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

250 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths																Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air										Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	—	—	1	2	2	2	2	4	6	7	6	23	29
16	3	—	—	—	—	—	—	1	2	2	2	3	3	4	7	8	8	27	35
20	3	—	—	—	—	—	—	2	2	2	3	4	4	6	9	10	9	36	45
25	3	—	—	—	—	—	—	2	3	3	5	6	7	8	11	13	11	50	61
30	3	—	—	—	—	—	1	2	3	3	5	7	7	10	14	17	12	60	72
35	3	—	—	—	—	—	1	3	3	3	7	8	8	13	16	23	13	75	88
40	3	—	—	—	—	—	2	3	3	3	8	9	9	15	19	29	14	89	103
45	3	—	—	—	—	2	3	5	5	5	9	12	12	19	26	33	23	111	134
50	3	—	—	—	2	3	3	6	7	7	10	14	15	22	35	35	31	132	163
55	3	—	—	—	3	3	4	6	7	8	12	16	18	27	35	35	34	143	177
60	3	—	—	1	3	3	4	6	7	9	15	16	21	30	35	35	36	152	188
65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

260 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths																Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air										Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	—	1	1	2	2	2	2	4	6	7	7	23	30
16	3	—	—	—	—	—	—	1	2	3	2	2	3	5	7	10	9	29	38
20	3	—	—	—	—	—	1	1	2	3	3	4	4	6	9	13	10	39	49
25	3	—	—	—	—	—	1	2	3	3	5	6	6	9	12	16	12	54	66
30	3	—	—	—	—	—	2	2	3	3	6	7	8	10	15	19	13	65	78
35	3	—	—	—	—	2	3	3	5	5	8	10	11	14	23	26	21	92	113
40	3	—	—	—	3	3	3	3	7	7	9	11	15	17	34	34	29	120	149
45	3	—	—	1	3	3	4	4	7	7	11	13	16	22	35	35	32	132	164
50	3	—	—	2	2	3	4	6	7	7	13	17	18	28	35	35	34	146	180
55	3	—	—	2	2	3	5	6	7	9	15	18	22	30	35	35	37	155	192
60	3	—	—	2	3	4	5	6	7	10	17	18	25	32	35	38	40	165	205
65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

270 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths															Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air									Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	—	1	1	2	2	2	2	4	6	7	7	23	30
16	3	—	—	—	—	—	1	1	2	2	2	3	3	5	8	10	9	31	40
20	3	—	—	—	—	—	1	2	2	3	3	4	6	6	9	15	11	43	54
25	3	—	—	—	—	1	1	1	3	3	4	6	8	9	12	19	12	58	72
30	3	—	—	—	—	1	2	2	3	3	6	8	8	10	18	21	14	71	83
35	3	—	—	—	2	2	3	3	5	5	8	9	10	13	28	28	23	96	119
40	3	—	—	2	2	3	3	4	7	7	9	12	16	19	34	34	31	124	155
45	3	—	—	2	3	3	4	5	7	7	12	15	18	25	35	38	34	143	177
50	3	—	—	2	3	3	5	6	7	7	15	18	19	29	40	40	36	161	197
55	3	—	—	2	3	4	5	6	7	10	17	18	23	30	40	40	40	168	208
60	3	—	1	2	3	5	5	6	7	12	18	18	28	31	40	40	44	175	219

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

280 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths																Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air										Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	—	1	1	2	2	3	3	4	7	7	7	26	33
16	3	—	—	—	—	—	1	1	2	3	3	4	5	6	10	11	10	39	49
20	3	—	—	—	—	1	1	2	2	3	5	5	7	9	13	15	12	54	66
25	3	—	—	—	—	1	1	2	3	3	8	8	12	13	18	19	13	78	91
30	3	—	—	2	2	2	3	3	4	7	10	10	17	18	21	21	26	97	123
35	3	—	—	2	2	3	3	4	6	7	10	12	17	19	29	29	30	116	146
40	3	—	1	2	2	3	4	4	7	7	11	13	17	25	34	35	33	135	168
45	3	—	1	2	3	3	5	5	7	8	14	16	19	28	35	38	37	150	187
50	3	—	1	3	3	4	5	6	6	9	16	19	22	31	38	38	40	164	204
55	3	—	1	3	3	5	5	6	8	11	18	20	26	31	38	38	45	171	216
60	3	—	2	2	4	5	5	6	9	13	19	21	29	32	39	39	49	179	228

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

290 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths																Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air										Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	—	1	2	2	3	3	4	4	7	8	8	29	37
16	3	—	—	—	—	—	1	1	2	3	3	5	6	7	10	12	10	43	53
20	3	—	—	—	1	1	1	1	3	3	6	7	9	10	16	19	13	67	80
25	3	—	—	1	2	2	3	3	3	7	9	10	11	17	24	25	24	96	120
30	3	—	—	2	2	3	3	3	5	7	10	11	17	19	27	27	28	111	139
35	3	—	1	2	2	3	4	4	6	7	11	13	18	22	31	32	32	127	159
40	3	—	2	2	2	3	5	5	6	7	12	16	19	27	35	35	35	144	179
45	3	—	2	2	3	4	5	6	6	9	15	17	20	29	36	38	40	155	195
50	3	—	2	3	3	5	5	6	6	11	16	18	21	31	40	40	44	166	210
55	3	—	2	3	4	5	5	6	8	13	17	21	25	31	40	40	49	174	223
60	3	1	1	3	5	5	5	6	10	14	19	21	29	33	40	40	53	182	235

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

300 FEET

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths																Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air										Breathing Oxygen								
	Time for Ascent to First Stop	150 ft.	140 ft.	130 ft.	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
12	3	—	—	—	—	—	1	1	2	2	3	4	4	5	8	8	9	32	41
16	3	—	—	—	—	1	1	1	3	3	4	5	6	7	12	13	12	47	59
20	3	—	—	—	1	1	1	1	3	3	7	7	9	12	18	20	13	73	86
25	3	—	1	1	2	2	3	3	4	7	11	11	13	18	28	28	26	109	135
30	3	—	1	2	2	3	3	3	6	7	11	11	18	20	32	32	30	124	154
36	3	—	2	2	2	3	4	5	6	7	13	15	18	23	36	36	34	141	175
42	3	1	2	2	2	3	6	6	6	7	15	18	19	28	38	38	38	156	194
45	3	1	2	2	3	4	6	6	6	10	18	18	20	30	38	38	43	162	205
50	3	1	2	3	3	5	6	6	6	13	18	18	21	32	40	40	48	169	217
55	3	1	2	4	4	5	5	6	9	14	18	20	25	33	40	40	53	176	229
60	3	2	2	4	5	5	5	6	11	14	19	22	30	34	40	40	57	185	242

The above figures represent minutes, except where otherwise stated.

SIEBE, GORMAN & CO.'S DIVERS' DECOMPRESSION TABLES

(AIR AND OXYGEN)

TABLES FOR USE IF DEPTH OF 300 FEET IS ACCIDENTALLY EXCEEDED

Time in minutes from leaving Surface to beginning of Ascent	Stoppages in minutes at different depths													Period of Ascent during which Air is breathed minutes	Period of Ascent during which Oxygen is breathed minutes	Total Time for Ascent in minutes
	Breathing Air							Breathing Oxygen								
	Time for Ascent to First Stop	120 ft.	110 ft.	100 ft.	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.			
									310 *feet*							
12	3	—	—	1	2	2	2	3	4	4	5	8	10	10	34	44
16	3	—	1	2	2	2	3	4	5	6	8	12	14	13	49	62
									320 *feet*							
12	3	—	1	1	2	2	2	3	3	4	6	9	12	11	37	48
16	3	1	1	2	2	2	3	4	5	7	8	12	15	14	51	65

The above figures represent minutes, except where otherwise stated.