ADMIRALTY EXPERIMENTAL DIVING UNIT

C/O H.M.S. VERNON

A.E.D.U. REPORT NO. XXIX

DEEP DIVING TRIALS 1962

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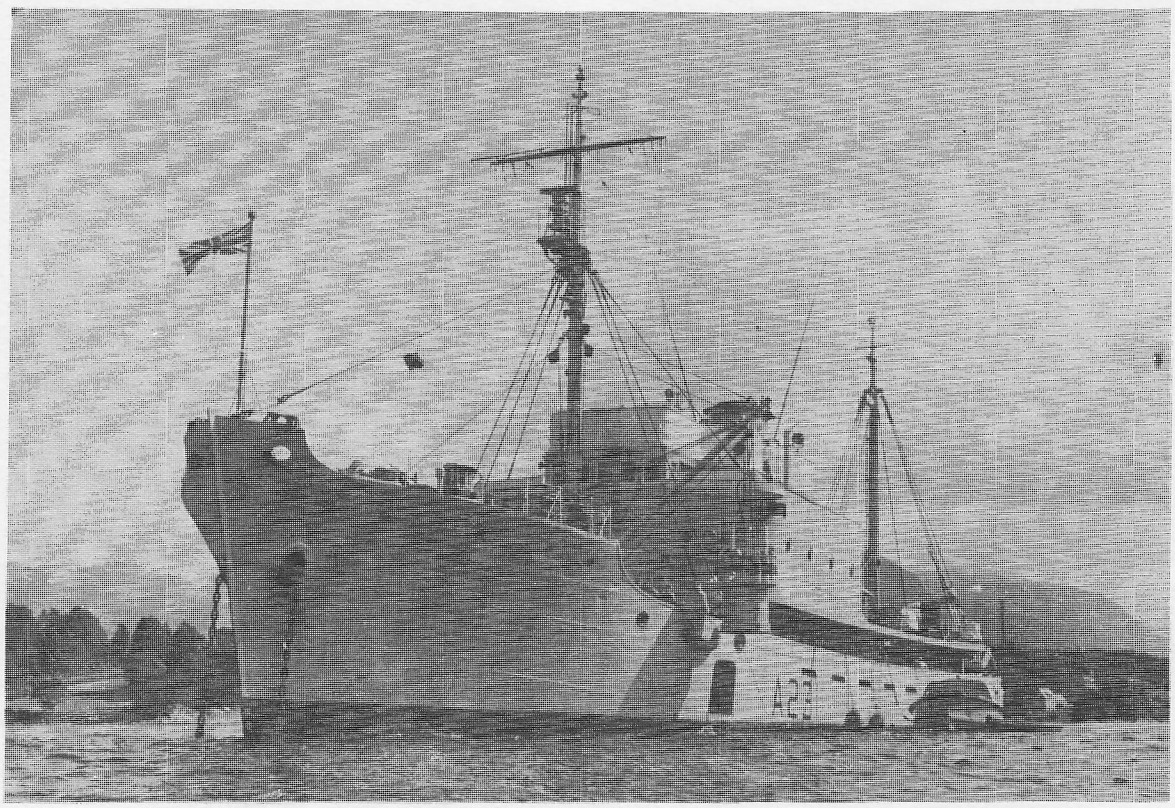


PLATE 1. H.M.S. RECLAIM - Showing Port Diving Door

DEEP DIVING TRIALS 1962

SUMMARY

Trials were carried out in a Norwegian fjord in the Summer of 1962 with the object of developing a technique for diving with Surface Demand Diving Equipment from a submersible Decompression Chamber, to depths as great as 1,000 ft. The trials consisted of two parts. Part I to extend to oxy-helium mixtures a technique already proved for air dives to lesser depths. Part II to test new decompression schedules which were aimed at reducing the time under pressure in order to make this type of diving a practical proposition operationally. In the event, for lack of a satisfactory decompression schedule, the maximum sea depth reached was 300 ft.

CONCLUSIONS

2. It is considered that diving from an S.D.C. using S.D.D.E. is a safe and practical method to depths down to 250 ft. on air, with or without Transfer Under Pressure facilities, in sheltered water without strong tides.

3. The safety precautions taken during these trials should be taken in future trials.

4. The decompression schedules using air after oxy-helium dives appear satisfactory if the interval between dives is sufficiently long - of the order of four days.

5. The decompression schedules using oxygen after oxy-helium dives appear satisfactory for dives 72 hours apart. They may be satisfactory for dives at shorter intervals.

RECOMMENDATIONS

6. As a result of Part I of the trials it is recommended that:-

See Para.18.

(a) As proposed in AEDU Report No. XXVI further trials of this method should be carried out where tides are strong and underwater visibility low.

See Para.24.

(b) If the technique can be proved in sheltered waters to depths of the order of 1,000 ft. consideration should be given to much more radical measures, such as an athwartship gantry or a submarine with a "wet and dry" egress, to allow its use in open water.

See Para.31.

(c) The air storage and supply system in H.M.S. RECLAIM should be modified to permit storage and use of helium with a simple, straightforward system.

See Para.23.

(d) That "Dead Load Testers" should be supplied to all ships and authorities with Recompression Chambers

7. As a result of Part II of the trials it is recommended that :-

See Para.50. (a) An intensive effort should be launched to prove new schedules on oxy-helium as far as is possible in the R.C.C. to enable deep living in the sea to be continued as soon as H.M.S. RECLAIM is again available.

See Para.50. (b) These trials should also aim to establish clearly the minimum acceptable period between oxy-helium dives.

See Para.39. (c) In all future trials of decompression schedules in the R.C.C. the divers should exercise while on "chamber bottom" before the schedule is accepted for use in the sea.

See Para.40. (d) Divers should be given extra pay for experimental dives.

INTRODUCTION

8. Deep Diving between depths of 180 ft. and 450 ft. using helmeted divers and specially equipped ships (H.M. Ships RECLAIM and KINGFISHER) was discontinued at the beginning of 1959. Diving in the Royal Navy was limited to 180 ft. - the maximum depth required for Mine Countermeasures Work. Since 1959, however, it has become increasingly apparent that there is a requirement for divers to be able to operate to depths considerably in excess of 180 ft. for such tasks as helicopter recovery, recovery of other crashed aircraft and missiles and possibly submarine escape and salvage. It was also considered that with the advent of S.D.D.E. and making use, in the first place, of the Transfer Under Pressure system in H.M.S. RECLAIM it would be possible to operate divers with considerable mobility to a depth of 360 ft. and with limited mobility to depths as great as 1,200 ft. Proposals to continue research into Deep Diving were accordingly put forward by the Superintendent of Diving in January, 1962 and, in May, Board Approval was given to start a programme of trials with the above aims in view.

HISTORY

9. In 1933 a report was issued by the Committee appointed by the Admiralty to consider and report on the equipment required for the provision of Deep Diving and Ordinary Diving in H.M. Service. Before this date flexible dress diving was limited to a depth of about 200 ft. Ordinary Standard Suits were used with hand pumps and the decompression tables only went to 204 ft. As a result of the trials carried out by the Deep Diving Committee special Deep Diving Committee special Deep Diving equipment was introduced. This included carbon dioxide absorption apparatus and the submersible Decompression Chamber. A new decompression table, Table III, was also introduced. This used oxygen for the later stages to shorten the decompression time. A new limit of 300ft. was established and, although greater depths were achieved during the trials, it was recommended that for the time being this depth should not be exceeded for this type of diving.

10. No further deep diving trials were carried out between 1933 and the outbreak of war, but the techniques established were exercised annually until 1939. They were not used operationally until 1946.

11. After the war it was clear that Deep Diving in the Royal Navy should be brought up to date to take advantage of the very extensive experimental work undertaken by the Admiralty Experimental Diving Unit between 1942 and 1945. War experience had also shown that submarines with "crash" depths far in excess of 300 ft. were needed. There was therefore a requirement for divers to go deeper as well. For the next three years, first with H.M.S. DEEPWATER and then, in 1948, H.M.S. RECLAIM, a series of trials was carried out with the aim of achieving greater depths for flexible suit diving. These culminated in a dive to 535 ft. in 1948. The programme, conducted by the Superintendent of Diving as head of the Admiralty Experimental Diving Unit, was backed by the resources of Royal Naval Physiological Laboratory and the Underwater Physiology Sub-Committee of the Royal Naval Personnel Research Committee. At the end of these trials it was concluded that the safe and efficient working depth could be extended to 360 ft. using oxy-helium mixtures.

12. The next seven years were devoted mainly to consolidation and to introducing the improvements recommended in 1948. The depth for efficient work was extended to 410 ft. although it was stated in 1954 that routine diving beyond 400 ft. could not be regarded as safe or practicable until a transfer under pressure system from the S.D.C. to the R.C.C. was installed in Deep Diving Ships. The primary reasons for this were:-

(i) For the treatment of bends appearing before the surface was reached.

(ii) To allow the diver to complete long stops in greater comfort.

(iii) To release the S.D.C. for further diving.

13. In 1956, as well as continuing dives in the 400 ft. range, one dive to 600 ft. was carried out to prove that limited work, such as shackling on the downhaul wire of the Submarine Rescue Bell, could be done at this depth. Although this dive achieved its aim, the importance of a transfer under pressure system was again demonstrated. In 1957 and 1958 deep diving training continued but experimental work was devoted to various trials in shallower depths. In the Summer of 1959, however, the transfer under pressure system was fitted in H.M.S. RECLAIM but by the end of the year the decision was made to discontinue deep diving in the Royal Navy. A.F.O. 532/59 outlined Admiralty policy and at the same time forecast the gradual replacement of Standard Diving Equipment in the Fleet. The last course to qualify Naval ratings as Standard Divers was completed in 1960.

14. Thus in May 1962, when Board approval was given to continue research into Deep Diving, the situation was as follows:-

(i) A technique for deep diving in special deep equipment using oxy-helium mixture to depths of 400 ft. existed, but the equipment had been disposed of.

(ii) The R.N. Diving Manual contained stoppage tables for oxy-helium diving to 500 ft.

(iii) Only a limited number of ships still had Standard Diving Equipment - with its normal limit of 180 ft. - and the pool of divers experienced in both Deep and Standard Diving was gradually dwindling.

(iv) H.M.S. RECLAIM, still available for part of her time for diving trials, was equipped with an S.D.C. and T.U.P. system but all her Deep Diving and Oxy-helium equipment had been removed.

15. It was clear that a new approach was necessary which would take advantage of the new equipments that were being introduced into the Service and the new generation of divers whose training was entirely in self-contained equipment or surface-supplied demand valve equipments. Trials in 1961 had successfully proved that divers using S.D.D.E. could operate from an S.D.C. lowered to the vicinity of the job in depths down to 180 ft. (AEDU Report No. XXVI). This proved a straight-forward and popular technique in sheltered waters. The aim, therefore, when the 1962 trial began, was to extend this technique to greater depths using oxy-helium mixture after 250 ft.

CONDUCT OF THE TRIALS

16. The trials extended from 25th May to 23rd July, 1962. There were two periods in H.M.S. RECLAIM, about a month apart, and during the interval some Recompression Chamber dives were carried out in the Royal Naval Physiological Laboratory. The trials can be divided into two main parts which took place concurrently:-

Part I - To develop a technique for diving on oxy-helium mixtures using S.D.D.E. from an S.D.C.

Part II - To prove decompression schedules.

PART I TO DEVELOP A TECHNIQUE FOR DIVING ON OXY-HELIUM MIXTURES

USING S.D.D.E. FROM AN S.D.C.

17. The method for Part I was based on the technique used for the trials to 180 ft. carried out in July, 1961 and reported in AEDU Report No. XXVI. The important difference was the need to supply oxy-helium to the divers at depths greater than 250 ft. For this series of trials air was used as the gas in the S.D.C. and the divers were provided with S.D.D.E. sets supplied from a bank of fourteen 150 cu.ft. cylinders mounted outside the S.D.C. For work-up dives these were filled with air at 2,400 lbs.per.sq.in. and for dives deeper than 250 ft. with 5% oxygen/95% Helium. In the latter case the pressure rarely exceeded 1,000 lbs.per.sq.in. During the descent and ascent the divers breathed S.D.C. atmosphere. The S.D.D.E's were used when they left the S.D.C. and could be used in emergency while inside it.

18. The trials took place in Sor Fjord, some ten miles north of Bergen, in the vicinity of the village of Utre Arne. Depths of over 1,500 ft. are available in this area and in practice, after the very first dives, the S.D.C. was never near the bottom. By mooring the ship in a depth well in excess of that required the need to move her whenever a new diving depth was wanted was obviated. By instructing the divers to swim at a depth level with the bottom of the S.D.C. an accurate indication of their depth was obtained. In this sheltered area where tide and weather had no effect on operations the technique used proved entirely successful both for work-up dives at 180 ft. and 250 ft. on air and for 300 ft. dives on oxy-helium. The divers did not in fact do any hard work, merely swimming round the S.D.C. but in such circumstances this method proved both straight-forward and popular. In due course it will be necessary to carry out trials in water where tides are strong and visibility low.

PROCEDURE

19. The detailed drill is given in Appendix 6. The procedure was as follows. At the start of the day's diving the S.D.C. was hung above the upper deck while gear was checked, vent valve checked closed, communications, light, air pressure etc. tested and the turns taken out of the S.D.D.E. air pipes. It was then hoisted over the side and lowered until the bottom was about 2 foot below the surface. It was also returned to this position ready for subsequent dives on completion of T.U.P. and blowing down. The divers already wearing U.S.D. then entered the water from the diving door and ducked into the S.D.C. Once in, they put on their fins, tested communications and reported ready. Normally the diver would then put on his S.D.D.E. set, except for the face mask, and sit with his feet dangling through the lower door. Before lowering, the supply valve to the S.D.C. on the panel was opened fully while the control valve in the S.D.C. was closed. While going down the attendant in the S.D.C. kept the water level down to about 6 ins. to 1 ft. above the lower door. The order to lower was given by the S.D.C. panel operator and the S.D.C. was lowered at a speed of 100 ft. per minute. This was achieved by varying the winch speed between that obtained by the 5th and 6th stops. Preliminary trials had been carried out to confirm that this speed of lowering, which was required for physiological reasons, could be achieved. It was found that the chamber could be lowered at this speed without difficulty and there was no need for extra ballast or other measures. Various methods of checking depth were tried but the method finally used was to mark the winch wire with seizing wire and check this by counting the revolutions of the winch drum (using a home-made abacus). After the S.D.C. had reached "bottom" an additional check was obtainable from the reading on the depth gauge on the panel. The order to stop lowering was therefore given by the man checking the marks on the winch wire.

20. During the descent, due to the rush of air into the chamber, telephonic communication was impossible. A push button was therefore fitted so that, should the divers wish to stop because, for example, of ear trouble, they could make a "burst of silence" of which the S.D.C. panel operator would be immediately aware. Suit inflation was unnecessary because the diver being "in the dry" could let air in his neck seal or cuff. No.2. Diver would put on his face mask as soon as he felt the jar of the chamber stopping. He was thus ready to slip into the water as soon as "carry on with the diver" was ordered (Plate 2). Halfway through the "time on the bottom" the panel operator would give the order for the divers to change over. This practice during these trials was carried out merely to give both divers a turn. On an actual operation, if the job could be best done that way, one diver would work at it all the time. Alternatively, if the work was exhausting, particularly for longer bottom times, the divers could change over as was done during the trials.

21. Communication between the diver and attendant was by single lifeline signals and two minutes before the time to start surfacing the order was given to call the diver in.

22. The orders to hoist to each stop were given by the S.D.C. panel operator, who was beside the timekeeper, but the orders to stop by the man checking the winch wire. This was because reliance could not be placed on the depth gauge. On one occasion (the first 300 ft. sea dive) at what should have been the 20 ft. stop, the S.D.C. depth was only 6 ft. The result of this was serious decompression sickness for both divers (see paragraph 44). Subsequent investigation revealed that this was due to the fact that an air pipe leak was suspected because the S.D.C. panel gauge reading started to fall off while the S.D.C. was stationary at 10 ft. An attempt to compensate for this by putting a small flow into the pipe resulted in a build-up of pressure which caused the gauge to indicate a greater depth than the true depth of the S.D.C. Again checks were provided by revolutions and panel depth gauge. The deeper stops were carried out with the lower door open until a convenient depth, when a stop of at least 8 minutes was provided for transfer under pressure to the R.C.C. In practice it was found that transfer could normally be completed in 3 minutes from the time of ordering "close lower door". The remaining decompression was completed in the T.U.P. Recompression Chamber and the S.D.C. was prepared for the next dive.

23. Once transfer under pressure had taken place accurate depth for stops could no longer be determined by markings on the winch wire but was entirely dependent on the R.C.C. gauges. It is therefore vital that these gauges should be accurate and it is considered that "Dead Load Testers" should be provided, not only for this chamber, but for all ships and authorities with R.C.C.'s.

HANDLING THE S.D.C.

24. In calm water, with no movement on the ship, handling the S.D.C. is perfectly straight-forward. In open water the problem would be very different particularly with the oxy-helium cylinders secured to the outside of the chamber. Some arrangement with a large amount of fendering and padding, and extra guys, might be feasible under certain conditions but if the technique can be proved in sheltered water to depths of the order of 1,000 ft. consideration should be given to much more radical measures, such as an athwartship gantry or a submarine with a "wet and dry" egress.

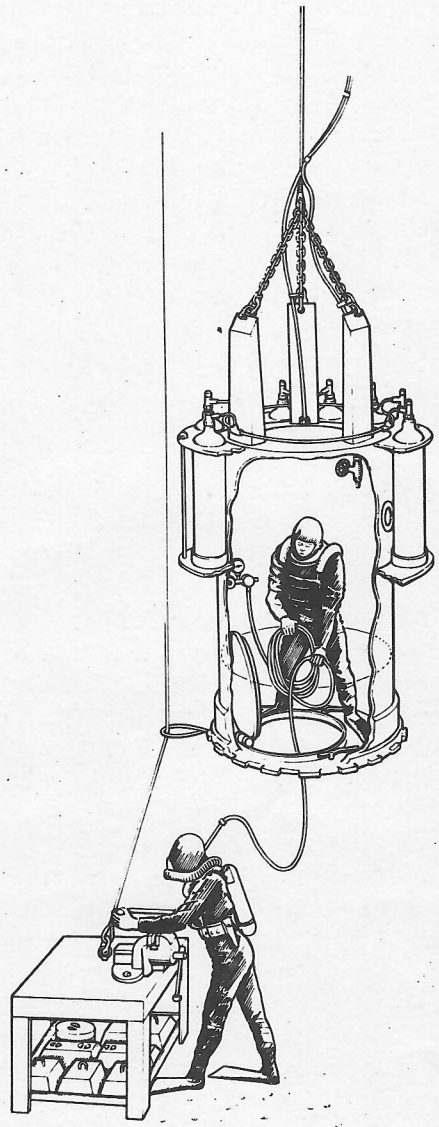


PLATE 2. Diver in S.D.D.E. Operating from S.D.C.

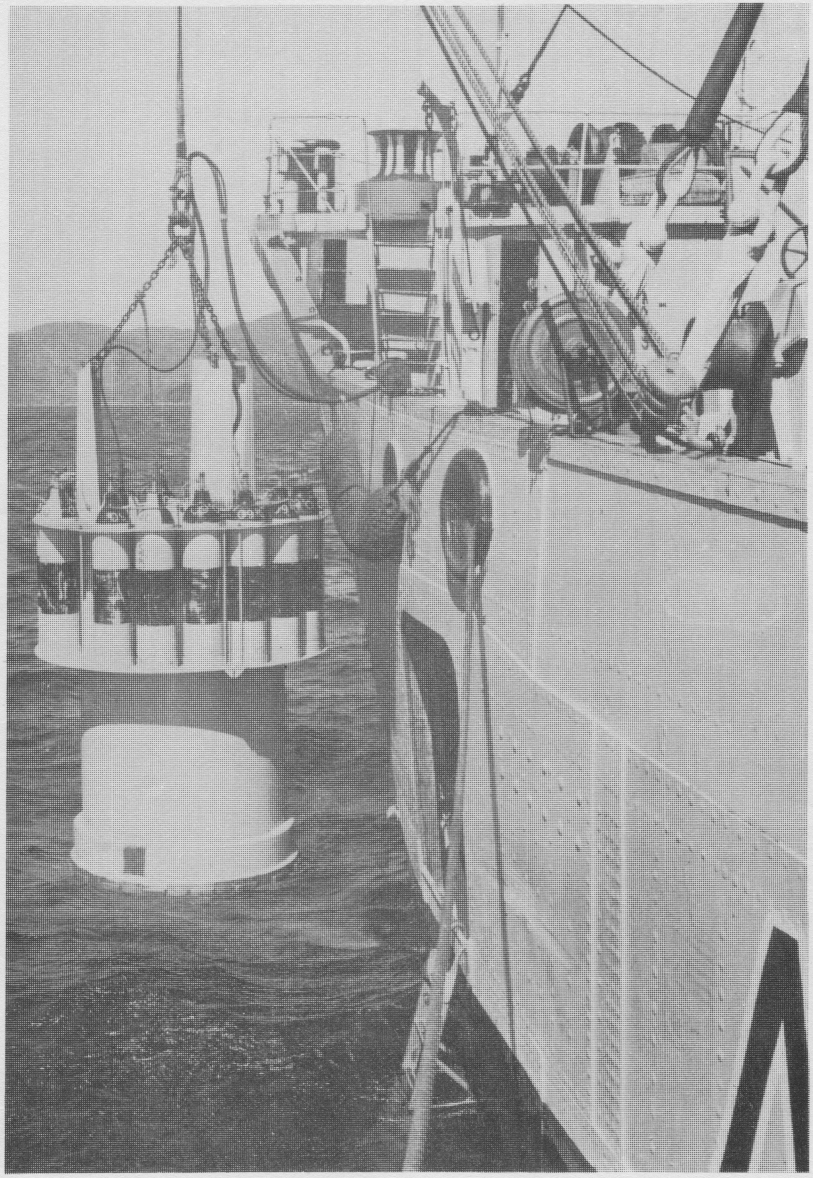


PLATE 3. Submersible Decompression Chamber (S.D.C.)

EQUIPMENT

THE SUBMERSIBLE DECOMPRESSION CHAMBER

25. The S.D.C. was modified to carry fourteen 150 cu.ft. light alloy cylinders round the outside of the upper half. (Plate 3). This left the lower half free to fit into the transfer under pressure hatch. The cylinders were connected to a common manifold with a charging connection at one end. The other end led into the chamber to an H.P. gauge, a reducer and two S.D.D.E. connections. Two S.D.D.E. sets were stowed in the chamber. Initially these had normal 60 ft. lengths of hose but for most of the trials special 30 ft. lengths were fitted. These shorter lengths gave plenty of freedom to the diver but greatly simplified the problem of stowing them when in the S.D.C. When fully charged the fourteen cylinders gave a total of 2,300 cu.ft. of gas at 2,400 p.s.i.

26. It was anticipated that at the deeper depths CO_2 build-up in the S.D.C. would present a problem. Accordingly four wire panniers, each holding about 2 lbs. of soda lime, were provided for hanging inside the upper half of the S.D.C. To assist absorption a gas driven fan was also mounted in the top of the chamber to stir up the atmosphere and blow directly on to one of the panniers, which could be moved round as necessary. The gas supply from the fan came from the S.D.D.E. breathing system and was tapped off on the I.P. side of the reducer. A needle valve here further regulated the supply and provided a fair range of speeds for the fan. It was noisy at speed but it was not expected that high speeds would be required. In fact, for the current series of trials, CO_2 build-up was negligible and the system was not used.

OXY-HELIUM MIXTURE

27. In order to be able to use the same mixture for all depths, a mixture containing oxygen between the limits 4½% and 5% in helium was ordered. This was supplied in Admiralty-owned 200 cu.ft. cylinders at 1,800 p.s.i. by the British Oxygen Company. Time did not permit obtaining supplies from American Naval sources which would have been considerably cheaper. On testing, with a Servomex Model 101 Oxygen Analyser, the contents of the 25 cylinders supplied for the first series the distribution was found to be:-

No. of cylinders.	1	1	5	12	5	0	1
Oxygen	4.75%	4.80%	4.85%	4.90%	4.95%	5.00%	5.05%

This was considered very satisfactory and, for the 75 cylinders supplied for the second series, only spot checks on selected cylinders were carried out.

GAS STORAGE

28. The facilities on board H.M.S. RECLAIM consist of two four-stage air compressors and ten 9.1 cu.ft. water capacity cylinders. During these trials the two cylinders on the starboard side of the Diving Flat were used for oxy-helium and the rest used for air. Before compression began the piping from the compressor to this twin bank was isolated from the rest of the complex pipe network and blown down to atmospheric pressure. The method of transferring the helium to the storage bank was as follows. The storage cylinders were blown down into a large rubber bag of 1,000 gallons (160 cu.ft.) capacity which was connected by a 3 in. hose to the intake side of one of the air compressors. (The bag was obtained from Fireproof Tanks Ltd., Portsmouth), and was of the type designed primarily for transporting oil. The compressor was run in the normal manner but drew gas from the bag instead of from atmosphere. Twenty one 200 cu.ft.

cylinders were blown into the bag and compressed into the bank. The resulting pressure was 3,100 p.s.i. By Boyle's Law this should have been 3,300 p.s.i. but the compressibility factor could reduce this by up to 10%. Furthermore, 100 p.s.i. was left in each 200 cu.ft. cylinder which, with the small bore manifold in use, could not be readily scavenged. It is fair to say, therefore, that there was no loss.

29. After compression a significant volume of helium remained in the compressor separator and filter, also at 3,100 p.s.i. This was scavenged by connecting these to the storage ring built round the S.D.C. and equalising. The resulting pressure was 200 p.s.i. so there was minimal wastage here. The compressed gas was free from odour.

30. Since the helium was compressed into a large volume (18.2 cu.ft. water capacity) containing air at atmospheric pressure and this was then equalised into the S.D.C. storage ring (10.5 cu.ft. water capacity) also containing atmospheric air, the resulting mixture in the ring should have had an oxygen content above the 4.90% originally put in. But if atmospheric air had also been drawn into the compressor on the input side then the oxygen content of the resultant mixture would be even higher. By computation the mixture in the S.D.C. ring, if uncontaminated at the compressor input, should have had an oxygen content of 5.14%. As measured by the Servomex instrument it was in fact 5.15%. The difference is within experimental error and it can be concluded that there was no contamination.

31. The improvised arrangements therefore gave completely satisfactory results and great credit is due to Mr. S. Williams, Experimental Officer, who devised and implemented them. Nevertheless they were complex and for future trials it is strongly recommended that more permanent arrangements be made to obviate the risks of mistakes in cross-connecting etc. It is also particularly important to pay careful attention to the tightness of valves, joints etc. when storing helium. It was some time before a constant pressure gauge reading could be obtained over a twenty-four hour period.

SUPPLY OF GAS TO THE S.D.C.

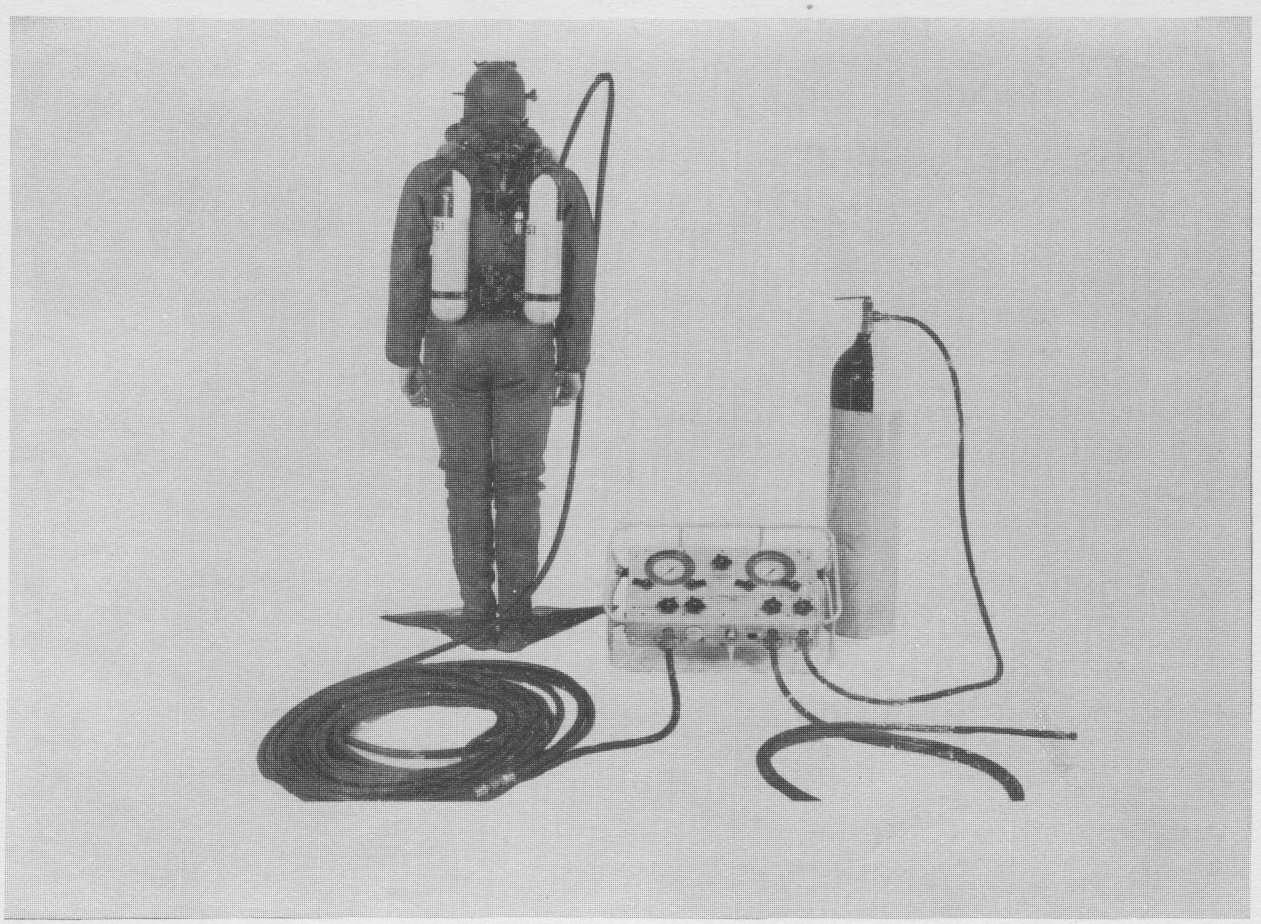
32. Gas was supplied to the S.D.C. by Standard Diving hose which had been tested to 900 p.s.i. although it was not intended to use it at more than 700 p.s.i. even for a 1,000 ft. dive. Control of the gas was given to the divers by setting sufficient pressure on the reducer supplying the S.D.C. The hose length was 495 ft. for all dives and a pressure of 450 p.s.i. was found adequate to keep the chamber dry for dives to 300 ft. with a rate of descent of 100 ft. per minute. This pressure would probably cope with a dive to 500 ft. and even deeper where helium was used instead of air.

SURFACE DEMAND DIVING EQUIPMENT

33. The S.D.D.E. breathing sets were modified to remove the mechanism which gives double compensation for depth. This was necessary because the high pressure delivered to the demand valve at depths over 300 ft. would make breathing heavy and also because, after a certain depth, the reducer pressure would exceed the relief valve setting and the set would blow off continuously. For the same reason the normal 100 p.s.i. plus one p.s.i. per foot of depth was not applicable. Instead a manual control was supplied which could be set to give the most comfortable breathing at depth. This was tested in the laboratory at the equivalent of 1,000 ft. and gave adequate, though not luxurious, breathing.

PLATE 4. Surface Demand Diving Equipment (S.D.D.E.)

(a) Front View



(b) Rear View

34. In practice the modified S.D.D.E. worked well and no trouble was experienced except on two occasions during the first dives to 300 ft. The reducer supplying the S.D.D.E. developed H.P. leaks due to metallic particles lodging on the valve seat which caused continuous blow-off of the breathing sets. On one of these occasions the resulting high flow caused a heavy ice deposit to build up round the reducer, but the diver in the water was quite unaware that there was a fault since his gas supply was unimpaired. Thus the system failed safe. No further trouble was met on replacing the seating but a large area porosint filter was fitted for the second series of trials.

SAFETY ARRANGEMENTS

35. The following arrangements were made:-

(a) The main Recompression Chamber was kept available for immediate use throughout the trials.

(b) Divers were required to remain on board for 4 hours after a dive.

(c) Adequate numbers of personnel were kept on board to deal with any incident which might arise.

(d) All divers were given written instructions, in Norwegian, to ensure that they would be returned immediately to the ship should they become ill while ashore.

(e) One diver in the S.D.C. acted as stand-by diver for the other. Except in emergency, which might require the second diver to go to the assistance of the first, only one diver was permitted to leave the S.D.C. at any time.

(f) A diver with S.A.B.A. was also immediately available in the Diving Flat in case of any difficulties with the S.D.C. or divers near the surface.

(g) A boat was always available while diving operations were going on to provide help to a diver in difficulties on the surface. For the same purpose a diver dressed in Underwater Swimmers' Dress, and Fins, with a long recovery line, was kept ready in the Diving Flat.

(h) Arrangements were made, and exercised, for hoisting the S.D.C. by forward capstan in the event of failure of the winch. Carpenters' stoppers were quite satisfactory on the special non-spin wire.

NOTE

Other restrictions which were aimed at safety and related to the interval between dives are described in Appendix 5.

GAS CONSUMPTION AND RESERVE AVAILABLE IN EMERGENCY

36. Before the trials consideration was given to the amount of gas available in emergency should the air pipe supplying the S.D.C. burst. In this event there are three sources of emergency gas supply:-

(a) The S.D.C. When dry and with two occupants this contained about 80 cu. ft. of gas. (This has been checked by practical measurement).

At 300 ft. (10 atmospheres) this is equivalent to 22,000 litres at surface. Initially this would be 5% oxygen so 1,100 litres of oxygen are available. At this depth the oxygen could be reduced to 2% so 660 litres of oxygen are consumable. A likely rate of consumption under these conditions would be about one litre per minute so two men could breathe for 330 minutes - 5½ hours. At 500 ft. they would have about 8 hours and as the depth increases so does the reserve of gas in the S.D.C.

(b) Storage Cylinders for S.D.D.E. When fully charged the cylinders contain 2,300 cu.ft. of free mixture. At 300 ft., due to the ambient pressure, only about 2,100 cu.ft. will be available. For an open circuit system a common rate of consumption is about 20 l.p.m. at the surface. At 300 ft. this would be 200 l.p.m., or 7 cu.ft. per minute, of atmospheric volume. Hence the system could supply one man for 5 hours or two men for 2½ hours. At 1,000 ft. the figures would be 86 minutes and 43 minutes. Thus the time on the open circuit system deteriorates as depth increases while that from breathing from the gas in the S.D.C. improves. However, in real emergency the S.D.D.E. supply should be blown into the S.D.C. atmosphere which would have the effect of doubling the endurance given in (a) above.

(c) The S.D.D.E. Emergency Cylinders. These cylinders contain 1,200 litres of atmospheric air but at 300 ft., at 200 l.p.m., only 6 minutes endurance could be expected. These cylinders can therefore virtually be discounted.

37. In any other emergency, when the supply hose to the S.D.C. is intact, the chamber can be fed continuously from the surface.

38. In practice it was found that the average consumption using S.D.D.E. was about 1.2. cu.ft. per minute at surface or 12 cu.ft. per minute at 300 ft. but, if allowance is made for the fact that moderate work was being done, this agrees reasonably well with the figure of 7 cu.ft. per minute, with minimum work, given in paragraph 36(b) above.

EXERCISE

39. During the earlier dives in the Recompression Chamber the divers did not exercise. In the sea dips they inevitably did more work and it is possible that this may have contributed to the incidence of bends. Some form of exercise should be taken during all future R.C.C. dives before the same schedules are used for sea dives.

PERSONNEL

40. The first phase of the trials was terminated by a serious case of decompression sickness which resulted in the paralysis of A.B. WANNERTON. In spite of this, and in the full knowledge that they might suffer the same fate, the divers who took part in the trials cheerfully carried out all that was required of them without hesitation. The standard of teamwork was high and all, whether fit for diving or not, played their part. At present no extra pay is given to divers to compensate for the risks inherent in normal diving using proven equipment, schedules and techniques. It is considered that for experimental diving, where the risks are unknown, extra pay should be given.

PART II TO PROVE DECOMPRESSION SCHEDULES

41. The progress of trials from this aspect are fully covered in Appendices 1 and 2 which deal respectively with the Medical and Physiological aspects of the trials. A summary is, however, included in this part of the report.

42. The requirements were that satisfactory dives in the Recompression Chamber, followed by satisfactory dives on the same schedule in the sea, should be carried out at each depth, starting at 300 ft. before moving on to a maximum depth of 450 ft. After the first series of trials it was stipulated that :-

(a) At least 10 successful dives should be carried out in the Recompression Chamber followed by 10 successful dives in the sea before moving down, in 50 ft. increments, to the next depth.

(b) Every diver should carry out a satisfactory dive in the Recompression Chamber before carrying out a dive at the same depth in the sea.

43. These stipulations were made by the Chairman of the R.N.P.R.C. after full consideration of the accident to A.B. WANNERTON which occurred during the first series of trials, the recommendations of the Flag Officer, Scotland and the conclusions of a meeting held by D.G.W.(U) to consider the trials. Copies of the Trial Orders for both trials and the Chairman of the R.N.P.R.C's letter of 29th June 1962 are included as Appendices 3, 4 and 5.

RESULTS

44. A new decompression schedule was used for the 250 ft. dives on air and resulted in a decompression time shorter than that for 180 ft. dives on Table I. It was used successfully with all but two divers who were eliminated from the trials as being unduly susceptible to the rapid rates of ascent involved. A schedule for 300 ft. air dives, based on the same principles, was used successfully for a total of 19 R.C.C. dives during preliminary trials by R.N.P.L. It was considered that the use of helium instead of nitrogen should be safer and two dives in the R.C.C. to test this theory appeared to be completely successful. It was therefore decided to start dives in the sea to 300 ft. Six dives, that is three descents of the S.D.C. with two divers in it in each case, were carried out using this schedule. The first dive resulted in serious decompression sickness for both divers. However, since it was clear that due to depth gauge errors (see paragraph 22) the 40 ft. stop had actually been done at 26 ft. and the 20 ft. stop at only 6 ft., this was hardly surprising. The two divers concerned reacted normally to treatment and there appeared to be no reason for not continuing the trials once their treatment was finished. Accordingly a second dive was carried out using the same schedule. This was completely successful but the third dive, under exactly the same conditions, resulted in the serious accident to A.B. WANNERTON which is fully reported in Appendices 1 and 2.

45. This incident brought the first series of trials to a close but, after full consideration by the R.N.P.R.C., approval was given for the second series of trials to proceed subject to the restrictions referred to in paragraph 42 above.

46. In the intervening period before trials were resumed some Recompression Chamber trials were carried out at R.N.P.L. but these had not produced a tested schedule when H.M.S. RECLAIM again sailed for Norway. Therefore, after sea dives to 180 ft. and 250 ft. to perfect drill and techniques, further 300 ft. trials in the Recompression Chamber had to be carried out before work in the sea could continue.

47. Nine divers tried out a new schedule but, since there were three major cases of decompression sickness, it was revised to make the change back from oxy-helium to air at 190 ft. (the first stop) instead of at 100 ft. Twelve divers carried out successful dives on this schedule. A thirteenth suffered a bend which was successfully treated on Table 4 but, since he was nearly eliminated before this dive because of undue susceptibility, it was decided to accept this schedule and proceed with 300 ft. dives in the sea.

48. Three two-diver dives were carried out on 13th July and one bend resulted. It was suspected that this was a result of the greater amount of exercise taken on the sea dives and it suggested that the schedule was very close to the limit. It was considered that far greater value would be obtained by carrying out five more dives at 300 ft. than from again altering the schedule. These were started after every diver had had at least 60 hours since his previous dive, but by the time eight divers had been down there were four major cases and three minor cases of decompression sickness. Only one diver was completely clear.

49. It was concluded that breathing an oxy-nitrogen mixture (i.e. air) after an oxy-helium mixture was causing stabilisation of minute helium bubbles formed during the oxy-helium breathing stage. It was therefore decided to use oxygen for decompression from 30 ft. and also, since there was no question in the time remaining of being able to go below 300 ft., to use a greater percentage of oxygen (about 20%) in the oxy-helium mixture. In the past oxygen was always used for the later stages of decompression when Deep Diving but it was thought that the object of this was to reduce the otherwise very long decompression times. No mention is made in any reports of any other reason for breathing oxygen.

50. A new schedule was worked out and so ten more trouble-free Recompression Chamber dives were needed before sea dives could be carried out. Four were carried out (two divers per dive) but one of the last pair suffered a bend which required treatment on Table 2. This diver had been under pressure for 30 hours (as R.C.C. attendant) 56 hours before, and 48 hours before had complained of minor symptoms. It therefore appeared that 48 hours between helium dives was not long enough and it was decided that those divers who had had clear dips should be given a further R.C.C. dive after a 72 hour interval. Three dives (two divers per dive) were carried out and they were all trouble-free. However, it would have been necessary to wait a further 72 hours before sea dives on this schedule could have been carried out and, since H.M.S. RECLAIM's trial programme did not permit this, the trials were concluded.

APPENDIX 1 TO A.E.D.U. REPORT NO. XXIX

REPORT ON MEDICAL ASPECTS OF DEEP DIVING TRIALS 1962

By

Surgeon Lieutenant Commander D. E. Mackay, R.N.

BACKGROUND

It has been known that frequent diving on air to depths of the order of 300 feet and deeper is dangerous because of the effects of the gases used, normally at atmospheric pressure, to sustain life. An artificial atmosphere has been shown to be a practical solution in the past, with helium as the gas chosen to form the inert volume expander and with the proportion of oxygen reduced as compared with air. However to avoid the consequences of a long duration for the return to the surface, it has been usual to breathe pure oxygen, rather than the mixture, from a predetermined depth, to encourage the elimination of the inert gas from the body.

2. The men who carried out such diving started as fully trained divers on air, with many years experience. During the practical deep diving training period, it was rare for any diver to have more than one helium dive in any week though he could have one or two other dives on air as the attendant to a helium diver during that week. It was customary to have at least 48 hours between dives for each individual; to devote Saturdays to maintenance and preparation for the following week; and to have Sundays as a day of rest.

3. These 1962 trials had several differences in procedure enforced by circumstances. The calibre of the men was as good as on previous trials, but their general experience was limited to a maximum of 180 feet; however 2 men had previously been deep divers but had not had any such experience for at least the past 4 years. Praiseworthy attempts had been made to give all divers experience of air at 300 feet in recompression chambers but nobody pretended that this was a substitute for the drill, techniques, equipment, and mental attitude involved in a dive in open water to a similar depth; it did reduce some of the element of strangeness and as such was highly justified.

4. The breathing equipment was not specially devised for deep diving but consisted of adaptation of existing equipment; this was perhaps an advantage in that there was familiarity with the actual breathing apparatus.

5. Other factors had to be considered; of these the most important were the shortage of helium and the fixed dates of the availability of H.M.S. RECLAIM. The effect of these limitations was that there was insufficient time to carry out the full experimental programme before joining the ship, especially in the section involving the exposure of men to the oxy-helium mixtures in a recompression chamber. This meant that part of the short time that H.M.S. RECLAIM was available had to be spent carrying out this work before the men could carry out the dives in the water. Relevant, though minor, factors were the shortage of divers available for experimental work to replace those in the team who either became unfit or were withdrawn as unsuitable; the loss of experience, both practical and theoretical, on the use of helium and its problems due to the long period of no-helium diving; and the lack of any means of analysing the inert constituents of a gas mixture so that some doubt always lingered about the helium and nitrogen percentages.

6. Some of these problems were appreciated before the trials started, others became obvious as they progressed. Consideration had to be given to many points, such as the number of dives which should be done at each depth both in the chamber and in the sea; the depth interval between schedules; the interval between dives for each individual; the tolerances (e.g. gas percentages, depth gauge, errors etc.) acceptable for a satisfactory dive; the standard of accuracy for depth, and, not least, the means of treating any casualties. The problems were resolved by meeting with members of the R.N.P.R.C. before the trials started and at the daily assessment meetings of the trials officers while the trials were in progress.

RESULTS

7. The diving time was divided into two periods by the operational calls on H.M.S. RECLAIM. The interval between these periods was spent testing tables in H.M.S. VERNON with a few of the divers from the team and some others that volunteered.

8. Altogether diving, in the chambers and in the sea, was carried out on 23 days. 29 divers in all took part and 197 dives were carried out in all circumstances. The first period in H.M.S. RECLAIM had diving on 7 days during which, in the chamber, 29 dives were done to 300 feet breathing air; 2 dives to 300 feet breathing an oxy-helium mixture, and 4 dives to 400 feet using the same oxy-helium mixture; 42 dives were done in the sea at 3 depths to 250 feet using air and finally 6 dives were done in the sea using an oxy-helium mixture. This makes totals of 35 chamber dives and 48 sea dives or, put another way, 12 helium dives and 71 air dives. The interval period in H.M.S. VERNON was occupied by diving in a recompression chamber on 4 days when 10 dives to 300 feet using an oxy-helium mixture were done. The second period in H.M.S. RECLAIM fell naturally into two phases. In the first phase 52 dives were carried out, breathing air continuously, to depths of 180 feet and 250 feet in the sea; this phase lasted 4 days. The second phase contained 8 diving days and all diving was at 300 feet using an oxy-helium mixture; 14 of these dives were in the water and 36 in the recompression chamber. The totals again are 52 air dives and 50 helium dives, or 36 chamber dives and 66 sea dives.

9. In all, 3 major cases of decompression sickness occurred during the air dives and 17 during the dives when oxy-helium was breathed. The cases of minor decompression sickness were 14 and 10 respectively. Due to the many changes in schedules there is no advantage in expressing these figures as percentages.

Table I summarises these dives.

THE DECOMPRESSION TABLES

10. The first tables used for dives to 300 feet breathing air were based on tables used successfully at R.N. Physiological Laboratory. The calculations assumed a descent rate of 100 feet per minute and a stay of 10 minutes at depth. If the descent was too slow then the balance of time was deducted from the bottom time so that the start of the ascent was never more than 13 minutes from the start of the dive. If the descent was too fast, the bottom time remained at 10 minutes so that the ascent began less than 13 minutes from leaving the surface. Experience had shown that the decompression schedules produced severe itching in a chamber (the degree varied with the chamber) and though it was appreciated that the problem would be less in immersed conditions, the use of the S.D.C.-T.U.P. could make this a troublesome complication.
A variation was therefore introduced in that there was a rest at 140 ft. on the

TABLE I

STATEMENT OF RESULTS

DATE 1962	MAY									JUNE			
	25	27	29		30		31			1		2	
	FIRST PERIOD												
DEPTH Ft.	300	300	300	80	300	80	300		180	400	250	400	300
SCHEDULE	First Air	First Air	Second Air	Table I	Second Air	Table I	Second Air	First Helium	Table I	Helium	Special Table	Helium	First Helium
ELEMENT	Dry	Dry	Dry	Wet	Dry	Wet	Dry	Dry	Wet	Dry	Wet	Dry	Wet
NUMBER OF DIVES	3	7	9	10	8	10	2	2	12	2	12	2	6
MAJOR CASES	-	DA	-	-	-	-	-	-	-	UL AN	-	-	CK MR WA
MINOR CASES	GR BO CO	WH.RO PR.FE	-	-	-	-	-	-	-	-	WH	-	-
CLEAR	-	RE WA	SC.MA MR.WI GR.CK AN.EN UL.	CO.WA RO.DR WL.WH RE.FE PR.BO	WH.FE DR.PR BO.CO RO.WA	SC.WI CK.AN GR.EN JA.UL MR.MA	GR MC	MA EN	PR.WA MR.CK WH.BO SC.CO BO.FE WI.DR	-	MR.CK FE.RO CO.SC PR.WA BO.GR WI.	GR WH	BO CO PR

NOTE: Heavy vertical line indicates interval of 48 hours or more between diving days.

TABLE I (contd.)

STATEMENT OF RESULTS

DATE 1962	JUNE				JULY			
	21	22	25	26	4	5	6	7
	INTERVAL				SECOND PERIOD - AIR			
DEPTH Ft.	300	300	300	300	180	250	180	250
SCHEDULE	Second Helium				Table I	Special Table	Table I	Special Table
ELEMENT	Dry	Dry	Dry	Dry	Wet	Wet	Wet	Wet
NUMBER OF DIVES	2	4	2	2	14	14	12	12
MAJOR CASES	-	FU	AD	-	-	DA RB	-	-
MINOR CASES	-	-	MK	MC	-	MR.RO RE.PR SC.	-	MR CO
CLEAR	CO RO	SC BE JC	-	PO	MR.CK FE.RO RB.RE WI.PR WH.BO SC.CO DA.DR	CK.FE CO..H BO.WI DR.	CK.MR FE.RO RE.DR PR.CO WH.BO WI.SC	CK.RE DR.RO FE.PR WH.BO WI.SC

NOTE: Heavy vertical line indicates interval of 48 hours or more between diving days.

TABLE I (contd.)

STATEMENT OF RESULTS

DATE 1962	JULY							
	9	10	11	12	13	16	20	23
	SECOND PERIOD - OXY/HELIUM							
DEPTH Ft.	300	300	300	300	300	300	300	300
SCHEDULE	Third Helium	Fourth Helium					Fifth Helium	
ELEMENT	Dry	Dry	Dry	Dry	Wet	Wet	Dry	Dry
NUMBER OF DIVES	9	4	6	3	6	8	8	6
MAJOR CASES	FE WH BO	-	-	WH	DR	BO PR CO WI	MR	-
MINOR CASES	MR	MC	-	-	MR	SC RO MR	SC RO	-
CLEAR	CK.RO CO.PR SC.	WI DR RE	CK.MR CO.PR SC.RO	FE BO	RE WI PR CO	FE	DR.RE FE.BO CO.	DR.FE RO.BO SC.CO

NOTE: Heavy vertical line indicates interval of 48 hours or more between diving days.

ascent for 1 minute to reduce the incidence of itching which, while of nuisance value only, could be most uncomfortable. This kind of pause was referred to as an "anti-itch" stop. A further departure from established custom was the disappearance of a decompression stop at 10 feet as the stay at 20 feet was made long enough to allow direct surfacing; (the main advantage of this is in open dives where depth keeping at 10 feet may be difficult in some kinds of sea state and weather). 10 dives were carried out, each with a total decompression time of 27 minutes. There were 7 cases of itching and 1 case of decompression sickness, which took the form of chokes with spinal symptoms.

11. In view of these findings, the air tables were modified to slow the rates of ascent between stops, and the stop at 140 feet was replaced by a pause at 150 feet and 2 minutes at 90 feet; the total decompression time thus became 35 minutes. 19 dives on this schedule were carried out with no minor or major incidents and this table was adopted. It was considered that the use of helium instead of nitrogen should be safer and two dives to test this theory appeared to be completely successful. A 5% oxygen/95% helium mixture was breathed from 100 feet during descent to 90 feet during ascent - a total of 15 minutes.

12. During the first part of the first period, when twenty practice sea dives to 80 ft. and twelve to 180 ft. were carried out, there were no cases of medical interest. These dives were followed by 12 sea dives on air to 250 ft. on a schedule calculated on the same principle as the 300 ft. schedule. This schedule gave 10 minutes on the bottom, "anti-itch" stops at 130 and 80 ft. and a total decompression time of 21 minutes. One incident occurred at depth which was not due to the routine used, in fact the subsequent decompression did not seem to affect the diver adversely.

13. The stage was now set for the first oxy-helium dives in the water; but as the water dives had to be anticipated, 4 dives on oxy-helium in the chamber to 400 feet were tried first so that a table would be ready for the sea dives; the tables were calculated on the same principles. The first dive led to serious symptoms in both divers which were not considered to be due to decompression sickness as generally understood; this attitude was apparently justified by a second pair. On this schedule the "anti-itch" stops were at 220 and 140 feet; the total decompression time was 106 minutes; and the helium mixture was breathed from 100 feet on descent to 60 feet on ascent, a total of 21 minutes.

14. It was decided to commence the dives in open water to 300 feet for 10 minutes at depth, using the schedule which had a total decompression time of 35 minutes. 6 dives were carried out with 2 serious cases and 1 very serious case of decompression sickness. This bad result terminated the first period of the trials.

15. During the interval between the periods, a second oxy-helium schedule for 10 minutes at 300 feet was produced. A major departure in technique was a stop of 8 minutes duration at 100 feet to allow the transfer-under-pressure to take place. It was also considered, as a result of the cases, that the ascent rate had been too fast when helium was used, so this was slowed and an extra pause added so that the "anti-itch" stops were at 190, 160 and 130 feet, each for 2 minutes. Oxy-helium was also used for the first 6 minutes of decompression at 100 feet before completing the decompression on air. A decompression stop at 10 feet was reintroduced. This meant a total decompression time of 64 minutes with oxy-helium being breathed from 100 feet on descent to 100 feet on ascent i.e. a duration of 29 minutes. 10 recompression chamber dives were carried out with 2 major cases and 2 minor cases of decompression sickness.

16. The second period therefore started without a tested decompression schedule for 300 ft. Twenty-six work-up dives to 180 ft. were carried out without incident. These were followed by twenty-six dives to 250 ft. which resulted in two major and seven very minor cases of decompression sickness. Elimination of unsuitable men took place after this. (There were two of these, D.A. and R.B., both men who did not seem to be capable of ascent rates faster than 60 ft/minute after a stay of 10 minutes at 300 ft.)

17. To permit the sea dives to continue work had to start in the recompression chamber on dives to 300 feet for 10 minutes using oxy-helium on the third oxy-helium schedule to be calculated. The main modifications, as compared with the second schedule, were the much greater time at 20 feet, so that the total decompression time became 93 minutes, and the disappearance again of the 10 foot stop. Total helium breathing time remained at 29 minutes. 9 dives were carried out with 3 major cases and 1 minor case of decompression sickness. Consideration of the last 19 oxy-helium chamber dives suggested that the real problem was the great increase in duration of breathing the oxy-helium mixture. Based on this assumption, a fourth version of the schedule was produced; this was identical but for the single factor that oxy-helium was discontinued at 190 feet, being breathed only for a duration of 14 minutes. 13 dives were carried out in the chamber on this revised version with one very minor case and one, the last dive, a major case in a diver whose suitability was being questioned. This fourth version was then tested in the water with a total of 14 dives over two days; the first day saw 6 dives with one nominal minor case and one major case and the second day saw 8 dives with 3 minor and 4 major cases of decompression sickness. A study of the individuals disclosed a pattern which suggested that breathing an oxy-nitrogen mixture (i.e. air) after an oxy-helium mixture, led to stabilisation of minute bubbles formed in the oxy-helium breathing stage. Mention of this factor did not seem to be made in previous literature when oxy-helium breathing was always followed by breathing pure oxygen, ostensibly to reduce the very long decompression time which would have been required by the methods of calculation then in use if air was breathed as the main decompression respiratory medium.

18. Several changes were again made to produce a fifth version of the schedule. The gas mixture was changed from 5% oxygen/95% helium to 20% oxygen/80%helium approximately; the gas change over levels were altered to 100 feet on descent and 30 feet on ascent; transfer-under-pressure took place at 30 feet instead of 100 feet with helium being used for the first 6 minutes, and 100% oxygen for the remainder of the time at 30 feet as well as for the remainder of the decompression. The schedule thus had a total decompression time of 46 minutes with the oxy-helium mixture being breathed for a duration of 42 minutes and pure oxygen for 16 minutes. Initially 8 recompression chamber dives were carried out on this schedule; these resulted in 2 very minor cases and 1 major case of decompression sickness. This disappointing result could perhaps be explained by the interval between dives being too short as the diver with the major case had been exposed to increased pressure for 30 hours after the others and had had minor symptoms. Accordingly it was decided to repeat the same schedule with chamber dives by 6 of the remaining 7 men after 72 hours at normal atmospheric pressure. This resulted in neither minor nor major cases of decompression sickness. Thus a total of 14 dives on the fifth schedule resulted in 2 minor incidents and 1 major incident, and tended to confirm the opinion on the aetiology of trouble on a second dive. Confidence was such that exercise was carried out in the chamber on each of these fifth schedule dives, (the exercise consisted in passing a 40 lb. back weight about 10 times per minute from one diver to the other, and could be considered moderately heavy work).

THE MEDICALS

19. All divers on board H.M.S. RECLAIM were examined by the ship's medical officer, Surgeon Lieutenant B.H. Delany R.N., before the start of the trials. This included the Norwegian volunteers. In the first period and during the interval period, men were also examined before each dive on oxy-helium mixtures. In the second period, the divers were examined before each dive. Divers were closely questioned after their dive and examined at surface pressures (if possible; if not, under recompression), if there were any complaints. Apart from the basic examination, the frequent medical checks were to ensure that a man was fit to carry out the detailed dive and was not handicapped by lack of sleep or any other cause; particular emphasis was placed on examination of ears, sinuses, chest and blood pressure.

20. In the first period one diver was excluded because of incomplete recovery from a rib injury; one diver developed aural barotrauma on his second chamber dive and one diver found that the rate of ascent used was too rapid for him, none of these took part again in that period as a diver. In the second period the effect of the rate of ascent was confirmed on the diver previously affected, and was discovered in the man who had previously had the rib damage but who was now fit to dive. The man with ear trouble was clear but another man developed a painless perforation in a scarred drum during a chamber dive; again these affected men were withdrawn from the trial. One man developed trouble in each period as a result of a late night and too much beer and, after several misleading statements, he also was withdrawn from further dives.

21. The interval between dives was accepted as 48 hours for dives of 300 feet and deeper but no fixed interval was agreed as the period of absence after an attack of decompression injury. Where there were no residual symptoms of decompression sickness 72 hours was regarded as suitable. The distinction between stiffness from the cramped position in the smaller chamber, or a feeling of bruising, and residual minor symptoms was not always clear - even if the patients were not intent on minimising symptoms - and some errors were undoubtedly made at the time which, in retrospect, became obvious and an interval of one week would have been more suitable. The last few days of diving showed that the interval between dives depended perhaps more on the gases breathed than the actual depth and duration of the dives.

THE DIVERS

22. There were 29 different men involved in the various stages and phases of the trial. 14 men carried the main burden and performed 169 of the 197 dives done; 7 of these were part of the diving team of H.M.S. RECLAIM, 5 from the Admiralty Experimental Diving Unit, 1 from the R.N. Physiological Laboratory and 1 from the Royal Norwegian Navy. Of the remaining 15 men, 4 rating divers of the Norwegian Navy did 3 dives each; the remaining 3 men of the diving team in H.M.S. RECLAIM carried out 6 dives; and 8 men from the Admiralty Experimental Diving Unit did 10 dives. The details of the men are described.

Diver A.D.	A.E.D.U.	Age 27	
	Experience	Clearance diver third class	10.10.54
		Clearance diver second class	4.12.56
		Clearance diver first class	22. 9.61

Diver A.D.	Dives: 1	a) 1 oxy-helium dive; 0 air dives
		b) 1 chamber dive; 0 sea dives
	Effects: 1	major case of decompression sickness
Diver A.M.	R.Nor. N.	Age Early twenties
	Experience:	Norwegian frogman (i.e. partly clearance diver, partly assault swimmer)
	Dives 3	a) 1 oxy-helium dive; 2 air dives
		b) 1 water dive; 2 chamber dives
	Effects: 1	major case of decompression sickness:
	Note:	not available after first period.
Diver B.E.	A.E.D.U.	Age 24
	Experience:	Clearance diver star 20. 3.59.
		Clearance diver second class 29. 9.61.
	Dive: 1	a) 1 oxy-helium dive; 0 air dives
		b) 0 water dive; 1 chamber dive
	Effects:	no ill effects.
Diver B.O.	H.M.S. RECLAIM	Age 21
	Experience:	Shallow Water diver 1. 2.58.
		Diver third class 18.12.59.
		Clearance diver star 2. 2.62.
	Dives: 15	a) 6 oxy-helium dives; 9 air dives
		b) 9 water dives; 6 chamber dives
	Effects: 2	major and 1 minor case of decompression sickness.
Diver C.O.	A.E.D.U.	Age 29
	Experience:	Shallow Water diver 20. 1.53.
		Clearance diver third class 17. 5.53.
		Clearance diver second class 3. 8.56.
	Dives: 17	a) 8 oxy-helium dives; 9 air dives
		b)10 water dives; 7 chamber dives
	Effects: 1	major and 2 minor cases of decompression sickness.

Diver C.K.	H.M.S. RECLAIM	Age 28	
	Experience:	Clearance diver third class	14. 5.54
		Clearance diver second class	4. 5.56
		Clearance diver first class	21.10.60
	Dives: 11	a) 3 oxy-helium dives; 8 air dives	
		b) 8 water dives; 3 chamber dives	
	Effects: 1	major case of decompression sickness	
	Note:	Perforation L. ear drum on 11.7.62 and withdrawn from trials.	
Diver D.A.	H.M.S. RECLAIM	Age 36	
	Experience:	Diver third class	6.50
		Diver second class	6.52
		Clearance diver third class	11.54
		Clearance diver second class	6.56
		Clearance diving officer	3.61
	Dives 3	a) 0 oxy-helium dives; 3 air dives	
		b) 2 water dives; 1 chamber dive	
	Effects: 2	major cases of decompression sickness	
	Note:	Withdrawn from trials.	
Diver D.R.	A.E.D.U.	Age 41	
	Experience	First diving experience 1941	
		Qualified supervisor 1947	
		Clearance diving officer	6.50
		Standard & deep acquaint 1956	
	Dives: 11	a) 4 oxy-helium dives; 7 air dives	
		b) 7 water dives; 4 chamber dives	
	Effects: 1	major case of decompression sickness.	
Diver E.N.	R. Nor. Navy	Age early twenties	
	Experience:	Norwegian frogman	
	Dives: 3	a) 1 oxy-helium dive; 2 air dives	
		b) 1 water dive; 2 chamber dives	
	Effects:	No ill effects	
	Note:	Not available after first period.	
Diver F.E.	H.M.S. RECLAIM	Age 21	
	Experience:	Shallow Water diver	18.12.59
		Clearance diver star	6.12.61
	Dives: 14	a) 5 oxy-helium dives; 9 air dives	
		b) 8 water dives; 6 chamber dives	
	Effects: 1	major case and 1 minor case decompression sickness.	

Diver F.U. A.E.D.U. Age 26

Experience: Clearance diver third class 4.12.54
Clearance diver second class 23. 3.62

Dives: 1 a) 1 oxy-helium dive; 0 air dives
b) 0 water dives; 1 chamber dive

Effects: 1 major case of decompression sickness

Note: withdrawn from trials.

Diver G.R. R.N. Physiological Laboratory Age 36

Experience: Special course for C.D.O. 1961

Dives: 6 a) 1 oxy-helium dive; 5 air dives
b) 2 water dives; 4 chamber dives

Effects: 1 minor case of decompression sickness.

Diver J.C. A.E.D.U. Age 23

Experience: Clearance diver star 7.10.60
Diver third class 20.12.57

Dive: 1 a) 1 oxy-helium dive; 0 air dives
b) 0 water dive; 1 chamber dive

Effects: no ill-effects.

Diver M.A. R. Nor. Navy. Age early twenties

Experience: Norwegian frogman

Dives: 3 a) 1 oxy-helium dive; 2 air dives
b) 1 water dive; 2 chamber dives

Effects: No ill-effects

Note: Not available after first period.

Diver M.C. A.E.D.U. Age 34

Experience: Diver third class 6.57
Experimental diving 5 years

Dives: 3 a) 2 oxy-helium dives; 1 air dive
b) 0 water dives; 3 chamber dives

Effects: 2 minor cases of decompression sickness.

Diver M.K. A.E.D.U. Age 31

Experience: Clearance diver third class 8. 6.56
Clearance diver second class 29. 9.61

Dives: 1 a) 1 oxy-helium dive; 0 air dives
b) 0 water dives; 1 chamber dive

Effects: 1 minor case of decompression sickness.

Diver M.R.	H.M.S. RECLAIM	Age 22	
	Experience:	Shallow Water diving	31. 3.60
		Clearance diver star	6.12.61
	Dives: 14	a) 6 oxy-helium dives; 8 air dives	
		b) 10 water dives; 4 chamber dives	
	Effects: 2	major cases and 5 minor cases of decompression sickness.	
Diver P.O.	A.E.D.U.	Age 26	
	Experience:	Clearance diver star	21. 3.58
		Clearance diver second class	29. 9.61
	Dives: 1	a) 1 oxy-helium dive; 0 air dives	
		b) 0 water dives; 1 chamber dive	
	Effects:	No ill-effects.	
Diver P.R.	H.M.S. RECLAIM	Age 24	
	Experience:	Shallow Water diving	6.60
		Clearance diver star	11. 8.61
	Dives: 14	a) 5 oxy-helium dives; 9 air dives	
		b)10 water dives; 4 chamber dives	
	Effects: 1	major case and 2 minor cases of decompression sickness.	
Diver R.B.	H.M.S. RECLAIM	Age 30	
	Experience:	Diver third class	15. 8.52
		Diver second class	22. 7.55
	Dives: 2	a) 0 oxy-helium dives; 2 air dives	
		b) 2 water dives; 0 chamber dives	
	Effects: 1	major case of decompression sickness	
	Note:	Withdrawn from trial. This man had not fully recovered from rib injuries so he did not take part in the first period.	
Diver R.E.	H.M.S. RECLAIM	Age 24	
	Experience:	Shallow Water diver	2.58
		Clearance diver star	4. 10.58
		Clearance diver second class	1. 7.60
	Dives: 9	a) 3 oxy-helium dives; 6 air dives	
		b) 6 water dives; 3 chamber dives	
	Effects: 2	minor cases of decompression sickness	
	Note:	Developed blockage of Eustachian tubes on compression on 30.5.62 and withdrawn from first stage of trials.	

Diver R.O.	A.E.D.U.	Age 22	
	Experience:	Shallow Water diver	10.57
		Clearance diver star	10.59
		Clearance diver second class	3.62
	Dives: 15	a) 6 oxy-helium dives: 9 air dives	
		b) 8 water dives; 7 chamber dives	
	Effects: 4	minor cases of decompression sickness.	
Diver S.C.	A.E.D.U.	Age 30	
	Experience:	Diver third class	3.52
		Diver second class	7.54
		Diver first class	11.57
		Clearance diver first class	3.62
	Dives: 14	a) 6 oxy-helium dives; 8 air dives	
		b) 8 water dives; 6 chamber dives	
	Effects: 3	minor cases of decompression sickness.	
Diver U.L.	R. Nor. Navy	Age early twenties	
	Experience:	Norwegian frogman	
	Dives: 3	a) 1 oxy-helium dive; 2 air dives	
		b) 1 water dive; 2 chamber dives	
	Effects: 1	major case of decompression sickness	
	Note:	Not available after first period.	
Diver W.A.	A.E.D.U.	Age 28	
	Experience:	Clearance diver third class	29. 9.56
		Clearance diver second class	23. 3.62
	Dives: 6	a) 1 oxy-helium dive; 5 air dives	
		b) 4 water dives; 2 chamber dives	
	Effects: 1	major case of decompression sickness	
	Note:	Withdrawn from trials.	
Diver W.H.	H.M.S. RECLAIM	Age 33	
	Experience:	Diver third class	17.11.50
		Clearance diver third class	22. 4.52
		Clearance diver second class	1. 6.54
		Clearance diver first class	11. 5.56
	Dives: 12	a) 3 oxy-helium dives; 9 air dives	
		b) 7 water dives; 5 chamber dives	
	Effects: 2	major cases and 1 minor case of decompression sickness.	
	Note:	This man had an attack of syncope at 250 feet in the water. Withdrawn from trials.	

Diver W.I.	R. Nor. Navy		Age about 30
	Experience:		Norwegian standard diver and frogman officer
	Dives:	11	a) 3 oxy-helium dives; 8 air dives b) 9 water dives; 2 chamber dives
	Effects:	1	major case of decompression sickness.

Note: 1. Divers A.D., M.K., F.U., B.E., J.C. and P.O. took part in the interval dives at H.M.S. VERNON and were not available for either period aboard H.M.S. RECLAIM.

Note: 2. Diver J.A. of H.M.S. RECLAIM and Diver W.I. of A.E.D.U. were prevented by their supervisory duties from taking part in the trial for other than 1 dive each on air in the water to a depth of about 80 feet.

THE CASES

Minor Decompression Sickness

23. There were 24 instances where divers reported symptoms which were due to the decompression tables used. 12 of these were cases of itching; it seems that some divers are unduly susceptible to itching and that the same schedule, used in different circumstances such as a different chamber or on a different day, may lead to cases of varying severity in the individual diver. Apart from the first two days of diving to 300 feet on air in the chamber when 7 out of 10 divers had severe itching, this discomfort was only volunteered on five other occasions, all after dives to 250 feet in the water on air. Diver G.R. showed some interesting aspects of the problem. He had carried out a great many similar dives on air at R.N.P.L. and he seemed to be a good subject on whom to test the "anti-itch" schedule. On board RECLAIM this modified schedule, though longer in decompression time than the ones he had previously used, made him itch much more. On the whole, it was decided not to mention the matter after a dive to avoid a psychological complicating itch and to await complaint - this policy resulted in only one further case.

24. There were 8 cases of "niggles" after various dives in 5 divers. These "niggles" are described as a mild ache in an area with a feeling of loss of confidence in the stability and power in the part of the limb involved (all cases involved the limbs). Divers M.C. and M.K. developed these sensations in the upper arm (one in the right and the other in both arms) after diving on the second oxy-helium schedule. Diver M.C. had a similar episode in the right upper arm using the fourth oxy-helium schedule (14 days after his previous oxy-helium dive with no other diving in between). Diver R.O. had two episodes, one in his right shoulder after an air dive to 250 feet, the day after an air dive to 180 feet, and the other deep in his right hand on the chamber dive on the fifth oxy-helium schedule. This latter dive was an exercise dive and took place 4 days after a water dive on the fourth schedule had led to neurological signs of decompression sickness. Diver P.R. developed left shoulder tip ache after a dive in the sea to 250 feet on air, 24 hours after a similar dive to 180 feet. It was possible that this was due to muscle strain as he had made an error in assuming the S.D.C. had completed its descent and he left the vehicle; he was then dragged the remainder of the journey - a matter of 40 feet at a speed of 100 feet per minute. "Niggles" usually clear fairly rapidly, particularly after a hot bath, and this happened on the above occasions.

25. The remaining two cases of niggles occurred in diver M.R. who also developed a feeling of weakness in his knees. The sequence was an attack of niggles in his right shoulder after a dive to 300 feet in the chamber on the third oxy-helium schedule, 48 hours after a dive to 250 feet in the sea using air. After a further 48 hours, he dived on the fourth schedule in the chamber but, repeating this in the sea after another 48 hours, he developed a very mild sensation of weakness in his lower limbs which could not be substantiated on examination. 3 days later he repeated this latter water dive and had some slight niggles at the 20 foot stop which cleared at the surface. However, in case it developed again, he was recompressed as attendant to a serious decompression case. After the treatment had progressed to 5 hours at 40 feet M.R. was relieved by another diver attendant and was decompressed breathing pure oxygen for 45 minutes at 30 feet and 75 minutes at 20 feet. 6 hours later he was wakened by aching in his right knee which eased over $1\frac{1}{2}$ hours and he went back to sleep. In the morning there was residual stiffness which was assumed to be the result of the cramped position for the therapeutic compression. This was probably wrong in view of his own florid attack of decompression sickness after a later dive.

26. Diver S.C. had two episodes of a sensation of tightness in his chest on deep inspiration; both cleared within minutes and examination revealed no abnormality. The first occasion was after his water dive on the fourth oxy-helium schedule 5 days after his chamber dive on the same schedule; and the second occasion was 4 days later after his working dive in the chamber on the fifth oxy-helium schedule. Diver R.C. had a serious symptom after his water dive on the fourth oxy-helium schedule - again 5 days after the chamber dive on the same schedule. He surfaced with paraesthesia of his right hand attributed to a tight cuff on the suit he was wearing and which cleared within 10 minutes of changing. 30 minutes later he reported flashing lights in his vision and blindness; examination showed a large blind area in the lower outer quadrant of his left field of vision; improvement occurred during the examination, it was decided not to recompress and vision returned completely over the next 24 hours.

Other Minor Events

27. Diver R.E. suffered minor barotrauma to his ears during descent to 12 feet at the start of a 300 foot chamber dive on air . This resulted in his exclusion for the remainder of the first period as he could not catch up the various stages. However he was fully recovered and remained fit throughout the second period.

28. Diver C.K. regrettably suffered a large perforation of his left ear drum during his chamber dive to 300 feet on the fourth oxy-helium schedule. Apparently, due to scarring, he had no sensation of trouble during his dive and only a query on itching of his external auditory canal led to examination of his ears about an hour after he had regained the surface. He was withdrawn from diving during the remainder of the trial.

29. Diver W.H. posed quite a problem. He was one of the most experienced and able divers. During the first phase, while at 250 feet on air, he felt very faint and almost lost consciousness. However, his partner was able to cope and both returned to the surface. W.H. still looked a little faint and he was taken to the Sick Bay where he broke down and was obviously very depressed. He was withdrawn from the water diving team for the next day (which was the final day) but he pled his case well to be permitted to do the chamber 400 foot oxy-helium dive. This he was allowed to do and he carried out the drill in a splendid manner. Then it transpired that the night before his water dive he had been up with divers C.O. and S.C. and others till 0400 drinking beer. Presumably hangover plus apprehension plus

high oxygen partial pressure had combined to give a case of oxygen syncope. It is of interest that divers C.O. and S.C. had no difficulties. During the second phase, diver W.H. was again a leading figure till he developed decompression sickness (see later). (About one month later W.H. was seen by a psychiatrist who considered that the patient was liable to periods of depression).

Major Decompression Sickness

30. 15 cases were treated by recompression and 5 by other means. The reasons for this difference are given with each case as the decision was made on the clinical picture each time with the best interests of the patient as the overruling guide.

31. Diver D.A. had trouble on two occasions, each time breathing air. The first time occurred after a 300 foot chamber dive on the anti-itch air schedule. He had carried out several chamber runs to this depth before, using the Table III in the R.N. Manual adapted for air breathing throughout. This time - it transpired later - he continued his usual habit of controlled deep breathing "to eliminate the nitrogen more rapidly" but now the rate of ascent was 120 feet per minute to begin with and the total decompression was much shorter. His symptoms started as very mild difficulty in inspiration at 40 feet and had worsened slightly as well as being accompanied by mild chest pain on surfacing. His condition improved considerably and rapidly but an error was made in allowing him to carry out duties involving the ascent and descent of 4 ladders, each about 8 foot high, on two occasions before examining him, because after 20 minutes he developed difficulty in controlling his legs and then loss of power of his legs. He was immediately recompressed to 165 feet. His symptoms had cleared at 100 feet and examination at 165 feet was negative. It was decided to use therapeutic Table III but to use only 2 hours and not 12 hours at the 30 foot stop. This was apparently completely successful and it came as a shock to be told several days later that he had had a slight woolly feeling of his right foot persisting, which was not detectable on examination at the time. Apart from the patient's objections to the therapy, as there did not seem to be any advantage to be gained by recompression, no further action was taken.

32. His second episode occurred in the second period, 39 days later. A successful dive on air to 180 feet in the water using R.N. Manual Tables had been carried out the previous day. On this occasion, the tables devised on the theories on which the oxy-helium tables were based, were used to 250 feet. 12 successful dives had been done during the previous period using these tables, so confidence appeared to be justified. However a fast rate of ascent, of 120 feet per minute, was required. On surfacing, Diver D.A. again had a pain in his chest; difficulty in breathing; pins and needles of his whole body; skin flush and a marked skin rash. Examination confirmed the rash and there was an area of hyper-resonance in his left chest as compared with the right but no alteration of the breath sounds. His condition was improving continuously, so rest and observation were ordered and in about $1\frac{1}{2}$ hours he had made a complete recovery. On the assumption that for some physio-anatomical reason he could not carry out a fast ascent after a dive, he was withdrawn from the trial. (He has successfully carried out submarine escape training at 240 feet/minute ascent but this procedure involves a short exposure at 100 feet.

33. Diver R.B. This man had the third and last case of decompression sickness breathing air. He did not dive in the first period as he had not yet returned to diving following rib injuries. However, he was fully fit and had been diving in the chamber to 300 feet during the interval period, so he was accepted. Like diver D.A., on the second day, diving to 250 feet on air

on the fast schedules, he developed symptoms attributable to the fast rate of ascent. He had an ache in his left shoulder which cleared completely in 10 minutes, leaving him with a sensation of tightness of his chest. Examination disclosed a similar difference in resonance of the lung bases to diver D.A. No evidence could be found to confirm a sensation of numbness over the right forefoot. Again symptoms cleared rapidly so no treatment other than rest was ordered and he was withdrawn from the trial. There is little to be gained from speculation on the effect of his rib injury on the occurrence of this case. The remaining 17 serious cases all occurred during diving with oxy-helium mixtures, 16 with 5% oxygen/95% helium and the last with 18.5%/ 81.5% helium.

34. Diver U.L. and Diver A.N. These Norwegian divers carried out a chamber dive to 400 feet. Both men were trained to clear their ears by swallowing. Inside the chamber one used a surface demand diving equipment and the other a built-in-breathing system submarine escape breathing unit and a nose clip. Both sets were connected to the oxy-helium supply by an S.D.D.E. panel. The sets were donned at 100 feet on descent and doffed at 140 feet on ascent the compression being continued while breathing chamber air which was changed often. At 20 feet, diver U.L. complained of discomfort, backache radiating round the abdomen, and he looked distressed. Diver A.N. mentioned that he had a mild ache over the left shoulder area. They were examined by Surgeon Lieutenant Delany, who thought that distension was the major though not the entire trouble. Both men were recompressed with relief, especially in the case of diver U.L., by vomiting and retching as well as by increased pressure. Therapeutic Table II was used with complete success. It was considered that unfamiliarity with equipment and gas and depth had led to excessive gas being swallowed during ear clearing. It was therefore assumed that they were not true cases of gas bubbles forming in the tissues.

35. Diver C.K. and Diver M.R. These two men had been diving every day in the first period on the planned programme of 300 feet on air in chamber, 80 feet on air in water, 175 feet on air in water, 250 feet on air in water and now 300 feet on oxy-helium in water on successive days with one dive each day. The dive started according to plan with oxy-helium breathing starting at 100 feet and continuing till 90 feet was reached on the ascent. On arrival at 20 feet, the lower hatch was closed and transfer-under-pressure started and hurriedly completed when the divers requested a rapid increase in pressure. They were joined at 20 feet by Surgeon Lieutenant Commander D. E. Mackay, Medical Officer for the trials, and, because diver M.R. was writhing on the deck of the chamber having difficulty breathing, he ordered a pressure increase to the equivalent of 100 feet. It transpired that between 40 and 20 feet both divers had noticed slight difficulty in breathing; at 20 feet this became very marked and in diver M.R. was accompanied by a tightness in the chest, developing into a severe pain in the left chest which radiated all over his body. In the case of diver C.K. the symptoms had had a similar development except that the radiation was confined to the left shoulder and on to the occiput. Both men had recovered as soon as pressure was increased and at 100 feet, examination was negative except for slight stiffness in both men. Presumably both men had suffered from "chokes"; however, because of the rapid application of treatment, the rapid disappearance of symptoms and the knowledge of recurrence after therapy in some 20% of cases, it was decided to try therapeutic Table I, though if there was any trouble, Table IV would be immediately tried. Treatment was successful, both men being left only with a feeling of stiffness. During inquiry into this accident, it was discovered that the decompression had erred grossly as the stop depths, instead of being 40 feet and 20 feet, were 26 feet and 6 feet respectively. In view of the gross abuse of decompression and the apparent speed and ease with which adequate treatment could be given, it was decided to continue diving on the same routine. Divers B.O. and C.O. then carried out a successful dive and the third pair of divers started.

36. Diver W.A. was accompanied by diver P.R. and the dive was carried out as in the previous incident free dive. On arrival in the transfer-under-pressure chamber it was obvious that diver W.A. was deeply distressed, so pressure was immediately increased to 60 feet where the divers were joined by Surgeon Lieutenant Commander Mackay. It transpired that diver W.A. had had some slight difficulty in breathing at 40 feet which had become much worse at 20 feet but on return to 60 feet everything had cleared. Because of the experience of diver C.K. and diver M.R., therapeutic Table I was started with 30 minutes at 100 feet. However after 25 minutes, W.A. complained of coldness of his feet and numbness of the front of his thighs; he was therefore compressed further to 165 feet with relief of his coldness and almost complete relief of his numbness. It was decided to treat him with 2 hours at 165 feet and then decompress on therapeutic Table IV. Unfortunately his condition deteriorated and after 2 hours, examination by Surgeon Lieutenant Delany showed that he had a complete paralysis to the nipple level and complete anaesthesia to the same level with paraesthesia for a proximal two inches. In the state of knowledge at that time, it was decided to continue the decompression and to use a 60% oxygen/40% nitrogen mixture for the last hour at 60 feet and the first hour at 50 feet with perhaps 100% oxygen at a later stage. Nursing problems were prominent and antibiotics and sedatives were used as required. The effect of the mixture breathing was mixed in that there did not appear to be any objective deterioration on examination but the patient was much worse; this seemed to be due to the resistance to respiration of the NOVUS apparatus used and the discomfort due to the weight and heat of the equipment. At any rate, his morale improved after it was discontinued and he was eventually transferred, in a similar physical condition, by BRITANNIA aircraft of R.A.F. Transport Command from Bergen to R.N. Hospital, Haslar. His attendant, diver P.R., was naturally exhausted and cramped and it was considered fair to relieve him after he had been at 30 feet for 1 hour by decompressing him for 1 hour at 20 feet and for 1 hour at 10 feet. He surfaced with a slight ache in his right knee which deteriorated to a fairly severe ache but, rather than recompress him, it was decided to use analgesics and sedatives and his condition improved over 48 hours. Consideration at a later date brought forth the suggestion that oxy-helium might have been used and perhaps an increase in depth to a maximum of 300 feet. Reading the U.S.N. Manual, it was found that these suggestions are in fact recommended there if required. Other literature recommends flushing doses of nicotinic acid and the use of urea has been discussed though it does not appear to have been used. The subsequent decompression was a problem that would have had to be solved at the time. It was hoped not to need such a table again.

37. Diver F.U. This diver took part in the chamber trials of the second oxy-helium table during the interval period at H.M.S. VERNON. He surfaced with a stiff right arm which fairly rapidly developed into a severe pain. There was a personality clash between diver and diving officers and he was not recompressed because of doubt as to his symptoms. His condition took over 3 days to reach full recovery; he was told at this time that he would not be taking any further part in the trials.

38. Diver A.D. Again this was an interval chamber dive on the second oxy-helium schedule. The diver had slight stiffness of both his shoulders on leaving the chamber but this gradually worsened till, when he reported after 2½ hours, he had to be recompressed because of severe pain in both shoulders but much worse on the right. Symptoms were relieved at 120 ft. and treatment was carried out on therapeutic Table II. There was a mild recurrence in the right knee which it was originally decided to treat conservatively. However after 24 hours he had not completely recovered and, in the absence of the trials officers, he was recompressed. Thirty minutes at 165 ft. gave little relief and he was returned to atmospheric pressure using therapeutic Table II. He considered that there was some relief at the surface. There was some fluid in his knee so there might have been some other

injury, even if this was not disclosed, to explain the change of site and the only slight response to treatment.

39. Diver F.E. This case occurred during the first oxy-helium dive on the third schedule . His last dive was on air to 250 feet in the sea 2 days before. There were four divers in the chamber using the equipment and there was a need to open some more supply cylinders. Diver F.E. became confused and moved valve openers the wrong way and strained at several cylinders before achieving his task. During decompression, after 8 minutes at the 20 feet stop he developed an ache in the sacro-iliac region which became severe in 3 minutes and then proceeded to clear over the next 15 minutes. Examination in the chamber was negative. However after 5 minutes on the surface, symptoms recurred as a mild ache, and on examination, there was weak extension of both legs. His condition was fair and in view of the earlier improvement, it was decided to keep him under observation and he recovered till there were no signs though he still felt some weakness after 2 hours. This condition persisted for 24 hours and the correct action would have been recompression but the patient was more comfortable and preferred the sick bay bunk to the recompression chamber: his treatment was therefore shorter and more comfortable than recompression. It was decided to continue the testing of the schedule.

40. Diver W.H. and Diver B.O. The last dive by this pair had been 48 hours before to 250 feet on air in the sea. These men were the 8th and 9th tests of the third helium schedule in the chamber and the dive continued normally to 20 feet. After 20 minutes there, diver B.O. developed a dull ache in the coccygeal area with slight numbness of his right foot, all of which cleared before reaching surface. However, the symptoms then recurred and increased in severity and there was a marked rash. The ache sharpened and spread to the perineum and pain developed in the left shoulder. Muscle power was lost in his legs while he was being put back in the compression chamber. Diver W.H. had been normal during the decompression but about 10 minutes after surfacing, he developed a sudden severe pain in his left calf and upper left thigh. Both divers were recompressed. Diver B.O. had recovered at 100 feet and diver W.H. at 165 feet; both men were decompressed on therapeutic Table II; and both men reported well afterwards. As always, there were some disclosures after such troubled dives. Divers F.E. and B.O. had been canoeing the previous evening for two spells of about 30 minutes in the course of 2 hours. Diver W.H. had been drinking heavily the previous day although he seemed well on examination, (it transpired he had been comatose at one stage in the evening).

41. 60 hours after leaving the chamber apparently perfectly fit, Diver W.H. was due to dive again. He seemed fit and there was definitely no indiscretion on that occasion and he was permitted to dive in the chamber on the fourth oxy-helium schedule. At the 20 foot stop, he complained of pain in his chest and numbness and stiffness of hands, wrists, thighs, feet and in his buttocks. His condition deteriorated and the pain spread as an ache to his lumbar area. He was recompressed, along with Surgeon Lieutenant Commander Mackay but there was little change at 60 feet and 100 feet and he was compressed with his attendant to 165 feet. He was examined by Surgeon Lieutenant A.G. Slark R.N.Z.N., observer on the trials, after 30 minutes and he reported scattered rhonchi in a very depressed patient - perhaps due to narcosis. He was decompressed on therapeutic Table III but on arrival at 100 feet his condition was reported as bad by his attendant. He was recompressed to 165 feet where he was examined by Surgeon Lieutenant Delany who reported that the patient's morale was much better and that he was recovering from a vaso-vagal type of attack. After 2 hours at 165 feet, therapeutic Table IV decompression was carried out. The patient complained of generalised body pains at 50 feet but some codein compound tablets cleared his symptoms and he surfaced well though extremely fatigued. It should be noted that he was accompanied on his dive by diver B.O. and diver F.E.

Diver W.H. was at last withdrawn from the trial as unduly susceptible to "bends". (One month later he mentioned that he still had feelings of stiffness in his shoulders which he attributed to his bend).

42. Diver D.R. It was considered that 12 clear dives had been carried out in the chamber on the fourth schedule and as both divers B.O. and F.E. had had no trouble, it was assumed that the 13th dive by diver W.H. was biased adversely by his habits and previous dives. Divers D.R. and R.E. had dived on this schedule in the chamber 3 days before. They started their dive and while out of the chamber swam continuously. About 20 minutes after surfacing, diver D.R. showed signs of syncope with marked body rash and he mentioned mild pains in his shoulders. He was treated by rest with elevation of feet and kept under constant close medical observation and his faint cleared over two hours. He then developed a mild ache in the low lumbar region and the next day his legs felt slightly weak. Again this diver might have been recompressed but it was considered such treatment would take as long as therapy by bedrest which would be far more comfortable. However he would have been symptom free, if unconfortable, in the chamber and the wrong decision was perhaps taken in his case in view of the duration of his minor troubles. If his condition had deteriorated, he would have been recompressed immediately as observation was kept beside the open door of a chamber. The other 5 divers on that day were relatively trouble free. 4 of these men repeated these dives 3 days later along with 4 other men who had not dived at all for 4 days.

43. Diver B.O. developed his second major case of decompression sickness 4 days after his last dive which was a chamber dive on the same fourth schedule. While at the 20 foot stop it appeared that helium had contaminated the chamber air supply and this was quickly corrected. Seven minutes later diver B.O. complained of mild ache in his right knee which eased and then worsened and eased again in the course of 1/2 an hour. Examination was negative. After surfacing, the ache in his right knee spread throughout his lower limb and up to the sacro-iliac region. He was recompressed 5 minutes after reaching surface, his symptoms clearing before 60 feet was reached. Therapeutic Table I was used and on surfacing, in the early evening, his right leg felt slightly rubbery: this however cleared after a night in Sick Bay comfort.

44. In an attempt to gain some knowledge of the behaviour of oxy-helium mixtures, it was decided to continue the dives as long as a recompression chamber was available for treatment. Eventually it became the turn of those four men who had dived 3 days before and the first such pair were diver P.R. and diver C.O. On the 20 foot stop, diver P.R. complained of a mild ache of his right shoulder which eased there. However it recurred on the surface, spread over both shoulders and he began to develop the signs of shock. Diver C.O. complained, on surfacing, of stiffness and mild aching in his ham strings bilaterally. They were both recompressed under the care of Surgeon Lieutenant Delany. Diver P.R. was free of symptoms by 60 feet but diver C.O. whose symptoms had improved at 100 feet, worsened and both were compressed to 165 feet and therapeutic Table III started. All symptoms were quite cleared on release from the chamber.

45. Diver W.I. and diver M.R. made up the final pair. During the 20 foot stop it was noticed that diver W.I. was restless and looked worried; he asked for frequent flushing of the chamber but he constantly maintained he was well; on arriving at the surface he complained of pain in the front of both thighs and he rapidly became shocked. He was immediately recompressed with Surgeon Lieutenant Delany and there was no improvement till 165 feet when he recovered. Diver M.R. had had a minor niggle at 20 feet which had cleared, but in case it developed into something serious it was decided to lock him in as attendant to diver W.I. on a therapeutic Table III. During his 40 foot

stop diver W.I. was examined by Surgeon Lieutenant Commander Mackay because of the development of dizziness and vomiting. He looked badly shocked, radial pulse and brachial blood pressure were unobtainable; his tendon, skin and eye reflexes were present. He was recompressed in stages but there was no improvement till 165 feet and even then there was not complete recovery. Therapeutic Table IV was started after 2 hours at 165 feet and 30% oxygen/ 70% helium mixture was used with a modified NOVUS for periods of 53, 21 and 18 minutes while going from 165 feet to 120 feet, from 100 to 80 feet and 80 feet to 60 feet respectively. The duration of each spell was at the request of the diver who could not bear the equipment for long. He obviously suffered from hypotension as he retched and vomited whenever he sat up and this aggravated matters by leading to dehydration; while intravenous or intragastric infusion was being considered, he managed to retain sips of water and his condition began to improve. Examination while he was at 50 feet disclosed that there was a slight weakness of his right thigh but otherwise he was in good condition. On release from the chamber he was quite recovered, except for fatigue, and his thigh weakness had cleared.

46. Review of the cases led to the fifth oxy-helium schedule and a new series of dives in the chamber. These began 4 days after all the divers but one had last dived. The exception was diver M.R., attendant to diver W.I. (see paragraph 45) who had been released from pressure $2\frac{1}{2}$ days before and had residual trouble. In retrospect, he should not have been allowed to dive but he was and he did and he became the last serious case of the trial.

47. Diver M.R. carried out a chamber dive on the fifth oxy-helium schedule which involved the use of 18.5% oxygen/81.5% helium mixture. 10 minutes after surfacing he complained of numbness in the sacro-coccygeal area and a feeling of heat radiating down the left leg. This developed into severe pain with loss of power - due to pain rather than paralysis - in both legs though worse in the left. He was recompressed and symptoms were relieved at 100 feet. Accordingly therapeutic Table II was used with stiffness as the only residual symptoms and this he reported as cleared with a few hours sleep. However, 2 weeks later, it was indirectly reported that he still had some stiffness of his shoulders on occasions.

MISCELLANEOUS MATTERS

24. Temperature was always a factor to be considered, both on the surface, at pressure in the chamber, and at depth in the sea. Over the period of this trial the air temperature varied between 50°F and 70°F (10°C and 21.1°C); the temperature of the sea water at the surface varied from 50°F to 62°F (11.1°C to 16.7°C) as the summer advanced; the temperature of the sea water at depths of 250 feet and 300 feet varied little from 43°F (6.1°C). Temperatures in the recompression chamber were only measured in the later dives to 300 feet when readings of 129°F (53.9°C) were obtained; (the reading of the thermometer may have been up to 5°F (2.78°C) high due to compression of the bulb).

25. Clothing was another relevant matter. The Norwegian divers wore brushed nylon undersuits which may perhaps be bulky and too warm for summer conditions in more temperate climates, but at depth, in Sorfjord, they were much preferred by R.N. divers to their customary cotton underwear, string vests and woollies. This preference was stated vocally by the divers and could be observed in fact as the R.N. personnel borrowed their colleagues suits. Some divers tried the wet suit but this was not popular; others who used the wet suit as an undersuit were quite comfortable - though they did not repeat the experiment due to the difficulty of dressing.

26. A very important matter was - and is - incentive. The motive provided was that of taking part in a new diving technique which could possibly lead to prestige depths being achieved. Even the discomfort of decompression sickness, the confinement in a small metal cylinder; the noise of frequent air changes which prevented both carbon dioxide accumulation and sleep; the recollection of colleagues with severe disablement; all these did not materially affect morale and keeness. On the contrary, there was tolerance and pity for the trial officers whose best laid plans were ganging aft agley. However, there was an undercurrent of pointed comments to the effect that special service pay was surely not intended to include such experimental work; that they were not truly volunteers in that they had not offered themselves as participants though their personal pride as well as esprit de corps would not permit them to opt out; that they would have received so much for such and such a dive in the old days. It did not help to know that Norwegian diver W.I. received about 75/- per hour for his dive to 300 feet - and this included the subsequent therapy! Even diver W.I. agreed that if the choice had been "no bend and no money" or "bend and £150" he would rather have been comfortable and poorer but, if he had to have a bend, the reward eased the after effects. That type of comment was typical of the attitude in the trial - they would do their best on the dive hoping that this time the right answer had been obtained and that they would not need any therapeutic measures or that any trouble would be so mild that a night's rest would clear it - anything almost in preference to 39 hours more or less in the recompression chamber.

DISCUSSION

27. This trial did not achieve all the stated aims but in falling short a great deal has been learnt. Fortunately one can say that very little, if anything, was being relearnt by those practised in earlier days but whose expertise had been almost forgotten through lack of practice. That using air as a breathing medium for decompression following a deep dive on oxy-helium mixture might be a source of trouble was a startling discovery, particularly as preliminary work had suggested that the main problem would rather be the total duration during which the mixture was used. The use of oxygen following dives involving moderately heavy work at high temperatures with prolonged oxy-helium breathing, as carried out on the last days of the trial, showed that the hypothesis which led to its use seemed reasonable. The old tables used oxygen during the decompression but the impression is strong that this was done to cut down the very long decompression which would otherwise be required - and done for that reason only. These trials suggest that oxygen must be breathed because of its safety but that the previous tables can be considerably shortened - probably within the compass of the self-contained diver for a dive to 300 feet.

28. While shortage of time prevented the testing of this schedule in the open water, there can justifiably be some confidence in trying this at the first oportunity. This shortage of time had an unexpected advantage in that the resulting heavy pressure on the programme led to very intensive diving and so led to the finding of the important factors involved in the interval between dives for each individual. A disadvantage may perhaps have arisen - however in that this pressure may have clouded - quite unconsciously - the medical assessment of the individual cases and the most suitable treatment. This may not have been real but the attempts to make treatment as tolerable as possible certainly led to departures from the strict application of the written word or of instructions when confronted with the patient in person. In the end, such a departure was seen in retrospect to be an error in the case of divers D.R. and W.A.

29. Another problem which exercised the minds of the medical team was how to define the criteria for selection of the divers. There were few divers, all keen, for various reasons, to dive and all qualified to a similar

standard. The solution chosen was that a man could dive as long as there was no reason why he should not dive rather than a positive selection to dive: at any rate the variation of fitness and personal habits on diet and drink, smoking and sleeping, and other points, was very great, and no advice can be given as a result of this trial.

30. The biggest problem, and the one that caused great perturbation, was the character of the cases of decompression sickness. There were times when a simple case of a limb bend would have been welcome as a reassurance that that type of case still occurred. As an example, diver W.I. surfaced with mild aching of the front of his thighs like an old-fashioned bend, and looking in good condition, so good in fact that he agreed to leave the chamber for a few minutes while cushions and blankets were put in to make it more comfortable for his expected $6\frac{1}{2}$ hours sojourn. However, he rapidly went into a state resembling primary shock and he was recompressed without further ado - having been on the surface about 2 minutes. His subsequent progress was worrying in the extreme as is shown by the use of the 30/70 oxy-helium mixture. (This mixture was chosen because the NOVUS equipment was adapted as a semi-closed circuit breathing set; the whole set-up was prepared before any dive in the interval period was done and it was carried intact to H.M.S. RECLAIM for the second period without further modification). There are records of only one other case in R.N. underwater work in which oxy-helium was used in therapy and that was a case in the Submarine Escape Training Tank in 1957 where the outcome was excellent but the amount of credit due to the mixture was debatable. There is no doubt that in this case the use of this mixture resulted in a greater interest in life as far as the attitude of the patient was concerned - if this lightening of "narcosis" was the only effect it was still justified - but it was felt by all who dealt with the case that the mixture also benefited the symptoms themselves, though the mechanisms allegedly involved are controversial. This case exemplified most of the lessons learnt on this trip as applied to decompression sickness therapy. It must not be overlooked that air dives as well as oxy-helium dives produced cases with signs of peripheral circulatory failure and central nervous system involvement.

31. A point that is rarely mentioned is the judgement of the doctor concerned in examining a patient under pressure; like his patient he is subject to the effects of gases breathed including the narcotic effect of nitrogen: other circumstances may require that he leaves the chamber and so he must limit the unavailability of the lock and this results, in his cramped circumstances, in a rapid, gross assessment of the case rather than the calm, collected, examination technique of the consulting room that would be ideal. Yet another point, of minor importance to the initiated, is the "Donald Duck" distortion of the voice due to the much greater density of air.

CONCLUSION

32. Facts have appeared which do not seem to have been known by our predecessors who, however, had the right answers if for different reasons. Some form of selection of men will be needed and the amount of diving will have to be regulated by the number available. With the best of intentions arbitrary limitations are set and the trials show just how arbitrary they are. It was some consolation that the mechanical part of the trial was carried on with great success.

33. The lessons to be learnt are relatively few. First the extreme difficulty of deciding the type of case with which one is faced and so the appropriate treatment, either explicit in the tables or improvised after initial preparation. Secondly, the prolonged testing that is required in slow time, in adequate numbers, under laboratory conditions, to determine the schedules for exercise dives and for the interval between dives, must not be skimped. Finally, the close association of practical divers and back-room scientists pays intangible dividends in mutual understanding and hence improved efficiency.

APPENDIX 2 TO A.E.D.U. REPORT NO. XXIX

PHYSIOLOGY REPORT

by

H.V. Hempleman, R.N. Physiological Laboratory, Alverstoke.

INTRODUCTION

These trials were undertaken with a view to seeing how deep underwater it was possible to go with experienced divers. The stay at depth for 10 minutes duration was taken as a minimum requirement to give the dive a practical value and a decompression schedule for such a dive not to exceed 3 hours, otherwise the procedure is exhaustingly long and not considered worthwhile for so short a stay at depth, except perhaps in exceptional circumstances.

THE DECOMPRESSION SCHEDULE CALCULATIONS

2. These calculations may be said to rest on the following set of observations:-

(a) The U.S.N. have conducted a number of no-stop dives from which it is clear that for a given duration at depth it seems possible to go deeper on helium (20% O_2, 80% He) than on air.

(b) The shape of the no-stop curve for air is well established, and this is taken as representing the uptake-of-gas curve for the situation which produces decompression sickness on air. Trials on this assumption have always proved successful.

(c) There is a safe decompression ratio to be used in conjunction with the quantity of gas obtained as in (b) above. This ratio varies somewhat with the pressure of the dive, being 1.9 at low pressures and reducing to 1.5 with high pressures (200 ft. sea water and above). This has been found experimentally on animals and tested on humans.

(d) Oxygen at pressure plays a part in the occurrence of decompression sickness. Thus for any mixture it is unwise to ignore the oxygen content, and for these very deep dives the mixture was treated as just gas, without discriminating between oxygen and helium, or oxygen and nitrogen.

3. With these observations and assumptions tables were calculated for:-

(a) 250 ft. on air with 10 minutes on the bottom.

(b) 300 ft. on air with 10 minutes on the bottom.

(c) 300 ft. on 5% O_2, 95% He with 10 minutes on the bottom.

(d) 400 ft. on 5% O_2, 95% He with 10 minutes on the bottom.

4. One particular part of these schedules was somewhat arbitrary and this concerned the rate of ascent to the calculated stop values. From considerable experience on volunteers it was clear that most normal persons could well tolerate a 120 ft./minute rate of decompression to the first stoppage. However most people experienced varying degrees of itching either during decompression or immediately upon surfacing. It was found that if a short stop was introduced approximately half-way between the bottom pressure and the first stop pressure, then there was a marked improvement in the comfort of the dive.

THE AIR SCHEDULES

5. 300 feet on air schedule

Depth		Time (Mins.)
Leave surface		0
Arrive	300 feet	3
Leave	300 feet	13
Arrive	140 feet	14½
Leave	140 feet	15½
Arrive	40 feet	17
Leave	40 feet	19
Arrive	20 feet	20
Leave	20 feet	37
Arrive surface		39

Despite the laboratory success of these anti-itch procedures this schedule created severe itching amongst the divers and even to one of our laboratory divers who tested it on board H.M.S. RECLAIM in order to compare it with Royal Naval Physiological Laboratory conditions. It was decided to introduce a further 'anti-itch' stop and try again. The temperature changes in the RECLAIM recompression chamber were unusually large and it was felt that this was mainly responsible for making the schedule less comfortable than at Royal Naval Physiological Laboratory.

6. 300 feet on air schedule with further anti-itch stop

Depth		Time (mins.)
Leave surface		0
Arrive	300 feet	3
Leave	300 feet	13
Arrive	150 feet	14¼
Leave	150 feet	15
Arrive	90 feet	16
Leave	90 feet	18
Arrive	40 feet	19
Leave	40 feet	23
Arrive	20 feet	24
Leave	20 feet	46
Arrive surface		48

This schedule was used with considerable success in the recompression chamber. In the light of the experience with anti-itch stops from 300 feet it was deemed prudent to introduce two such stops on the 250 feet schedule.

7. 250 feet schedule on air

Depth		Time (Mins.)
Leave surface		0
Arrive	250 feet	2½
Leave	250 feet	12½
Arrive	130 feet	13½
Leave	130 feet	14½
Arrive	80 feet	15½
Leave	80 feet	17½
Arrive	30 feet	18½
Leave	30 feet	21½
Arrive	20 feet	22
Leave	20 feet	32
Arrive surface		33

This schedule was used with complete success in the sea except for two incidents on July 7th 1962. Neither diver was given recompression treatment.

8. Summary of air dives

Depth	Time of Dive	Dives in Sea	Dives in R.C.C.	Incidents	
				A	B
300	13 mins	0	29	1	0
250	12½ mins	38	0	0	2

A Incident is one where resort was made to therapeutic recompression.

B Incident is one where resort was not made to therapeutic recompression, consequently it is milder in character than A.

Of the three incidents above, two involved the same diver.

OXY-HELIUM DIVING

9. The mixture 5% oxygen, 95% helium was chosen largely because of lack of storage and mixing facilities aboard H.M.S. RECLAIM. Using just this one mixture enables diving to be performed at all depths from 90 feet to 1200 feet. At 90 feet the oxygen content is just sufficient to support an active diver, and at 1200 feet the oxygen pressure is approximately 2 atmospheres which is the highest permissible pressure. As the mixture cannot be breathed at depths less than 90 feet there arises the question as to what can be breathed at these shallower depths. Without resort to further mixture breathing it is only possible to breathe air. Consequently air was used throughout these trials as the gas breathed during the bulk of the decompression procedure. This had the additional advantage that breathing masks or mouthpieces were not required, and using the ideas outlined above the decompression was not unduly prolonged. Knowing that anything accomplished on air should be more readily performed on helium the same schedule for helium breathing was used as for air breathing (paragraph 6) but, as noted above, the low oxygen percentage dictated turning over from

air to helium at 100 feet on the descent and from helium to air at the 90 feet stop on the ascent. This schedule was tested in the sea and in the dry chamber (recompression chamber).

RESULTS

10. First Period - 300 ft. Oxy-helium Dives

Depth	Time of Dive	Dives in sea	Dives in R.C.C.	Incidents A	Incidents B
300	13 mins	0	2	0	0
300	13 mins	4	0	1	0

11. Now the one case of decompression sickness recorded in the table above was the very unfortunate case of A.B. Wannerton who progressed to paralysis in the lower half of his body during the course of the therapeutic recompression. The exact cause of this major incident is very difficult to determine. It is clear that signs of decompression sickness were present at the 40 foot stop, thus either the rate of ascent following the changeover to air must be considered to be responsible, or the rate of ascent on the helium mixture from 300 feet to 150 feet.

12. Previous to this dive of Wannerton's six divers had withstood this part of the schedule without any trouble whatsoever, and the diver who accompanied Wannerton also was untroubled at the 20 foot stop. This Wannerton was the odd man out of eight divers. Nevertheless it is obvious that some allowance must be made for such persons, especially when failure may entail such a disastrous attack of decompression sickness. Accordingly it was decided to slow up the rate of ascent to the first true stop by means of a series of small stops based on using a hypothetical tissue with a two minute half-time and a decompression ratio of 1.5. The two minute half-time was chosen because this corresponds to the half-time of the blood and lungs, and bubbles in the blood were considered to be the major hazard of a too rapid ascent. It was also decided to change the stop at which the transfer under pressure took place. In the previous dives this had been at 20 feet, because this was the only stop of sufficient duration to allow the whole procedure to take place without undue haste. The new T.U.P. stop would be at 100 feet and be of 8 minutes duration, thus bringing the diver inboard for the whole of the decompression from 100 feet down to surface pressure giving maximum possible safety. The introduction of these two extra measures would considerably lengthen the schedule, especially if the original idea of surfacing from 20 feet was to be maintained. Accordingly this latter idea was temporarily abandoned and a 10 foot stop was used. A further change was made to see whether the schedule could be shortened and this was to try a 1.6 ratio instead of a 1.5 ratio. This schedule was tested at A.E.D.U. by 10 divers and found to be unsatisfactory, in that one bend and two or three 'niggles' resulted. Accordingly it was decided not to depart from 1.5 as a ratio, or 20 feet as the stop from which to surface. The second phase of this trial was entered with the following decompression schedule for use with 5/95 oxy-helium as the breathing mixture :-

Depth		Time (mins)
Leave surface		0
Arrive	300 feet	3
Leave	300 feet	13
Arrive	190 feet	$14\frac{1}{2}$
Leave	190 feet	$16\frac{1}{2}$
Arrive	160 feet	$17\frac{1}{2}$
Leave	160 feet	$18\frac{1}{2}$
Arrive	130 feet	$20\frac{1}{2}$
Leave	130 feet	$22\frac{1}{2}$

Arrive	100 feet	23½	T.U.P. stop 8 mins.
Leave	100 feet	31½	
Arrive	60 feet	33	
Leave	60 feet	35	
Arrive	50 feet	35½	
Leave	50 feet	37½	
Arrive	40 feet	38	
Leave	40 feet	40	
Arrive	30 feet	40½	
Leave	30 feet	42½	
Arrive	20 feet	43	
Leave	20 feet	105	
Arrive surface		106	

13. Using this schedule the diver descended on air and commenced breathing the oxy-helium at 100 feet depth and continued breathing this throughout the whole dive until, having completedsix minutes at the 100 foot T.U.P. stop, he removed the mouthpiece and went straight back on to air breathing for the remainder of the decompression. The first 4 dives on this schedule in the recompression chamber were somewhat confused. All four men were supplied from the same gas source simultaneously and a failure of the source to cope resulted in men being sometimes on air and sometimes on oxy-helium. In addition the time of descent to 300 feet was approximately 5 minutes and the total dive time was 14 minutes instead of the stipulated 13 minutes. Two bends and one mild bend resulted from this dive. Despite the mistaken behaviour at depth the decompression was performed correctly and it was clear that the schedule was too near the trouble level. This was further confirmed by another 5 correct dives in which two of the divers were obviously feeling ill effects. The cause of this was probably due to decompressing on oxy-helium (5/95) as though it was air (20/80) and consequently the divers were instructed in the next set of dives to turn over to air breathing at the 190 foot stop and do the great majority of the decompressing on air. This schedule proved to be a success and preparations were made to conduct experiments in the sea.

14. Six dives were made in the sea and this resulted in one bend which was not given recompression treatment and one case of temporary painful stiffness after surfacing. At first this day's diving was considered a typical result of decompression schedule testing i.e. quite safe in the dry chamber but not necessarily safe when tested in actual sea conditions. It was decided to give two clear days rest and re-test the same divers on the third day using the same schedule and again in the sea. In addition to re-testing these divers it was also agreed that four divers who had not dived for some days, but who had passed trouble-free through the dry chamber routine, should also be dived.

15. The results were completely unexpected but so clear cut and easy of interpretation that despite the set-back to the hopes of going deeper the facts gathered are of great theoretical and practical importance. Only eight men were dived that day, and not ten, as was originally intended. This was because all pressure chamber facilities were occupied with divers undergoing therapeutic recompressions by the time the last pair were due to dive. To the results. Four men who had dived entirely trouble-free on Friday July 13th complained of symptoms of decompression sickness at the

20 foot stop during the dive on Monday July 16th. Any schedule which gives decompression sickness at 20 feet in four fit men is very grossly wide of the mark. Yet these men had already proved the dive was trouble free for them both in the dry chamber and in the sea on the previous Friday. Only two conclusions are possible, either the dives were not conducted in the same manner on these two occasions or else the men themselves had changed. A careful check of the procedures adopted showed that the time-pressure course of the sea dives on both Friday and Monday was identical and that the composition of the breathing mixtures was identical. It could only mean that the men themselves had changed. To turn now to the other four results obtained that day. These were four divers who had not dived for some days. Two of the four (FE and BO) had had trouble-free dry chamber dives on Thursday 12th July and two others (SC and RO) had had trouble-free dry chamber dives on Wednesday 11th July. Of the Thursday men one man (BO) had a bend which responded readily to therapeutic recompression, of the Wednesday men both came through the dive with only minor troubles that required no therapy. Thus although the numbers are small the situation presented seemed capable of only one interpretation.

TABLE I

Days Between Last Two Dives	Number of Men	Number of Bends	Therapy
2	4	4	Table IV Table II
3	2	1	Table I
4	2	0	Rest

The column headed Therapy serves to show the decreasing severity of the attacks in the various cases. The men have changed in their sensitivity.

16. Let us now apply some elementary statistical analysis to the situation presented by the sea dives. Fourteen sea dives were performed by a total of 10 men, all using the same decompression schedule. Four of these men had carried out 4 trouble-free dives in the dry chamber, 4 trouble-free dives in the sea (Friday) and 4 bend dives in the sea (Monday). The distribution of their bends performance is therefore 0,0,4 on the three occasions they dived. This result has a relatively small probability of having arisen by chance. There are 81 ways in which 4 bends may be distributed amongst 4 men on 3 separate occasions. The arrangement 0, 0, 4 is unique. Such arrangements as 2, 1, 1, can occur no less than 12 times, and say 3, 0, 1 or 1, 0, 3 occur 4 times each. There is thus approximately a 1 in 7 chance of 2, 1, 1, occuring, approximately a 1 in 20 chance of 1, 0, 3 occuring and only a 1 in 81 chance of 0, 0, 4 occuring. It must be concluded that the diving results obtained were unlikely to have arisen by chance. Are sea dives significantly more dangerous than chamber dives?. This question is unanswerable with the present data because the 2 sea dives which were performed produced such different results. Clearly the Friday sea dive with one untreated bend and a 'niggle' out of 6 dives is not significantly different from 0 bends out of 6 dives which these same 6 men previously performed in a recompression chamber. This set of sea dives is obviously worse than the compression chamber diving in the sense that an incident did occur, but this could well have been just random variation in the divers performances. The sea dive on Monday was, as seen above, a very different affair and significantly different from all previous diving for at least 4 of the men.

17. Further than these conclusions it is not possible to go with the small numbers available. The conclusions was tentatively reached that Monday's diving was different from all the previous diving because it represented the end of a period of considerable diving activity using helium-oxygen at depth and air as the decompression medium. This conclusion became reinforced when a further schedule was tested in the recompression chamber. This schedule was calculated for 18% oxygen 82% helium at depth and oxygen as the decompression medium. (See Final Schedule). Fourteen dives were carried out in the recompression chamber on Friday 20th July and Monday 23rd July using this schedule and one major case of decompression sickness occurred on Friday 20th July. This one case was a further piece of evidence for the idea that some residual effects can remain after oxy-helium diving and subsequent air decompression, as this diver (M.R.) was the last man to suffer ill effects from previous diving and in fact had complained of pain and stiffness in the legs on the morning of Wednesday 18th July. This pain and stiffness was directly attributable to his unsuccessful dive on Monday 16th July and the subsequent very prolonged therapy which terminated on Tuesday 17th July at 2200 hours.

18. It is also necessary to note:-

(a) The therapy for many cases of decompression sickness from oxy-helium and subsequent air decompression was not as dramatically effective as usually experienced. Recurrences of signs and symptoms whilst still under considerable pressures were not uncommon.

(b) A number of unusual after effects occurred. Rubbery feeling in legs, which in one or two cases persisted for many days.

(c) The type of decompression sickness was unusual. Numbness in the buttocks, woolly feeling in the foot, stomach trouble and lower back pain were common occurrences.

(d) The decompression schedule used throughout the period 10th to 16th July appears to become less and less effective with the passage of time.

19. Thus with this type of diving we appeared to be progressively sensitising the divers. The time necessary between dives to ensure safety must be of the order of 5 or 6 days. That a highly stable bubble system can be formed from this type of deep diving was amply demonstrated by the difficulties encountered with the therapy. It is perhaps not too surprising therefore that a dive which is apparently trouble free can leave behind an unusually stable asymptomatic bubble. Whilst one cannot really give credence to a minute bubble (or bubbles) remaining intact for several days, it is quite feasible that as a result of the presence of foreign bodies (bubbles) in the body for a considerable time there arises in the tissue concerned a situation which is not normal, and consequently all subsequent diving is affected until the tissue returns to its normal state. This complicating factor in decompression sickness is an extension of findings that have been known amongst compressed air workers for many years. Here it has been known that a work-up period for beginners in compressed air is good practice. Such introductory periods serve to decrease the workers' chance of getting a bend in his first few shifts. It is further known that the work-up period must extend over several days to be effective. This is then a further example of a cumulative effect lasting over several days. However, as opposed to these findings we at Royal Naval Physiological Laboratory have not discovered any such effects from air dives. For instance, quite recently several men performed air dives to 300 ft. with a bottom time of 11 minutes and this dive, which had a very short decompression schedule of the type used aboard H.M.S. RECLAIM, never gave rise to trouble despite men

diving regularly every 48 hours, for runs of 3 and 4 dives at a time. It must therefore be deduced that either the helium dives used aboard H.M.S. RECLAIM were nearer to threshold bends than the corresponding air dives or that helium diving is more prone to produce bubbles which subsequently stabilise with nitrogen when the diver is decompressed on air. Consideration of the results tends to support both factors. It was proved that by decreasing the total helium breathing time from 28½ minutes to 13½ minutes, without altering the time and pressure course of the dive in any way, then the schedule was turned from being a bend-prone one to being a bend-free one. Thus less helium breathing using the same schedule was safer. We are therefore nearer to trouble on the oxy-helium dive than on the air dive. Accordingly the assumption that oxygen is playing a part in bends formation and that, for dives to these depths, the hazard from 5/95 is similar to 20/80 is not true. Using this assumption and decompressing on 20/80 (air) from 190 ft. to the surface has just managed to render the schedule safe for most divers. This presumably because there is always a fairly large safety margin in most of the calculations. However, being a 'just safe' schedule has meant that after effects have been more likely. Once this became clear in the course of the trial then a shift was made in the method of calculation, and for the last series of dives two major changes were made.

20. In the first place the mixture used was 18% oxygen 82% helium and due account was taken of the oxygen percentage in the calculations, in the second place oxygen was used from 20 ft. to the surface. This latter change meant that the longest stop was spent entirely on oxygen breathing. By this means it was hoped to overcome all the troubles so far encountered. Any bubbles formed upon surfacing would have a high oxygen content due to the oxygen breathing at 20 ft. and would consequently have a very short life span. This would very much minimise the risk of any cumulative effects from this type of diving. Further, by making allowance for the oxygen content of the mixture breathed at depth, the stops became deeper and longer than would otherwise have been the case. For instance 18% O_2, 82% He has an equivalent air depth of 310 ft. for a dive to 300 ft. Up to the present the calculations, being based on an active role of oxygen, had assumed the depth to be only 300 ft. and the ratio used was 1.5. As it appears that oxygen is not playing such a large part as was supposed then the new method of calculation is doubly safe, gaining the benefit of an increased oxygen content and yet still using 1.5 ratio.

FINAL SCHEDULE

21. 300' for 13 minutes breathing 18% Oxygen + 82% Helium

Depth (Feet)		Time (Minutes)
Leave surface		0
* Change to Oxy-Helium at 100'		
Arrive	300'	3
Leave	300'	13
	Rate 70' per min.	
Arrive	200'	14½
Leave	200'	16½
	Rate 40' per min.	
Arrive	160'	17½
Leave	160'	19½
	Rate 30' per min.	

Depth (Feet)		Time (Minutes)
Arrive	130'	20½
Leave	130'	22½
	Rate 30' per min	
Arrive	100'	23½
Leave	100'	25½
	Rate 20' per min	
Arrive	80'	26½
Leave	80'	28½
	Rate 20' per min.	
Arrive	60'	29½
Leave	60'	31½
	Rate 20' per min.	
Arrive	50'	32
Leave	50'	34
	Rate 20' per min.	
Arrive	40'	34½
Leave	40'	36½
	Rate 20' per min.	
Arrive	30'	37
Leave	30'	45
	Rate 20' per min.	
⁂ Arrive	20' ⁂ Change to Oxygen on	45½
Leave	20' arrival at this stop	57½
Arrive surface		58½

STOPS:-

DEPTH (FEET)	200'	160'	130'	100'	80'	60'	50'	40'	30'	20'
DURATION (MINUTES)	2	2	2	2	2	2	2	2	8	12
	← 18% Oxygen + 82% Helium →									O_2

22. For sea dives on this schedule it was suggested that transfer-under-pressure should take place at the 30' stop. For convenience it was also agreed that gas change-over from oxy-helium to 100% oxygen could take place after 6 minutes at the 30' stop. In the chamber dives these conditions were strictly adhered to. This schedule was used with considerable success in chamber dives (with exercise). As explained previously, the sole case of an attack of decompression sickness occurred to a diver who 48 hours prior to this dive had suffered limb pains as a result of a prolonged sojourn in compressed air, acting as attendant to a diver undergoing a therapeutic recompression on Table IV. This further emphasized the conclusions reached above that insufficient time had been allowed between the dives, especially when symptoms of decompression sickness are involved.

CONCLUSIONS

(a) Diving on oxy-helium mixtures using air as the decompressing medium is quite feasible and safe except when the diving interval is less than four or five days.

(b) Calculating helium schedules in a similar manner to air schedules is also successful except that rates of ascent to the first stop must be slower on the helium mixtures.

(c) Oxygen does not play as big a part in the aetiology of decompression sickness as was suspected, and represents the only gas for breathing during decompression at the lower stops in order to render repetitive diving a reasonable proposition in deep diving.

(d) A good deal of successful air diving (chamber and sea) has been carried out and it is clear that with minor alterations these new schedules represent a major advance over the existing Table III schedules.

APPENDIX 3 TO A.E.D.U. REPORT NO. XXIX

TRIAL ORDERS FOR H.M.S. RECLAIM - PERIOD 25TH MAY - 5TH JUNE, 1962

Authority

1. Director General Weapons, Underwater Weapons Division's AC.525 dated 14th May, 1962.

Aim

2. To carry out trials to prove a new technique for Deep Diving (i.e. in excess of 180 ft.) with a view to achieving depths of the order of one thousand feet at a later date.

Ship and Authorities Taking Part

3. H.M.S. RECLAIM
Admiralty Experimental Diving Unit
Royal Naval Physiological Laboratory.

Date and Place

4. The trial will be carried out in Sor Fjord between 28th May and 5th June, 1962.

Equipment

5. As described in the enclosure to S. of D's 68.9. (232/62) dated 17th May, 1962. The trial equipment will be delivered to H.M.S. RECLAIM before departure for Bergen.

Conduct of the Trial

6. The trial is to be started with dives at a convenient depth with a view to:-

(a) Proving new equipment.

(b) Assessing the fastest practical lowering rate of Submersible Decompression Chamber and associated water level required.

(c) Compiling decompression schedules from results obtained from (b).

(d) Developing a drill to be used for subsequent deeper dives.

7. On satisfactory completion of the tasks enumerated in paragraph 6 above, the diving depth is to be increased by suitable increments to a maximum of 450 feet.

8. Scrutiny on the performance of the divers is to be maintained. The least suitable are to be eliminated from the trial. A team of six of the most experienced divers should be nominated for the subsequent deeper trials.

SAFETY PRECAUTIONS

9. Decompression

(a) Schedules for each specific depth and time under compression will be provided by Mr. Hempleman P.S.O. - R.N.P.L.

(b) The main Recompression Chamber is to be kept available for immediate use throughout the trials.

(c) Divers are to remain onboard H.M.S. RECLAIM for 4 hours after a dive.

(d) Adequate personnel should be retained onboard H.M.S. RECLAIM to deal with any diving incident which may arise as a result of diving.

(e) Arrangements should be made to ensure that should a diver become unwell whilst ashore, he can be returned to H.M.S. RECLAIM immediately. This should be promulgated to all divers.

10. Medical

Divers are to be medically examined before and after each dive.

11. Stand-by Diver

(a) With diving technique to be used, one diver in the Submersible Decompression Chamber is to act as Stand-by for the other. Only one diver is to leave the Submersible Decompression Chamber at any one time except where an emergency may require the second diver to go to the other's assistance.

(b) A diver, with Swimmer's Air Breathing Apparatus equipment is also to be available in the Diving Flat to assist in any difficulties that may arise with the Submersible Decompression Chamber or Divers near the surface.

12. Emergency Surfacing

A boat is always to be available during diving operations to assist a diver in difficulties on the surface and in addition, a diver fully equipped in Underwater Swimmer's Dress and a long recovery line is also to be available in case a diver surfaces away from the ship and urgently requires recompression.

13. Diving Intervals

Divers are NOT to dive more than once in 24 hours.

14. Responsibilities

The Commanding Officer H.M.S. RECLAIM is in general charge of the trials.
Lieutenant Commander G.M.H. DRUMMOND -
Representative of the Superintendent of Diving.
Responsible to the Commanding Officer H.M.S. RECLAIM for the safe conduct of the trials.

Surgeon Lieutenant Commander D.E. MACKAY, Medical Officer - Admiralty Experimental Diving Unit.
Medical Officer for the Trial.

Mr. H.V. HEMPLEMAN, P.S.O. - Royal Naval Physiological Laboratory.
Responsible for Diving Physiology and Decompression Schedules.

Mr. S. WILLIAMS, E.O. - Admiralty Experimental Diving Unit.
Responsible for design and operation of trial equipment.

Reports

15. Mr. WILLIAMS is to prepare an interim report immediately on completion of the trial, in order that plans can be drawn up for H.M.S. RECLAIM's 2nd Diving Period.

A full report of the trial is also to be prepared by Mr. WILLIAMS to include detailed reports from other Trials Officers as appendices.

APPENDIX 4 TO A.E.D.U. REPORT NO. XXIX

TRIAL ORDERS FOR DEEP DIVING TRIALS - PERIOD 30th JUNE TO 27th JULY 1962

Authority

1. Director General, Weapons, Underwater Weapons Division's AC.525 of 14th May, 1962.

Aim

2. To carry out trials to prove a new technique for Deep Diving (i.e. in excess of 180 ft.) with a view to increasing the operational potential of Royal Naval Divers.

Ships and Authorities Taking Part

3. H.M.S. RECLAIM
Admiralty Experimental Diving Unit.
Royal Naval Physiological Laboratory.

Date and Place

4. The trial will be carried out in Sor Fjord between 30th June and 27th July, 1962.

Equipment

5. As described in the enclosure to S. of D's 68.9.(232/62 of 17th May, 1962) with minor adjustments as a result of experience during previous trials.

6. The S.D.C. panel and T.U.P. panel gauges are to be checked for accuracy daily with a Dead Load Tester.

Conduct of the Trial

7. The trial is to be started with each diver making 2 dives to 180 ft. and 2 dives to 250 ft. on air. The trial will then be continued using O_2He_2 to 300 ft. for all divers and thence to 450 ft. maximum with a selected number of divers as governed by the quantity of helium available.

8. Decompression schedules for dives deeper than 300 ft. are to be tested in the Recompression Chamber before being used in the sea.

SAFETY PRECAUTIONS

9. Decompression

(a) Schedules for each specific depth and time under compression will be provided by Mr. Hempleman P.S.O. - R.N.P.L.

(b) The main Recompression Chamber is to be kept available for immediate use throughout the trials.

(c) Divers are to remain onboard H.M.S. RECLAIM for 4 hours after a dive.

(d) Adequate personnel should be retained onboard H.M.S. RECLAIM to deal with any diving incident which may arise as a result of diving.

(e) Arrangements should be made to ensure that should a diver become unwell whilst ashore, he can be returned to H.M.S. RECLAIM immediately. This should be promulgated to all divers.

(f) Close observation of the performance of the divers is to be maintained and any showing signs of unsuitability for these experiments are to be eliminated.

Medical

10. Divers are to be medically examined before and after each dive.

Stand-by Diver

11. (a) With diving technique to be used, one diver in the Submersible Decompression Chamber is to act as Stand-by for the other. Only one diver is to leave the Submersible Decompression Chamber at any one time except where an emergency may require the second diver to go to the other's assistance.

(b) A diver, with Swimmer's Air Breathing Apparatus equipment is also to be available in the Diving Flat to assist in any difficulties that may arise with the Submersible Decompression Chamber or Divers near the surface.

Emergency Surfacing.

12. A boat is always to be available during diving operations to assist a diver in difficulties on the surface and in addition, a diver fully equipped in Underwater Swimmer's Dress and a long recovery line is also to be available in case a diver surfaces away from the ship and urgently requires recompression.

Diving Intervals

13. Divers are NOT to dive more than once in 24 hours.

Responsibilities

14. Lieutenant Commander G.M.H. DRUMMOND, Deputy Superintendent of Diving (desig).
Responsible for the conduct of the trials.
Surgeon Lieutenant Commander D.E. MACKAY, Medical Officer - Admiralty Experimental Diving Unit.
Medical Officer for the trial.
Mr. H.V. HEMPLEMAN, P.S.O. - Royal Naval Physiological Laboratory.
Responsible for Diving Physiology and Decompression Schedules.
Mr. S. WILLIAMS, E.O. - Admiralty Experimental Diving Unit.
Responsible for design and operation of trial equipment.

Reports

15. Lieutenant Commander DRUMMOND is to prepare a complete report of the trials, including the reports of other representatives as appendices.

APPENDIX 5 TO A.E.D.U. REPORT NO. XXIX

From: The Chairman,
R.N.P.R.C.

To: Director General, Weapons,
Underwater Weapons Division,
Ensleigh, Bath.

Date: 29th June, 1962.

Copy to: D.U.S.W.

The detailed report of the results of the diving trials carried out in H.M.S. RECLAIM during the period 29/5/62 and 5/6/62 has now been received from S. of D. and studied with particular reference to the medical and physiological implications of the incidents which occurred. The case of Wannerton has been the subject of careful consideration. The letter from the Flag Officer for Scotland, and the findings of the Board of Enquiry on the diving accident to Wannerton have also been considered. The main conclusions reached at the meeting convened by D.U.W. on 27th June, 1962 have been discussed with Mr. H.V. Hempleman (R.N.P.L.) and Mr. F.E. Smith (Secretary R.N.P.R.C.) who were present as no minutes of the meeting are yet available.

Following discussion, the endorsement by the R.N.P.R.C. of dives to 450 ft. which are due to commence in H.M.S. RECLAIM from 21st July, 1962, is reaffirmed subject to the following conditions which are now imposed in light of the information contained in the papers referred to above.

The purpose of these conditions is, on the one hand, to make it possible for H.M.S. RECLAIM to keep to the experimental diving programme and, on the other, to prevent further incidents which might well jeopardise plans for the future and the achievement of the aim of the trials, i.e. to dive to 1,000 ft. The proposed conditions take account of the fact that the trials are based on still unproved tables, and that the purpose is to establish an operational schedule rather than simply to achieve, once or twice, some given depth.

(i) Every case of any pain, disability or itching (other than mild itching) should be regarded as decompression sickness.

(ii) Therapeutic recompression should be enforced rigorously according to the Therapeutic Tables. In addition, in the event of a recrudescence of the symptoms at 165 ft. the diver should be returned to his working depth using the gas mixture he breathed during his dive. No patient should be decompressed until it is proved that no improvement can be obtained by further compression.

(iii) No diver should be exposed to depths deeper than 200 ft. on successive days. If a diver is exposed to a depth of 300 ft. or more he should not be permitted to dive again for 48 hours.

(iv) Diving should commence at 300 ft. with increments of 50 ft. subject to the following provisos:-

(a) Every diver available should carry out a satisfactory dive in the Recompression Chamber and in the sea at a given depth before deeper dives are undertaken.

(b) If this is not practicable at least 10 satisfactory dives in the Recompression Chamber and 10 dives in the S.D.C. should be made at each depth.

(c) A satisfactory dive should be considered to be one in which there is no decompression sickness as defined in (i) above.

(d) In the event of an unsatisfactory dive at a given depth, the tables should be modified and satisfactory dives carried out before deeper dives are attempted.

Ref: AC 525 of 14/5/62,
UPS 3/62 of 19th June.

(signed) G.L. BROWN.

APPENDIX 6 TO A.E.D.U. REPORT NO. XXIX

DRILL FOR DEEP DIVING USING SURFACE DEMAND DIVING EQUIPMENT FROM A SUBMERSIBLE DECOMPRESSION CHAMBER

PERSONNEL

The following are required:-

(a) S.D.C. Panel Operator. Communications, control of air supply valves and relaying of depth readings.

(b) Recorder. Compilation of Form S. 288 and regulation of timing schedule.

(c) No. 1 Winch Operator. Hoisting and lowering S.D.C. on purchase wire at varying speeds as ordered.

(d) No. 2 Winch Operator. Hoisting and lowering topping lift as ordered.

(e) Speed Controller. Regulating rates of ascent and descent by stop watch. On descent, counting the number of revolutions of the winch drum to obviate any errors by the wire checker.

(f) S.D.C. Wire Checker. Continuous checking of depth by wire seizings on purchase wire.

(g) Transfer Under Pressure Panel Operator. Controlling T.U.P. Routine.

(h) Transfer Under Pressure Chamber Attendant. For closing the heavy top hatch in the T.U.P. Chamber after transfer.

(i) Capstan Operator. For swinging the S.D.C. into position above the T.U.P. Chamber by power.

(j) Guy Hands. For controlling guys and for steadying S.D.C. during locking on and unlocking.

(k) No. 1 Diver. In S.D.C.

(l) No. 2 Diver. In S.D.C.

(m) No. 1 Stand-by Diver. Dressed in Underwater Swimmers' Dress with S.A.B.A. set ready to put on.

(n) No. 2 Stand-by Diver. Dressed in Underwater Swimmers' Dress and ready to swim out with a recovery line should a diver surface.

NOTES. (i) No. 1 Winch Operator mans the winch on the side of the ship on which the S.D.C. is being operated.

(ii) Stand-by divers are normally the divers for the dive after the one in progress.

CHARGING AND TESTING EQUIPMENT PRIOR TO DIVING

2. The following points must be considered:-

(a) Test all gauges with Dead Load Tester. This should be done at sufficiently close intervals to ensure accuracy.

(b) Build up air line pressure to S.D.C. to 450 p.s.i. and hold at this pressure for 2 minutes to test for leaks.

(c) Test telephone and lighting circuits to S.D.C. including "cut-out" push.

(d) Charge S.D.D.E. sets and check automatic cut-in.

(e) Charge external cylinders on S.D.C. and test for leaks.

(f) Stow ancillary equipment in S.D.C. - fins, torch, mallet, spanners etc.

(g) Hoist S.D.C. over the side and submerge completely to test for leaks (bottom door open).

(h) Raise S.D.C. until bottom is about 1 ft. below the surface. The S.D.C. is now ready for the divers.

CARRYING OUT THE DIVE

3. Before the dive starts:-

(a) First four divers get dressed in Underwater Swimmers' Dress - 2 divers and 2 Stand-by divers.

(b) The two divers drop into the water from the ship's side diving door, duck under the S.D.C. and enter it by the bottom door.

(c) No. 1 Diver closes equalising valve on deck of S.D.C., closes control valve for chamber air, sets the line pressure for the S.D.D.E's and tests communications with S.D.C. Panel Operator.

(d) S.D.C. Panel Operator opens S.D.C. Air Supply Valve fully.

(e) No. 2 Diver puts on his fins and sits on deck of S.D.C. with his feet out through the bottom door. No. 1 Diver puts S.D.D.E. set on him - face mask off.

4. The dive now proceeds:-

(a) S.D.C. Panel Operator. "Testing Communications - How do you hear me".

(b) S.D.C. One blow with mallet signifying "Message has been heard and communications are satisfactory".

(c) Panel. "I hear you loud and clear" (on hearing the blow) "Report when ready to leave".

(d) S.D.C. - One blow (to acknowledge message) followed by 5 BELLS when ready.

(e) Recorder. "One Minute To Go". This is to give the Well Deck Party a "Stand-by". If the Panel Operator keeps his telephone push down it also gives the divers a warning.

(f) Panel. "Lower". Again telephone push should be pressed so divers can hear this order.
The S.D.C. is then lowered at 100 ft/min. the control valve in the chamber being opened and the air supply regulated by the divers to maintain a convenient water level in the chamber. (N.B. Keeping about 2 ft. of water inside the chamber improves visibility through the bottom door, avoids waste of air and facilitates egress and ingress).
The S.D.C. can be stopped at any time by the divers (e.g. for ear trouble) by pressing the "cut out" push and causing a "burst of silence".
The S.D.C. is stopped at the required depth by order of the wire checker, a cross-check is provided by the count of winch revolutions and, eventually, by depth gauge reading. (See (i)).

(g) Panel. "Carry on with the Diver".

(h) S.D.C. One blow ("Understood"). The Panel Operator can hear the breathing cycle of the set and knows when the diver is breathing from it.

(i) Panel. "Open Control Valve". This order is given after the main supply valve on the panel has been closed and is used to register the depth at the level of the water in the S.D.C., allowance being made for the pressure required to open the non-return valve (should be less than 1 p.s.i.).

(j) S.D.C. One blow.

The Recorder calculates the timing of the dive and passes the various times to the Panel Operator.
Half way between the time of starting the dive and two minutes before the time of leaving bottom:-

(k) Panel. "Change over divers".

(l) S.D.C. One blow ("Understood"). 5 BELLS by No. 2 Diver when No. 1 Diver is in the water.

Two minutes before the time to leave bottom:-

(m) Panel. "Call the Diver In. Report when Ready to Leave".

(n) S.D.C. One blow, followed by 5 BELLS when ready to leave.

(o) Panel. "Understood". "Stand by". "Hoist".
As the S.D.C. is raised at a laid down rate, according to the schedule in use, the panel operator calls out each 10 ft. reading from the gauge to enable the Speed Controller to check the rate of ascent by stop watch and adjust the speed of the winch accordingly. The S.D.C. is stopped at the appropriate depths for each stop by the wire checker.

At the stop before the T.U.P. Stop:-

(p) Panel. "Stand by Bottom Door".

(q) S.D.C. One blow. The door is lowered and held ajar by leaving a clip on top of a dog.

When the S.D.C. reaches the T.U.P. Stage:-

(r) Panel. "Close Bottom Door".

(s) S.D.C. One blow followed by 5 BELLS when door is closed.

(t) Panel. "Hoist and T.U.P.".

The S.D.C. is now raised at maximum speed consistent with safety and positioned on top of the T.U.P. Chamber. The T.U.P. Panel Operator looks on the S.D.C. and raises the pressure in the T.U.P. Chamber to that in the S.D.C.
On hearing the shut-off of air into the T.U.P.:-

(u) Panel. "Equalise and Lock Through".

The bottom door is opened and both divers drop into the T.U.P. chamber where the top hatch is closed by the T.U.P. Attendant.

(v) T.U.P. Panel Operator. "Locked Through. Hatch Closed".

The vents on top of the S.D.C. are then opened and, when the pressure has fallen to atmospheric pressure, the S.D.C. is unlocked and re-positioned in the water alongside the diving door ready for the next dive.

The decompression of the divers in the T.U.P. Chamber is carried out in the normal way, the necessary information from the Recorder being passed by telephone to the T.U.P. Panel Operator.

OXY-HELIUM DIVES

5. The above drill is related to air dives to depths not exceeding 250 ft. For deeper dives using oxy-helium mixtures the drill is similar except for the additional requirement to change over from air to oxy-helium and vice versa. In the 1962 trials decompression was done on oxy-helium or air. In future trials it is likely to be done on oxy-helium or pure oxygen.

6. The variations in drill are as follows:-

(a) On descent the S.D.C. is stopped at 100 ft. by the Wire Checker. This is the signal for both divers to put in their mouthpieces and start breathing oxy-helium. When both are on mixture 5 BELLS are signalled on the "Cut Out" Push. On receipt of 5 BELLS lowering is resumed.

(b) At the bottom "Carry on With The Diver" is answered by one blow followed by 5 BELLS when the diver leaves the S.D.C.
(N.B. This differs from the procedure for air diving, paragraph 4(h), because the divers will have been breathing from their sets from 100 ft.)

(c) On hoisting, both divers continue to breathe oxy-helium from their sets until the T.U.P. Stop is reached.
(N.B. This is only applicable if the later stops are being carried out on air. The change over from oxy-helium to some other gas will depend on the schedule in use).