Excellent excerpt from

Oxygen and the Diver

by KENNETH DONALD

The Admiralty Experimental Diving Unit

After serving as Flotilla Medical officer in the Second (Captain Warburton-Lee VC., RN.) and Fifth (Captain Lord Louis Mountbatten, D.S.O., RN.)Destroyer Flotillas I was posted to HMS Forth in Holy loch. The ship serviced submarines patrolling in the North Atlantic, the Arctic and the North Sea. It was a fascinating experience to meet and work with these extraordinary men. However, although Holy Loch was a beautiful and serene place there was, apart from routine duties, little to do except read, meditate and, occasionally, walk about.

Thus, in March 1942, after volunteering for 'special service' whatever that meat, I found myself proceeding to HMS Dolphin (Fort Blockhouse, Gosport). I soon discovered that I was to be associated with underwater activities, which were quite apart from those of the submarines based there. The reasons for these developments were highly confidential. The Italian Navy, which has always had a penchant for unusual and gallant underwater operations, had, in December 1941, struck a critical blow against the Royal Navy by severely damaging the two battleships HMS Queen Elizabeth and HMS Valiant in Alexandria harbor. Both ships were rendered non-operational for a considerable time. The harbor was shallow and lists were rapidly controlled. This was possible, as the entire human torpedo crews involved had been captured. All drills, shore leave, receptions and band parades continued with due pomp and ceremony. Steam' was kept up as if ready to sail at short notice.

This brilliant attack was made by specially designed torpedoes, which were ridden and controlled by two divers. The powerful warhead, with neutral buoyancy, could be detached from the torpedo and clamped onto the ship's bottom or laid on the seabed. The torpedoes were carried to within a few miles of the harbor by a parent submarine. This was by no means the first of such underwater operations. A similar planned assault on Alexandria harbor in August 1940 had been unwittingly frustrated by the bombing and sinking of the Italian parent submarine Iride. In November 1940, thee, human torpedoes, had launched an attack on HMS Barham in Gibraltar harbor. Only one of three craft penetrated the harbor defenses. It was ridden solo by Lieutenant Brindelli who had ordered his number two to 'balls out' after respiratory difficulties. Brindelli cane within 100 yards of the Barham when his torpedo engine failed. He pulled the inert torpedo to within 30 yards of the ship when he suffered breathing apparatus failure and probably, carbon dioxide intoxication. This remarkable man survived and was only captured as he nearly succeeded in boarding a Spanish ship. A similar attack on Gibraltar harbor in September 1941 resulted in the destruction of two large tankers and a cargo vessel. The Italian Navy also had underwater swimming teams who were attaching limpet mines to ships in different harbors with increasing effect.

These events had not gone unnoticed by 'A Former Naval Person' and a brisk signal went to the Chiefs of Staff in January, 1942: "Please report what is being done to emulate the exploits of the Italians in Alexandria harbor . . .Is there any reason why we should be incapable of the same kind of scientific aggressive action that the Italians have shown?"

At long last Their Lordships moved and ordered the development of 'human torpedoes' and other unorthodox methods of underwater attack. It was estimated that we were at least seven years behind the Italians in this field, although new types of midget submarines were already being developed. Flag Officer, Submarines, Admiral Max Horton, D.S.O. was placed in charge of all these activities with the support of HMS Excellent (Gunnery and Diving School, Portsmouth). Flag Officer Submarines was represented in this regard at HMS Dolphin by Commander G.M. Sladen, D.S.O., RN.

On my arrival at Blockhouse I was put through refresher courses of air diving and submarine escape followed by oxygen diving in Horsea Lake. It was here that the first British 'charioteers' were being trained. They were using a self-contained oxygen breathing apparatus, which had a well-designed rubber counterlung and a large radial carbon dioxide absorbent canister (4.5 lbs). Although it had been developed with considerable urgency it appeared to be more robust and safer than the captured Italian models. Oxygen breathing was essential in these covert underwater attacks on ships and harbors so that no gas needed to be vented and the risk of detection minimized.

My duties as a humble Surgeon Lieutenant were simple. I attended all oxygen diving carried out by future charioteers in case anyone 'faked' or suffered other misfortunes. With regard to the safety times and depths when breathing oxygen under water, it was tacitly assumed that these could be directly inferred from the oxygen tolerance determined in the 'dry' hyperbaric

Chambers when the resting subject breathed oxygen in compressed air. The safety limits at this time (1942, Royal Navy and US Navy) were of the order of 2 hours at 50 feet and 30 minutes at 90 feet of sea water (see Chapter 1). In April and May there were a number of incidents at Horsea Lake (maximal depth just over 25 fsw) when oxygen divers' did not feel right' or were transiently dissociated. It was felt that minor symptoms were inevitable in groups of men who had not dived before and were under intense training. Again, the mouthpiece, nose clip and soft helmet' set-up of the "human torpedo" oxygen diver was far more claustrophobic than air diving with a large, rigid and windowed helmet in which fresh air sweeps constantly past the face. Then, suddenly, an oxygen diver was lost at these relatively shallow depths. The precise events leading to his death were not fully determined but there was a strong suspicion that oxygen poisoning had occurred. There was a growing realization that it was desirable, if not essential, to have a constant background of careful investigation to ensure the maximal safety of these men during training and during their dangerous covert operations.

In May 1942 the Royal Navy took over the experimental wing of Siebe, Gorman and Company at Surbiton. This exceedingly well equipped unit contained a large open 12 foot tank, a smaller open 25 foot tank, a wet' pressure chamber (the 'wet pot') and several dry pressure chambers of different sizes. Expert technical help was immediately available. Every member of the company from Sir Robert Davis and his sons to the nurse in the sick bay provided all the assistance possible. It had been decided to test all operational personnel (charioteers, X-craft (miniature submarines) crews, underwater swimmers etc.) in controlled and reasonably safe conditions while breathing oxygen underwater at increased pressures in the wet pressure chamber. I traveled daily from Portsmouth to Surbiton to act as medical officer in these trials and saw experimental diving in hyperbaric chambers for the first time. It was a strange scene as divers were lowered into the 'wet pot', particularly as a considerable number were hauled out unconscious after convulsing. On occasions, the next diver stepped over the last casualty to take his turn. There was an air of extreme urgency as the planning and method of attack on enemy harbors and the proper defenses of our own, depended on a full knowledge of how deep these oxygen divers, friendly or hostile, could go with reasonable safety. The grand mal types of convulsion occurring made it absolutely clear that we were encountering acute and severe oxygen poisoning at depths and in times then considered quite safe by all authorities.

After about a fortnight of this unusual and occasionally chilling experience I received a 'chit' from Their Lordships instructing me to proceed forthwith to some obscure posting in the Shetland Islands. Next day I was traveling for the last time from Portsmouth to Surbiton by train and, by sheer chance, Commander Sladen came into the same compartment. Sladen, who had played rugby football for England on a number of occasions, was a man of unlimited energy and quick decisions. He was a highly successful and much decorated submarine commander having been in many actions, including the torpedoing of the heavy German cruiser, the Prinz Eugen. I informed him of my new appointment and must have shown my regret at leaving this brave company. He asked me point-blank if I would like to be responsible full time, for the safety of the subjects and for the investigations and program at the Unit. I replied that I certainly would. "Give me your chit," he said, "You'll hear no more from their Lordships." Nor did I.

Thus, there I was, a Surgeon Lieutenant, aged 30, with no research and little hyperbaric experience, with a not inconsiderable research unit on my hands. I was, by some strange and splendid accident, in no way responsible to any senior medical or scientific person or committee and apart from operational demands, I was given a carte blanche in program and supplies. My immediate responsibility was to Commander Sladen and Commander W.O. Shelford, RN., Submarine Escape Officer and later Superintendent of Diving. In a relatively short time the staff of the Unit expanded and consisted of

Commissioned Gunner Mr. E. Crouch, RN., two diving Chief Petty Officers, a gas analyst, a typist secretary and a variable number of hands for diving, routine and maintenance.

A further piece of extreme good fortune was the discovery that J.B.S. Haldane (fils) was working in one of the dry chambers for two days a week completing a contract to investigate the physiological factors relevant to the submarine HMS Thetis disaster in 1939, (Alexander et al, 1939; Case & Haldane, 1941; Haldane, 1941). During the next year, while Haldane was completing his program, he gave most valuable advice particularly during the development of oxygen-nitrogen mixture diving (see Chapter 5) and also on the statistical treatment of the Unit's early studies of oxygen poisoning (see Chapter 2).

In August 1942, in addition to the many operational personnel passing through the Unit as subjects, we were joined by a team of twelve carefully selected volunteers. These men also acted as experimental subjects, particularly in longer-term projects. The Unit program was rapidly becoming engaged in more and more operational problems. We needed a larger staff that could service and maintain respiratory and other apparatus, who could dress the divers and who could help to attend and observe subjects both in the open water and in chambers. Care was taken to ensure that they were briefed and involved in all Unit activities. One of my most pleasant memories was of an Able Seaman showing a senior visiting academic how to handle a wayward spirometer during marked pressure changes. The teacher and pupil were completely engaged without a trace of disrespect or false dignity. Another visitor wrote some years later "in spite of the risk and unpleasantness of the job, the experimental department was always a scene of cheerful activity." Some of these divers transferred to operational teams and some operational personnel came back in to the 'experimental' group. This leavening both ways was good for morale and increased efficient communication with those in the field.

While ordering notepaper for the Unit I decided that we fully deserved a more definite and prestigious identity. I adopted an Admiralty crest and titled ourselves the Admiralty Experimental Diving Unit. During the next three years we were in constant touch with the Admiralty over a host of problems. They also sent many VIPs, including those of our allies, to see our work. No one objected to our splendid self-bequeathed title.

In the large study of oxygen poisoning in divers, which is fully described in Chapter 2, it was necessary for the observers to assess the various symptoms and signs reported by the divers. Convulsions are the only unequivocal end-point of oxygen toxicity but other symptoms, even lip twitching in a soft helmet, are largely a matter of report. The morale and reliability of these men were therefore critically important. They were well aware that the success of future operations and the safety and competence of operational personnel completely depended on the accurate and faithful reporting of symptoms in these urgent investigations. When we first transmitted our findings elsewhere concerning the quite unexpected and marked increase of oxygen toxicity under water, there was, initially, almost total disbelief. Most unfortunately, mention must have been made by some unknown persons of possible "feigned symptoms". Such remarks were not only unforgivable but die hard. Indeed, the author only learned of this recently when, to his astonishment, he was asked, in writing, by a US research worker 45 years later "which was the study spoiled by feigned symptoms?" It is therefore necessary to point out, somewhat reluctantly, that the subjects in this oxygen study, including members of the experimental team, received many gallantry awards (Victoria Cross, 4; George Cross, 5; Distinguished Service Order, 10; Distinguished Service Cross, 21; Distinguished Service Medal, 8; George, 5 Conspicuous Gallantry Medal, 5; British Empire Medal, 16, etc). It is most unusual, if not unique, for an investigator to be able to produce such tangible evidence of the intrepid mould and resolution of his subjects. The extraordinary fantasy of such brave and responsible men feigning convulsive attacks and other signs and symptoms in front of their colleagues and medical officer in these critical trials dose not merit polite consideration.

Oxygen-Nitrogen Mixtures

In October 1942, it was decided that, as oxygen diving was so dangerous below 30 fsw, it was necessary to develop the use of oxygen-nitrogen mixtures in self-contained counterlung breathing apparatus for use at greater depths. The oxygen breathed could be diluted with nitrogen, although not so much as in air, and this would allow diving to considerably greater depths without the risk of oxygen poisoning.

The midget submarines were now working up to operational efficiency. In their harbor attack procedure, a member of the crew might be required to lock out of the craft, surface and inspect and inspect or even cut defensive nets and then return to the submarine and then return to the submarine and lock back in. This might be necessary at depths greater than 30 fsw and such oxygen-nitrogen mixtures would be very useful in this context as oxygen poisoning could be avoided. The development of oxygen-nitrogen mixture conterlung breathing apparatus is discussed in some detail in Chapter 4. This work was completed and reported in March 1943 (Donald 1943 (i)).

In May 1943, counter-mining officers, on entering Bizerta, Tunisia, found many large German mines with six-day clocks for use in harbors and basins. These had no magnetic or acoustic units and could not be detected and, swept, by the usual methods. This meant that it would be difficult, if not impossible; to guarantee the safe handling of troop and supply ships in newly captured ports. Unless some means of locating these mines were found, the planned invasion of Europe was in jeopardy. After considerable consultation and much rumination, it was proposed by Officer-in Charge of Counter Mining that the only way to deal with this problem was, if possible, to organize large teams of divers too search for these mines systematically. Commander John Stuart Mould, G.C., G.M., RANVR. (called, Mouldy', of course) came to see me about, the problem'. Mouldy had achieved considerable distinction in many dangerous counter-mining operations which, to quote the London Gazette, "include the recovery, rendering safe and investigation of the first Garman magnetic/acoustic unit and moored magnetic mines." Oxygen diving was out of the question, as depths up to 80 fsw would be encountered. Thus, a few weeks after completing the first mixture counterlung development, an unexpected itself.

A number of large teams of divers were required and it was essential that they were highly mobile and able to dive and search anywhere at short notice. Each diver moved on bottom along a jackstay on a grid, searching one side and then, on return, the other. It was necessary to test the efficacy of oxygen-nitrogen mixture even further and to assess the feasibility of large teams using this not altogether simple procedure requiring scrupulous supervision. During 1943 P Party personnel (P for Port Clearance) were trained at the Admiralty Experimental Diving Unit, particularly in the care and maintenance of mixture breathing apparatus. They also acted as attendants and subjects in many experimental dives 'in the dry' and 'in the wet'. Officers were taught the theory and calculations. Involved in mixture diving. It was felt strongly that this considerable degree of understanding and involvement was essential for the reliable use of mixture by counterlung divers in demanding and dangerous operational conditions. It was a great pleasure to work with these brave and intelligent men, whose sense of humor was never far below the surface. In thousands of oxygen-nitrogen mixture dives in Europe after D-day by P Parties, there was no instance of oxygen poisoning, oxygen lack or decompression sickness. Their quite remarkable operational record in Europe is well documented (Grosvenor and Bates, 1956). Their first task was to clear Cherbourg harbor for the US forces. General Eisenhower sent a warm signal of thanks. They worked their way along the coat of Northern Europe, sometimes bypassing unfinished battles and uncaptured ports to return later. The clearing of Antwerp harbor and its approaches was a tremendous undertaking, much of it carried out under enemy fire. Over eight and half million square feet were searched. Rotterdam, Hamburg and Bremen were finally cleared. Bremen was to be the port for the US occupation zone and its clearance was the greatest task of all. All six British P Parties and the Dutch P Party (trained in the United kingdom) took part in this operation. It is estimated that 9,500,000 square feet of docks and harbors in Bremen were searched and cleared. These were certainly days of high courage and great achievement.

Underwater Oxygen Swimmers

In 1930, Commander de Carlieu deigned and introduced rubber swim 'fins' attached to the feet. These were widely adopted by sportsmen, some of who carried air cylinders giving a steady flow of air in to their mask. The adoption of a closed circuit with oxygen breathing and widely adopted by sportsmen, some of whom carried air cylinders giving a steady flow of air into their mask. The adoption of a closed circuit with oxygen breathing and without venting was ideal for covert underwater fin-swimmers and was used by all combatants. These divers were, of course, known to the public as frogmen. A 'crawl' leg stroke provided the propulsion, the two swim-fins and legs imitating the driving action of a dolphin's tail.

In view of our recent findings, these oxygen swimmers did not go deeper than 25 feet, except for very brief periods and only for urgent operational reasons. The higher flow required would have necessitated considerable venting of gas with greater risk of detection. Endurance would have been reduced and the large cylinders needed would have impaired mobility and stream lining. Water turbulence was most undesirable as it, too could alert harbor and coastal defenses.

The Royal Navy frogmen often worked in northern waters and needed protection from the cold. Their beautifully designed and streamlined rubber suits were the most efficient and elegant ever produced. The main contributors were W. Gorham of the Dunlop Rubber Company and Commander Shelford. Colonel H.hasler, D.S.O, R.M. (of 'cockleshell' fame) and Lt. Cdr. B. Wright, RCNVR. An experienced spear fisherman, both stimulated and helped for a host of operational requirements, the sabotage of ships, docks and bridges (limpeteers), boom and ship defense units, beach reconnaissance (the frogman could slip off his mask and carry his flippers), and so on.

In the early days of training these frogmen encountered a new and terrible danger called shallow water blackout (SWBO). These blackouts occurred at depths of 20 fsw or less. Several swimmers were lost. Those who surfaced safely described how they had become dissociated and even unconscious. The investigation and elimination of SWBO is described in detail, with references, in Chapter. Briefly it was discovered that these swimmers could have oxygen uptakes and carbon dioxide production far beyond those ever encountered in booted divers. This led to CO2 absorbent canister overload and the divers being anaesthetized by their own carbon dioxide.

At this time increasing interest was being taken in the oxygen uptake of divers as the safety of both oxygen divers and oxygen-nitrogen mixture divers depended on this being accurately known. In the early development of mixture diving, a somewhat approximate estimation of oxygen uptake had been obtained by balancing the oxygen supply with the oxygen uptake in a steady state at rest and during various degrees of exertion. A new and far more accurate method was developed. This depended on a demand valve* fed through a reducing valve and a long intermediate pressure line to the diver's counterlung. No venting was allowed and the diver's face, mouthpiece and nose clip could usually be observed. The oxygen was supplied from a relatively small cylinder in which exact changes of pressure could be read by the observers at the surface, using a very sensitive and accurate pressure gauge (Donald and Davidson, 1944). This new method could be used in any conditions even in open tidal water and was ideal for determining oxygen uptake (P Party divers, frogmen, etc.), under operational conditions. The very high oxygen uptake of frogmen swimming at speed, already mentioned, was a great surprise to us. Looking back, of course, it should have been obvious that the liberation of the diver's legs from his heavy restraining boots to free swimming would inevitably bring many more powerful muscles into play.

In late 1943 and early 1944 the Unit carried out a large program of dives to determine oxygen tolerance at relatively shallow depths (25 to 40 fsw). The effect of exercise and temperature on oxygen tolerance underwater was also carefully studied at various depths. The great variability of tolerance in individuals and between individuals, already demonstrated, made large series essential.

A system for diving on oxygen to greater depths in covert operations was evolved at this time. Relatively short stays at' toxic' depths (50 to 70 fsw) were alternated with brief intermissions near the surface (Donald cit. admiralty fleet Order 4565, 1944). This potentially valuable technique has not been used operationally since that time.

As D-Day approached we felt ready for all predictable requirements for a major assault from the sea. There were some last-minute requests, such as a light escape apparatus for the crews some of amphibious tanks and other heavy vehicles that might be sunk on the way in. the part played by the underwater section of the Royal Navy and Royal Marines in the invasion of Europe is little appreciated. Beach reconnaissance frogmen, who determined the slope, the depth of approach and suitability for tanks and heavy vehicles, including sampling, were landed surreptitiously before D-Day from miniature and ordinary submarines and from light surface craft. The formidable array of obstacles to prevent landings, both on the beach and underwater, were located and studied in detail. These obstructions could, of necessity, only be demolished just before landing, usually under heavy enemy fire. The ten gallant teas (6 RN, 4 RM) of Landing Craft Obstruction Clearance units performed one of the most critical and dangerous tasks of the whole war. Miniature submarines were submerged about three miles off the coast and surfaced at the agreed time to flash hooded lights seaward to guide the assault. The Port Clearance Parties were close behind to search and clear all docks, basins, harbors and canals and to check lock gates and clear all docks, basins, harbors and canals and to check look gates and bridges for mines. The harbors, both old and new, were in turn, protected by the Royal Marine Boom Defense Units who also patrolled under water.

At home the transfer of P Party Headquarters to Brixham gave the Admiralty Experimental Diving Units better facilities for even more realistic operational trials in the harbor and open sea. In August 1944, Surgeon Lieutenant Commander W. Davidson, RN. joined the Unit to train in hyperbaric work and gave valuable help. As victory in Europe became more certain we turned our attention to a number of new problems. Lighter swimsuits were developed and there was a sudden interest in the dangers of the Pacific and other Far Eastern seas. We were able to commence a number of projects that had been set aside because of unremitting operational demands.

One of these projects was to determine the margins of safety in the method of Surface Decompression being used somewhat tentatively by the Royal Navy in air diving during World War II. In this procedure the diver came straight up from the bottom to the surface at about 100 feet per minutes maximum). He was then recompressed in a deck chamber to his original depth. The maximal total time allowed from ‘bottom to bottom’ was five minutes. After another five minutes at maximal pressure a standard decompression (air and oxygen) was carried out.

It has since been claimed (Davis, 1951) that this technique that this technique had been used during diving on the Empress of Ireland (190 fsw) in 1914 and on the Laurentic (130 fsw) from 1917 to 1922. in fact the most careful enquiries reveal that that immediate recompression and subsequent decompression had only been used after emergency surfacing due to ‘blow up’ or other severe accidents or illness, as was the case in air diving the world over. The first deliberate, planned use of immediate surface decompression in air diving originated in HMS Tedworth, the Royal Navy deep diving vessel, during World War II. A table was developed with maximal time allowed on bottom ranging from 50 minutes at 120 fsw to 15 minutes at 250 fsw. The surface decompression procedure and table were not its overall safety ever been tested and approved. The attendant dangers of almost immediate fatal decompression sickness or of irreversible paralyses were indeed fearsome. Consultation with diving officers at the “lesser” depths (120 to 200 few). Not surprisingly, urgent requests were now being made (1945) that the pr0cedure and table should be formally examined and tested before further use.

In these 1945 Admiralty Experimental Diving Unit trials (Donald & Davidson, 1945), for obvious reasons, the first surface decompression profiles were performed in compressed air using goats as subjects. Human chamber divers were then carried out, followed by full sea dives from HMS Tedworth. These investigations showed that it was highly dangerous to use this method with exposures greater than 20 minutes at 190 fsw.

The summary of recommendations made after this investigation were as follows (Donald & Davidson, 1945):

1. The 'Tedworth Method' of surface Decompression is safe for the following depths and times on the bottom:

Depth	Time on Bottom
Up to 130 fsw	50 minutes
130- 150 fsw	40 minutes
150- 170 fsw	30 minutes
170- 190 fsw	20 minutes

2. This time should never be exceeded. If this occurs inadvertently e.g. the diver is fouled, then the stops must be carried out on the shot rope.
3. This method should be employed only by TRAINED personnel in a properly equipped dived diving ship, as speed in recompressing the diver is essential.
4. Oxygen breathing is essential during decompression from the 60 fsw stop to surface.
5. This method should not be employed at depths greater than 190 fsw owing to the grave risk of "CHOKES' on rapid surfacing."

Air diving is now restricted to 50 msw (165 fsw) but surface decompression is still practiced a great deal, especially in 'shallow' oil and gas fields. Recompression to the full depth is not necessary.

The main dangers of this procedure are always present if there is any slackening of the rigid discipline of accurately measured and restricted 'times on bottom to bottom' time. Rapid handling of the diver on deck requires ballet-like skill and precision. Any clumsiness or causing delay at surface is particularly hazardous.

We next turned, out attention to the ever-present problem of submarine escape. The number of successful escapes from sunken submarines during World War II, even from moderate depths, had been disappointing. The hazards of main compartment flooding followed by serial escape through a trunk or escape lock were now realized to be great at shallow depths and appalling at greater depths. The breathing of compressed contaminated air, followed by the breathing of oxygen near equalization and during escape, was full of dangers, which were compounded in a stressed and exhausted group of survivors.

Experience before and during the war has shown that the majority of survivors, particularly from greater depths, were not wearing any breathing apparatus and had escaped from air locks or compartments that had equalized with the outside pressure during or after the incident. A whole new look at submarine escape was patently necessary. We proposed to imitate and exploit these successful but somewhat fortuitous escapes without breathing apparatus from air locks (Donald, Davidson and Shelford AEDU Report XVIII, May 1946, Published J. Hyg. Camb. 1948). The air breathing escape procedure to be adopted was as follows:

Stage 1:
Escaper enters the relatively small escape compartment and pressure is raised by flooding to the pressure at which the submarine is lying. An air lock is maintained. Time: 2 minutes approximately.

Stage 2:
At full pressure, manipulating and opening hatch and emerging from submarine. Time: variable.

Stage 3:
Free ascent from submarine to surface at approximately 2 feet per second. Time: varies with depth, 2-2.5 minutes. The rate of ascent had been determined in open water trials by commander Shelford.

In view of the considerable risk of irreversible decompression sickness, goats were used in these initial experiments, which were conducted in compressed air. Escape profiles were carried out from 150 to 300 fsw. Time at full pressure (Stage 2) was varied from 3 to 7 minutes. Symptom less escapes with no decompression sickness were successfully concluded with up to 5 minutes at maximal pressure (Stage 2) at 150, 200 and 250 fsw. The use of oxygen-nitrogen mixture instead of air (33% oxygen; 67% nitrogen) allowed safe escape profiles from 300 fsw with up to 7 minutes at full pressure. In these experiments the time at full pressure before escape was deliberately excessive. As regards decompression sickness, it was felt that escape by this method, with a short Stage 2, were feasible from far greater depths. The problem as to whether the escaper could continue to vent and not inhale while ascending from these great depths was yet to be investigated.

Another important question was whether nitrogen intoxication would jeopardize the competence of the escapers. A series of cancellation tests were performed during and after very rapid compression to 300 fsw. It was shown that compression to 300 fsw, in times as short as one minute, did not cause undue psychological disturbance although there was a slight euphoria in several instances. The cancellation tests showed that the subjects were able to concentrate moderately well during compression and after arrival at full pressure. A few subjects showed marked slowing but maintained accuracy and others lost accuracy without slowing. No subject stopped his test or lost control.

All these air breathing submarine escape experiments were performed in 1945 between VE day (8^{th} May) and VJ day (14^{th} August), a good augury, we hoped. The Ruck-Keene Committee on submarine escape (august 1946) supported this new method of escape and recommended further research and development with a view to its adoption, If feasible. A whole series of animal and human experiments in the late forties, fifties and sixties culminated in escapes in the open sea from a submarine made, in the 600 fsw escapes the compression time was 33 seconds, the full pressure period 3 seconds and the time of ascent, when most nitrogen is absorbed, (rate 8.5 feet per second) 68 seconds. The great increase in the rate of ascent was largely and somewhat fortuitously due to the development of a survival suit with a hood and a buoyancy stole to prolong survival at surface. Thus the escaping crew were compressed from atmospheric pressure in the submarine to 600 fsw (19 ATA), locked out and ascended to the surface and atmospheric pressure in the astonishing time of 104 seconds. The twenty-five years work to make this feat possible has been described and reviewed by the author elsewhere (Donald, 1970, 1979 and 1991). These two reports made it clear that, although successful escapes were now possible from 600 fsw and even deeper, there were considerable attendant risks, which were only justifiable in real escapes from disabled submarines. Calculations had shown an undesirable degree of nitrogen super-saturation of various 'fast' tissues on surfacing after deep escapes (500 to 700 fsw). It was considered highly probable that there were free bubbles of nitrogen in the circulation after such escapes. For these reasons it was recommended that further deep escape trials should be approached with considerable caution and that repeated deep escapes at relatively short intervals by a single individual should be avoided.

The submarine escape study was my last project. I left the Royal Navy in November 1945. The Admiralty Experimental Diving Unit at Siebe, Gorman, Surbiton was shut down shortly after the was and the remaining staff returned to HMS Vernon, Portsmouth, where the diving headquarters and school were now established. It had been an interesting and concentrated three and a half years.

References

ALEXANDER, W., DUFF, P., HALDANE, J.B.S, G. and RENTON, D. (1939): After effects of Exposures of men to carbon dioxide.

Lancet, 2, 419-420. CASE, E.M. and HALDANE, J.B.S. (1941 (i)): human physiology under high pressure.

J. Hyg. Camb., 41, 225-249. DAVIS, R. (1951): Surface Decompression. Deep Diving and Submarine Operations. Fifth ed. St. Catherine Press, London, 97-99.

DONALD, K.W. (1943(i)): Low supply of mixtures in counterlung type of breathing apparatus. Admiralty Experimental Diving Unit (R.N) Report VII/43.

DONALD, K.W. (1970): A review of submarine escape trials from 1945 to 1970 with Particular emphasis on decompression sickness. Royal Naval Personnel Committee U.P.S. 290. Recently published DONALD, K.W. (1991) J. roy. nav. med. serv. 77, 171-200.

DONALD, K.W. (1979): Submarine escape breathing air. A review and analysis of experiments by the Royal Navy. Bull. Europe. Physiopath. resp. 15, 739-754.

DONALD, K.W. and DAVIDSON, W.M. (1944): Oxygen uptake of divers. Admiralty Experimental Diving Unit (R.N) Report XV/44. later published: DONALD & DAVIDSON (1954). Oxygen uptake of booted and fin Swimming divers. J. Appl. Physiol. 7, 31-37.

DONALD, K.W. and DAVIDSON, W.M. (1945): Surface Decompression. Admiralty Experimental Diving Unit (R.N) report XVII/45.

DONALD, K.W., DAVIDSON, W.M. and SHELFORRD, W.O. (1946): Immediate surfacing from increased pressures with a view to submarine escape. Admiralty experimental Diving Unit (R.N) Report XVIII. Later published (1948) DONALD, DAVIDSON & SHELFORD, Submarine escape breathing air. J.Hyg. Camb., 46, 176-183.

GROSVENOR, J. and BATES, L.M. (1951): open the Ports. The story of the human Minesweepers. Wm. Kimber, London.

HALDANE, J.B.S. (1941): Human life and death at high pressure. Nature, 148, 458-460.