The Little Story of the Underwater Cutting

By

Francis Hermans

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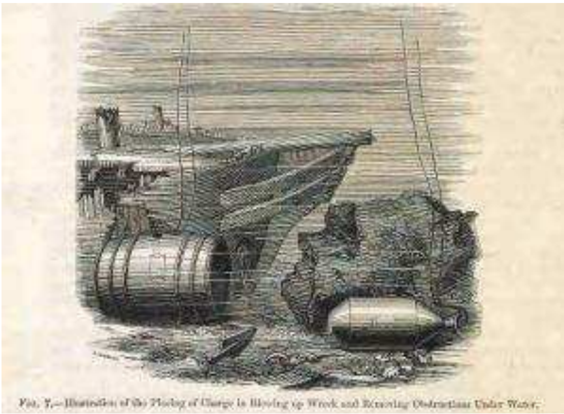
Since under water Cutting exists it has always interested not only the general public who sometimes wonders how it is possible to burn something under water but also most commercial divers who generally like to practice this particular discipline.
Currently the divers have at their disposal a variety of tools and methods to accomplish this type of mission, but as you can imagine this has not always been the case. I therefore propose you to follow me through these pages and discover the story of these wonderful tools

From the time when John and Charles Deane brothers invented the first modern diving helmet with which they would create the diver profession in 1832 our elders have been faced with situations where they had to make use of a tool capable of cutting.
For these pioneers of underwater work the range was not very big and it was generally limited to a knife, a saw, an ax or a hammer with his chisel.
At the time many of the underwater works was done on wrecks and consisted to recover their cargo. Sometimes when the wreckage hampered the traffic it was destroyed and in this case the tools used were of course not these hand tools but rather black powder or gunpowder developed in 1354 by the monk Berthold Schwartz and used as explosive for rock excavation from 1627.
Under water, the technique has been developed by Colonel Pasley during the works on the wreck of the Royal George. As this type of low explosive did not withstand humidity it was necessary to place it in a sealed container that could either be made of wood or

metal. The lighting of the charge was generally performed using large voltaic battery.
Then later since 1864 these products were replaced by the famous dynamite invented by Mr. A. Nobel.

Figure n° 1: Wreck demolition with black powder (1)



Towards the end of the 19th century things were deteriorating a bit for our divers with the appearance of the first steel hull ships and the various port structures made of the same metal. The steel cutting using strands of explosives continues to be used but this technique was not always well controlled.
Either the charge was too small and nothing was cut, or she was too high and much more was destroyed that planned.
Fortunately for small cutting jobs, in addition to the hammer and chisel our elders now had at their disposal the pneumatic drill which was invented by Mr. Simon Ingersoll in 1871 which was followed a little later with the chipper.

With these tools they could now by making a series of contiguous holes cut short lengths of steel. This is also the method that was used on the wreck of *H.M.S Gladiator* which sank in April 1908 following a collision with the *St. Paul* (the same that we will find later in another article). Indeed, to avoid certain structures to hinder the salvage, the 15 tons guns, the 3 chimneys the masts and all other disturbing structures were cut using pneumatic chisels.

Photo n° 1: *H.M.S Gladiator* before sinking (2)

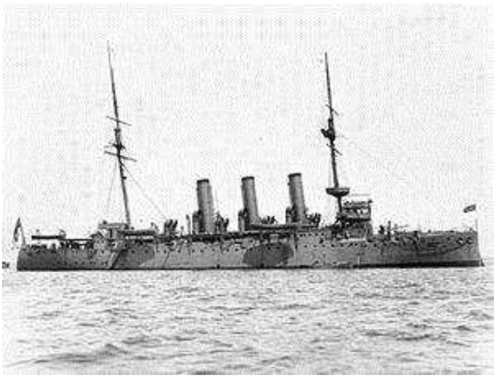


Photo n° 2: *H.M.S Gladiator* during salvage (3)

It is needless to say that in those days the cutting of a steel structure was particularly laborious and tedious and it was therefore necessary to find some other more suitable equipment.

The first effective tool that would be available to divers in the early 20th century was the underwater gas burning torch, but this fabulous machine that would revolutionize the underwater works would however never have been possible without the genius of some men.

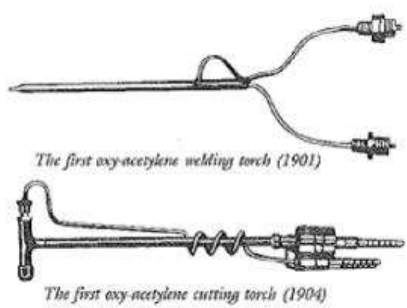
The first named Edmund Davy was an Irish professor of chemistry who in 1836 discovered the C2H2 (acetylene) and imagined that this gas could when burned in air be used as lighting.

Then comes Henry le Chatelier a French chemist who in 1895 discovered that the burning of an oxygen / acetylene identical volume generates a flame whose temperature reaches about 3130 ° C which exceeds the temperature of combustion of other known mixtures. Three years later this same chemist suggested inventing a device capable of exploiting this gas mixture so that it could be used for the welding and the cutting of ferrous metals gas.

In 1896 two other French scientists Albert Claude and George Hess invented a method for storing acetylene in cylinders under pressure without risk of explosion.

Another key figure who promoted this invention was Carl von Linde a German engineer who in 1902 built the first factory for the industrial production of oxygen and nitrogen with an air liquefaction process. And finally, last but not least, Edmond Fouché and Charles Picard, who in 1902 invented the first oxyacetylene torch for welding metals (Patent No. 325,403, filed October 18, 1902) then followed in 1904 by the first cutting torch.

Figure n° 2: The first oxyacetylene welding and cutting torches (4)



Obviously, this new invention quickly goes round the world and many countries buy the rights to this patent to also manufacture this tool.
Unfortunately for our divers despite the rapid implementation of this cutting device on demolition sites in the open air they had still to wait until 1909 for that someone get interested in it and starts to transform the torch for underwater works.
Previously it had been tried to let the torch burn under water, but the flame extinguished constantly because of turbulence caused by the flow of residual gas bubbles.
How then do about it? Why not create an artificial atmosphere allowing the flame to burn in an air bubble insulating it from contact with water.
It seems that this idea was born more or less simultaneously in the head of two.

That of Charles Picard who works for the Acétylène Dissous plant in Champigny and the other, the engineer A. Heckt of the German company der Deutsch-Luxemburgischen Bergwerks und Hütten-A-G.
The latter, however, takes a small lead over the French since 1909 the company buys 4 German patents through which it will be able to manufacture the first underwater gas burning torch (5).
To protect the flame of his blowtorch our engineer invents a kind of iron collar which surrounds the nozzle of the torch in which compressed air is sent.

Photo n° 3: The first underwater gas burning torch (6)

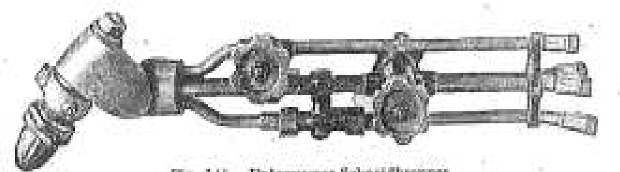


Fig. 141. Unterwasser-Schneidbrenner.

Photo n° 4: Detail iron shield (7)

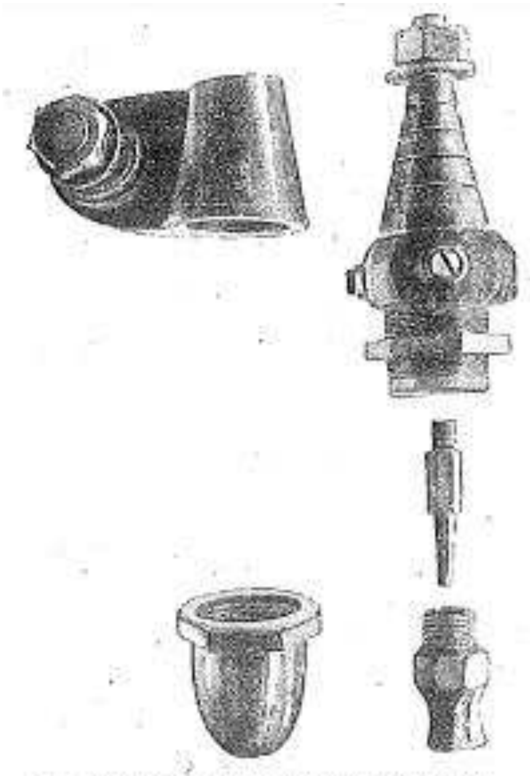
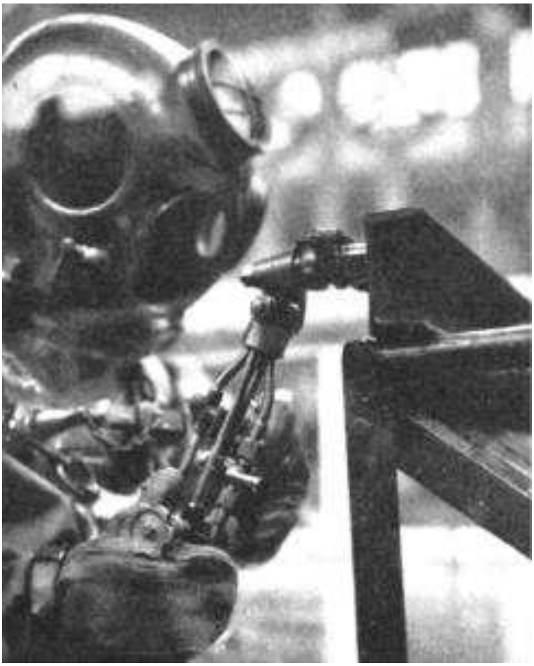


Fig. 140. Auseinandergenommener Brennerkopf.

In addition to the oxyacetylene gas mixture he also uses very rapidly an oxy-hydrogen mixture.
The first tests are carried out in a tank equipped with portholes in the presence of many engineers and representatives of the Kaiser Wilhelm Canal department

and on this occasion a diver cuts a flat iron 100 x 20 mm with an oxyhydrogen cutting torch (8).
On another occasion a diver goes down to 5 meters deep in the port of Kiel and cut a square 60 mm iron bar in thirty seconds which is then followed by a plate 300 x 20 mm that he manages to cut in 90 seconds (9).

Photo n° 5: German diver with his gas burning torch (10)



In 1914 this German torch starts to be used to cut sheet piles, pieces of metal structures, pieces of wreckage and from the writings the cutting speed can reach 1.45 meters of sheet pile at a time while the thicknesses that may be cut with this first tool can reach 150 mm (11).

Photo n° 6: Sheet piles cutting 1914 (12)

In 1915 a second German torch made its appearance, that of W. & BRUSCH WFJ BEYER but apparently extinguishing problems seem to exist because a few months later the two inventors are developing an electric ignition system in which the current is delivered by a small portable transformer that saw his weight also serves as ballast.

Figure n° 3: W. BRUSCH & W. F. J. BEYER Patent (13)

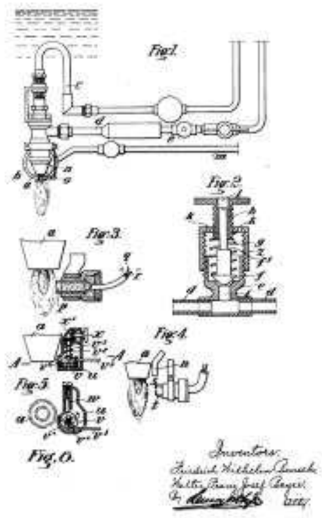
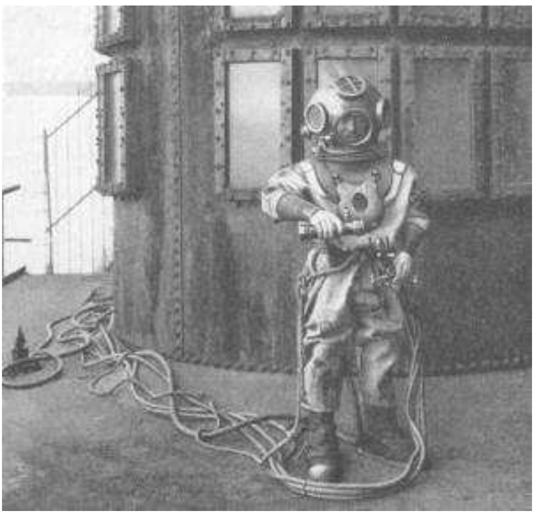


Photo n° 7: Diver holding his portable transformer (14)



In 1932 a new torch made its appearance, that of the Berliner Mr. H.Töpper.
The special feature of this device is that the heating flame is not fed with a combustible gas but rather with a conventional liquid fuel such as gasoline, benzene or other.
This liquid fuel is sent to the torch by a bottle of compressed air or nitrogen where it will be heated and then vaporized by the heating resistor that is incorporated into the body of the torch.

Photo n° 8: H. Töpper gasoline torch (15)

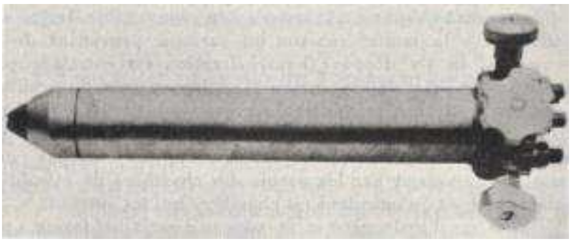


Photo n° 9: H. Töpper Torch detail (15)

Figure n° 4: Sketch installation (15)

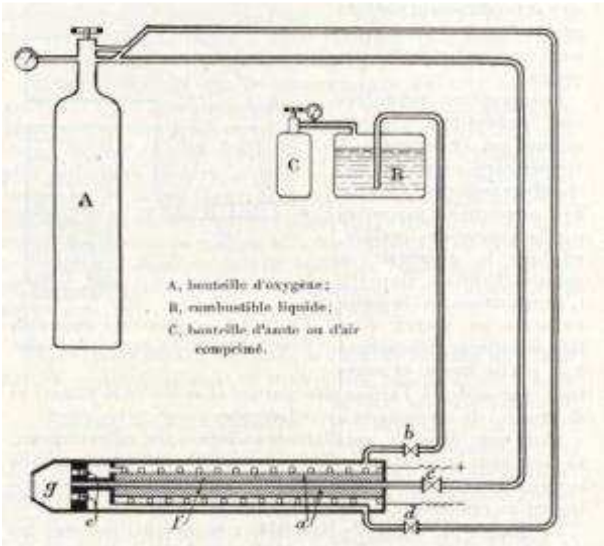


Fig. 3. — Schéma de l'équipement d'un chalumeau Töpper fonctionnant sous l'eau.

With this torch the diver could in function of the thickness (10-40 mm) cut a steel sheet of 1 meter between 160 and 220 seconds (16).
A year later it is the turn of Messer Griesheim to arrive on the market with its underwater cutter.
It was developed to be used on wrecks lying up to 60 meters deep.
The operating principle is more or less identical to its predecessor; it is - to - say that the gasoline is also send the torch head via compressed nitrogen where it is then sprayed in the oxygen.

Photo n° 10: Messer Griesheim gasoline torch (17)

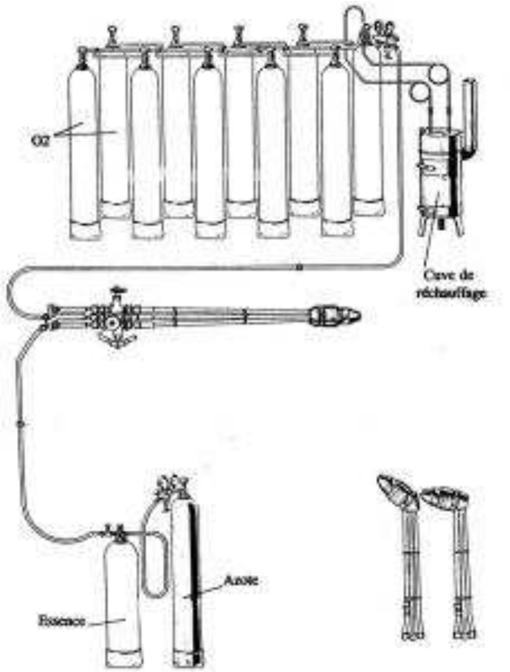
The torch body consists of three valves: one for the supply of the cutting oxygen, one for the heating oxygen and the last one for the nitrogen - gasoline mixture.

Photo n° 11: Messer Griesheim gasoline torch (18)

Three tubes then bring the gas and liquid to the torch tip. The tubes as well as the torch head are interchangeable thereby obtaining a different inclination of the nose, which facilitates the handling of the tool according to the cutting work.

One big advantage of this torch is that it has no bubble skirt, it has been replaced by a combustion chamber (see Picard H7) allowing therefore to better seeing the cutting flame if there is a little visibility.
Since its commissioning the performance of the device are such that it will quickly become the most powerful burning torch of the market because depending on the thickness to be cut (10 mm to 100 mm) it can reach a cutting speed of 30 to 6 meters per hour (19).
For the common contemporary professional divers, these cutting speeds are quite unimaginable, yet in a cutting made in Paris during the seventies, I witnessed the daily performance of an Old Dutch hard hat diver who with this torch managed to cut between 145 and 160 meters of sheet piles in six hours of diving.
To achieve such a performance the torch needed to use high oxygen pressure which in the cold period tended to cause freezing of the gas.
To avoid this, the manufacturer had planned to send the oxygen through a tank of heated water. Widely used in the years 40-45 for the cutting of numerous wrecks, it employment then declined sharply because despite its high performance this torch had also some serious drawbacks:
Indeed the noise generated by the combustion flame was comparable to that generated by a jet and was widely exceeding 100 decibels.
Secondly as with all torches, the flame does not fully consume the gas or in this case the liquid fuel which tended to rise to the surface with the resulting pollution of the environment.

Figure n° 5: Sketch Messer Griesheim installation (20)



All this equipment was quite laborious to implement and could become dangerous if all safety rules were not respected, and finally this torch consumed a lot of fuel (25-40 liters / hour) and therefore it became less and less profitable because of the fuel price increase.

The French approach was quite different. They also understood that to prevent the extinction of the flame it had to be isolate from the water but instead of using the iron shield as that used by the Germans, Mr. C. Picard will instead use a kind of flared bell.
In 1912 his underwater gas burning torch called the "oxy-Secator" working with an oxyacetylene mixture appears for the first time in France (21).

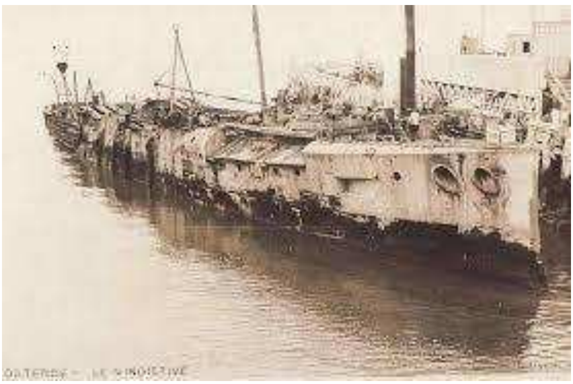
Figure 6: Sketch the oxy-Secator (21)

FIG. 129. — Chalumeau découpeur sous l'eau.

As seen in the sketch, the nozzle of the torch was equipped with a bell in which two diametrically opposite small tubes are connected. These supply the compressed air which is designed to remove the water from the bell and the metal area to be cut.
Around its periphery the bell was also equipped with 3 small guides to keep a constant distance between the flame and steel.
To achieve the development of his machine he organizes from 1912 one series of dive but these were unfortunately interrupted because of the war.
Finally, the torch is ready and on June 10, 1917 a new cutting demonstration is organized in a tank in front of

some personalities during which a diver managed to cut a steel plate of 400 mm long x 40 mm thick (22).
Unfortunately the literature does not states the time taken to achieve this cut but it seems that the torch worked properly because at the end of the war various "oxy-Secator" are commissioned to assist in the removal of 5750 T English cruiser *H.M.S Vindictive* that was scuttled on May 10, 1918 to bottle the Ostend Harbor.
Prior to disposal and to complicate a possible salvage by the enemy, the crew of the battleship had packed her full of sacked cement that once submerged were going to harden and be very difficult to remove.
And that was indeed the case not for the Germans but to the English company "Liverpool Salvage Association" who had been entrusted the work.
The salvage started the following summer under the direction of Captain Young who already had good experience of this kind of work.

Photo n° 12 : *H.M.S Vindictive* (23)



One of the first works that would be entrusted with hard hat divers was the removal of these cement bags and thus to get there some double deck plates needed to be cut using the oxy-Secator in order to allow the demolition of this concrete layer (24).

This was made using pneumatic hammers and minuscule explosive charges.

After that, thirty lifting tunnels were dug under the wreck so that lighters and pontoons could aid in the lift.

All the operation was led in a masterly fashion and the work completes successfully October 16, 1919.

As it was a British company that had done the job it's a safe bet that some British divers had the opportunity to use this torch.

We again find the oxy-Secator a few months later in 1920 on a sheet pile cutting in Theux on the Meuse (25).

In the region many structures suffered severe damage or even complete destruction because of the war and so to restore them correctly sheet curtains were driven around the structure.

At the completion of such kind of repairs and whenever possible the sheet piles were pulled out but according to the ground configuration that was not always possible and in that case the only remaining solution was the cutting under water.

It was this type of work that had been given to our underwater worker for a number of "Ransome" Type D sheet piles were completely blocked in the ground.

Photo 13: Reconstruction of the Theux bridge (26)

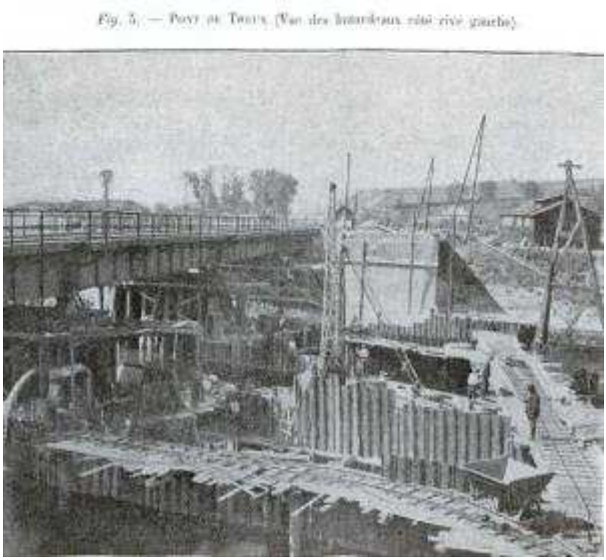
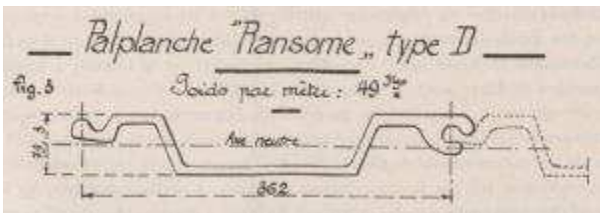


Figure 7: Configuration of a "Ransome" sheet pile (27)



According to a report at the time, our burner managed to cut the flat sides without too much difficulty but because of the size of the torch's bell the interlocks and the inside angles of the sheet piles had not been completely severed and the cracking of the curtain had been necessary.

The problem with this first torch was that because of the inside volume of the bell quite a large amount of compressed air was needed to keep it dry. This was provided by a compressor at a pressure of 5 bars but because of the air bubble back-pressure the torch vibrated strongly emitting a shrill whistle and it was quite difficult to keep her against the work. Moreover, just like the German torch, the flame tended to go out frequently.

Photo 14: Oxy-Secator provided with its Corné ignition system (28)

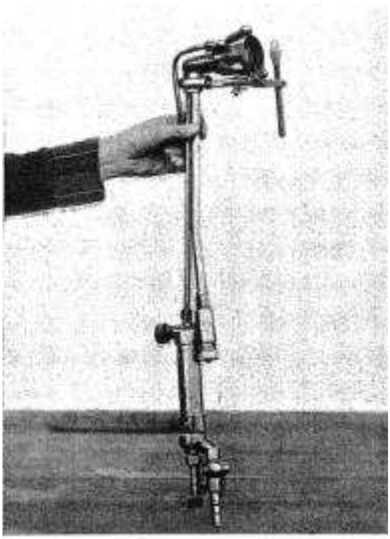


Fig. 1. — Chalumeau armé de l'allumeur sous-marin Corne.

Luckily to counteract this disadvantage, Mr. Corné manager of Scientific and Industrial Research and Inventions had developed an underwater lighting system in the form of a brass tube in which a reactive mixture

was compressed who was kindled spontaneously on contact with water allowing the relight of the torch.
In 1922 Mr. Picard who now works for the Air Liquide present at the Marseille Colonial exhibit a different kind of submarine torch on which the cumbersome bell was removed and replaced by a combustion chamber which eliminates the use of compressed air.

Photo 15: Cutting demonstration in Marseille (29)

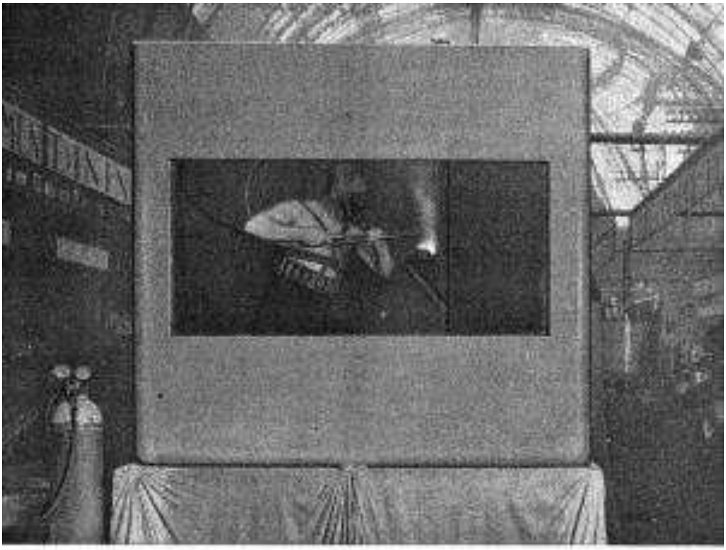
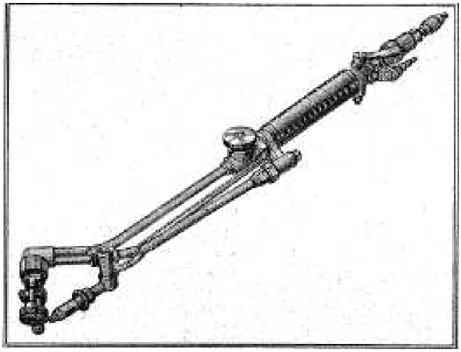


Fig. 1. — Expérience de découpage de l'acier sous l'eau au moyen du chalumeau.

Indeed with this new device the flame burns inside a brass protection mantel which prevents the ingress of water.

Figure 7: Picard AD-8 torch (30)



To facilitate ignition under water, the use of the Corné system is also replaced by a small pilot flame which burns continuously in the immediate vicinity of the main nozzle.

Figure 8: Details combustion chamber and pilot flamme (31)

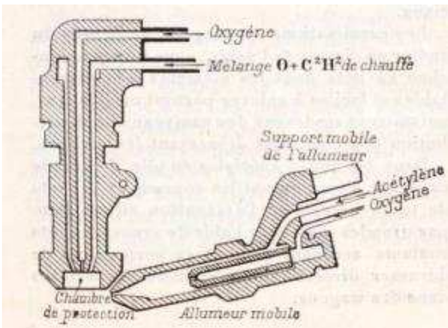
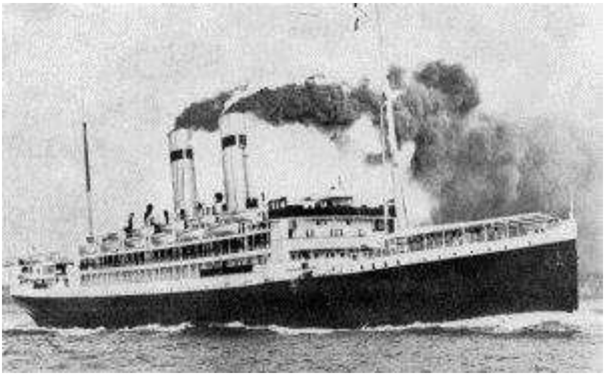


Fig. 1. — Détails du chalumeau coupeur sous l'eau, système Picard.

The first field trials of this new torch will be made on the wreck of the *Tubantia* a Dutch ship that was torpedoed March 16, 1916 by the German submarine *UB13*.

Photo 16: The steamer *Tubantia* (32)



The boat was lying on the bottom at 33 meters deep just 55 miles off Ostend in a very busy shipping area subject to strong current.
The tests drove off in late April 1924 with a team of six divers (a French and five English) but very quickly it became a fiasco (33).
The torch was burning well at that depth, but the flame was unable to bring the plate to the ignition temperature. To reach this temperature the surface team tried to calibrate the regulators to increase the pressure in the torch head, but what was bound to happen happened. A tremendous explosion occurred causing the bursting of the entire length of flexibles and also set the acetylene gauge on fire.
What had happened?

Nothing too surprising except that the new torch was working like its predecessor with an oxyacetylene mixture. But be aware that acetylene cannot if it is not dissolved in acetone be compressed above 1.5 bars. Above this pressure, the gas decomposes quickly into carbon and hydrogen and explodes spontaneously. In other words, this type of mixture can only be safely used at depths less than 10 meters.
Fortunately, this incident had no adverse consequences, but the use of the burning torch was stopped and the cutting was made by using a different method to be described later.
This first failure (which does not involve the torch) did not prevent it use on shallower sites such as for instance on the battleship of 15,000 tons *Liberté* which had following a fire exploded in the Toulon port September 25, 1911, killing no less 110 people and injuring 236 others.

Photo 17: The battleship *Liberté* (34)

The method used to lift the ship was that advocated by Mr. SIDENSNER former chief engineer of the Russian navy who had to his credit by a compressed air method the salvage of the battleship *Impératrice* - *Marie* who sank in the bay of Sevastopol in 1917 (35).

So here in Toulon the main work for the divers consisted to inject compressed air into the compartments that were not too damaged and to set up both inside and outside the wreckage a lot of big pontoons in order to achieve sufficient buoyancy to move the battleship to the dismantling place.

Needless to say that all these works that would last nearly 40 months necessitated the presence of many divers including several burners.

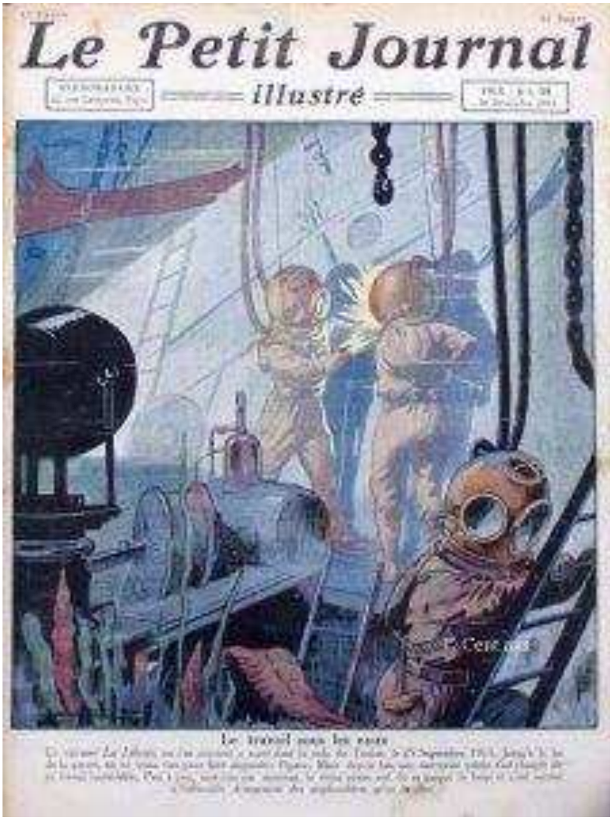
Indeed, between June and November 1924 three new Picard torches had been commissioned on this site during which no less than 500 hours of various cuttings were provided at a depths between 3 and 7 meters, thus far of the acetylene critical pressure (36).

On the same site, another submarine torch appeared.

It was the one of the engineer Royer, director of S.A. du Chalumeau Eugene Royer, from Lyon who in 1922 had applied to patent an oxyacetylene torch for underwater purpose.

His blowpipe consisted of a brass tube approximately 50 cm in length equipped at one end with 4 fittings for receiving the supply hoses and at the other side the head of the blowtorch.

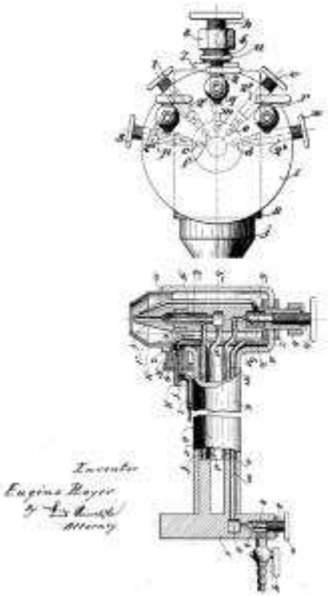
Figure 9: Illustration work on the *Liberté* (37)



As can be seen from the sketch of Figure 10, the flame is protected from contact with water by an air nozzle which surrounds the tip.

The Royer torch is also equipped with an in water electric ignition system and two rollers can be installed to facilitate the movement of the cutting tool on the sheet.

Figure 10: Royer gas burning torch patent (38)



Although this torch had only recently been put on the market, it seems, however, have quickly proved its effectiveness through some demonstrations organized in the ports of Marseille, Lorient, Brest and La Ciotat and in the company's headquarters in Lyon.

The torch cutting performances were (apparently) relatively high since the manufacturer announced cutting speeds in the order of 12 to 15 meters per hour. It was therefore not surprising that the appointed diver of the Royer company (probably Mr. Thudot) was asked to help on site to complete the underwater cutting of an opening 60 meters long in a very narrow passage.

About 45 meters had been cut away behind some temporary cofferdams with ordinary torches but the last 15 meters could only be done under water.
Preliminary tests were made by drilling contiguous holes with a pneumatic drill, but within 6 hours of diving only 0.8 m were cut.
Our diver had afterwards cut this strip of 15 meters (30 m cut) in length in just 14 hours (39). A few small hangers prevented the metal strip from falling to the bottom but it could easily be torn out with a 25 tons crane.
With all these specialists work ended in February 1925 and despite the extremely difficult work conditions, no serious accident was to regret in the underwater workers community.
Only some of them had to suffer the (unpleasant) effects of some residual gas explosion trapped in confined spaces.
For the record one can also report the attack of an octopus that in December 1923 threw himself on the diver Jean Negri and clasped him so hard with its tentacles that the diver had to return to the surface where his assistants had to use axes to deal with beast (40).
After this prestigious salvage the press became a little stingy with information regarding the use of these torches. This was probably due to the fact that they were now part of the basic tools divers and their use became more and more common.
Yet in France the underwater burners faced a major problem: The depth limitation on their cutting performance. Unlike those used in other countries, their torches were in the twenties only equipped with tips

suitable for oxyacetylene mixture which you know were dangerous when the depth of 10 meters was exceeded .
So no doubt that for some deeper projects the companies used torches from abroad which used another cutting gas: Hydrogen.
To the calorific point of view, the temperature of an oxy-hydrogen flame is about 430 degrees lower than that of oxyacetylene but the properties of hydrogen make that this gas is not limited in depth.
It was thus necessary that the French manufacturers adapted their tool if they would not lose a significant part of the customers specialized in underwater work.
Mr. Picard was the first to react and in 1936 he developed his new torch the "Picard H7".
This is successfully tested in Toulon between 1 and March 20 of that year to the depth of 38.6 m (41) and following the success of these trials the H7 is marketed in the summer of that same year.
This torch is again an equipped with a combustion nozzle and while it is powered by three hoses, one for the oxygen cutting, one for the heating oxygen and one for the fuel gas, that torch comprises only 2 valves.
One quarter-turn valve that the diver has to open fully and ensures the arrival of the oxygen and the fuel gas in the mixing tip and one circular cutting valve for the oxygen.
As on the previous model this torch also possesses a small mobile pilot flame to enlighten this device underwater.

Photo n° 18: Picard H7 gas burning torch (42)

The big advantage of this new PICARD compared to all other existing underwater burning torches was due to the fact that now the diver did not have to worry about the pressure adjustments because it could now be done based to the depth via an automatic gas control unit that stayed at the surface (43).

Figure 11: sketch automatic gas control unit (44)

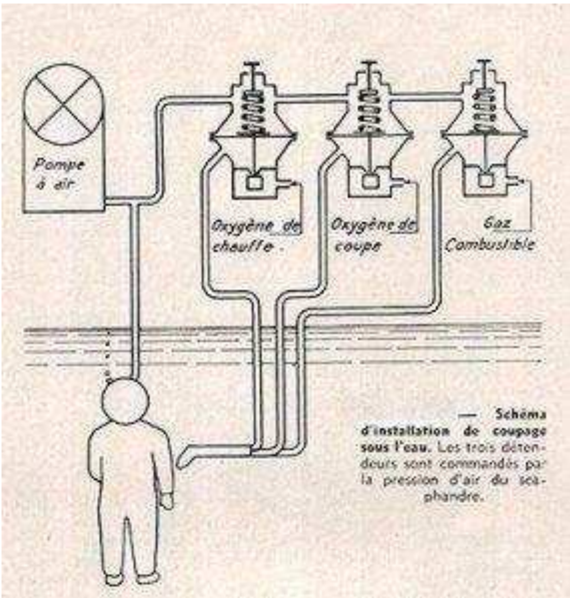
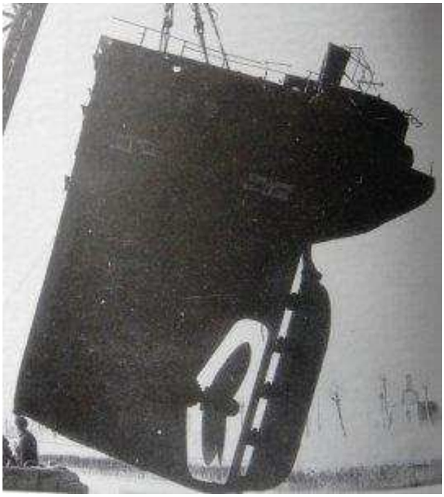


Photo n° 19: Automatic gas control unit (45)

Obviously, this new model was quickly adopted by most of the French and foreign companies and during the 4 decades that followed it was used successfully on numerous sites including of course the removal of the many wrecks sunk during World War II.
The dexterity of our Elder was unparalleled.
The sections that came back to surface were often so perfectly and straightly cut that they could have been welded again without special machining.

Photo 20: lift of a wreckage piece cut off with a Picard (46)



Apart from the salvage works the H7 torch was also much used by the inshore divers to namely realize the underwater cutting of the numerous sheet pile cofferdams that had served for the restoration or construction of new bridge foundation destroyed during WWII.
Yet for those civil engineering divers two small problems would soon appear. As mentioned above, the Picard H7 worked with an oxygen / hydrogen mixture and for the torch to work correctly the mixing ratio of these gases needed to be about 1 volume of O_2 for 3 volumes of H_2 which gave if we used the torch at 10 meters an hourly consumption of about 7 m^3 of oxygen and 23 m^3 hydrogen which means for the sole heating flame a daily consumption of about 180 m^3.
To this we had also to add the 57 m^3 for the cutting oxygen. This meant that the teams that were working on

land had to travel with an impressive number of gas cylinders. Once again Air Liquide solved the problem by changing the mixing nozzle. The 22 small gas exhaust holes from the H7 were reduced to 12 with the result that in the fifties the divers could now use the Picard (P9) with propane gas (and later with other hydrocarbon-based gas). With this new model the needed proportions became equal to 1 volume of O_2 to 0.3 volume C_3H_8 thereby reducing at the same time the handling of bottles.
The other small problem encountered in civil engineering was due to the length of the Picard gas burning torch.
Indeed, it was sometimes difficult in some sheet piling configuration to cut them all at once without changing the torch position. To remedy many companies had quickly solved the problem by removing themselves the torch handle (and sometimes more) which not only shortened the torch but also made it a little lighter.

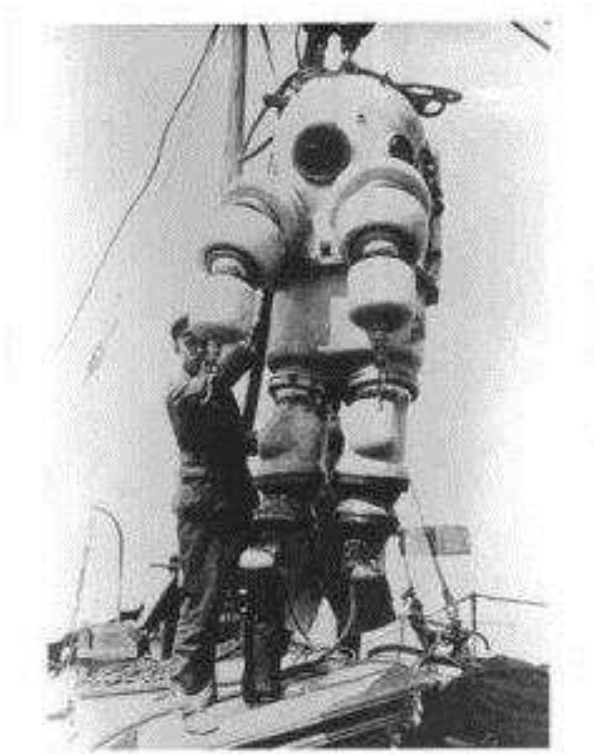
Photo 21: Result of some changes realized within the company (47)

At about that time, end forty early fifty (date not found) another French torch reaches the market: the Charledave.

Photo 22: Charledave oxy-propane torch (48)

Equipped with four valves, the oxy-propane torch used the principle of the air bubble to prevent the extinction of the flame.
Following its users the torch was difficult enough to adjust but once done, it was cutting perfectly.
Regarding the "Royer" torch oddly enough there isn’t more of it after the work on the *Liberté* and no pictures seems available.
In 1939 his inventor instituted a trial with the court of Rennes against the SORIMA because he pretended that his oxyacetylene torch had been used by the Italian company during the gold recovery campaign on Egypt, which lasted from 1930 to 1932 and therefore he hoped to receive 10% of the recovered value which made approximately 9,200,000 francs (old French francs) (49).

Photo 23: Neufeldt-Kunhke armored suit (50)



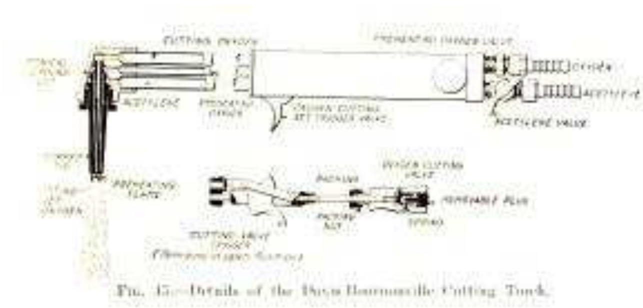
When we know that this wreck was lying some 127 meters deep that can leave us as septic especially if Mr. Royer claimed he had worked with acetylene.
Another fact to the detriment of this statement is that because of the depth all dives on the wreck had been carried out with the Neufeldt-Kunhke atmospheric diving suit equipped articulated arms and it can therefore be difficult to imagine that such a suit could hold and guide a submarine torch.

On this wreck five bridges had actually been cut to get access to bullion room but following the Italian firm all these cuts were exclusively performed with bundles of explosives (51).
Today, no underwater gas burning torches are made in France only a combustion nozzle that can be mounted on a classic Pyrocopt torch is still available.

Picture n°24: Pyrocopt torch equipped with a combustion nozzle (52)

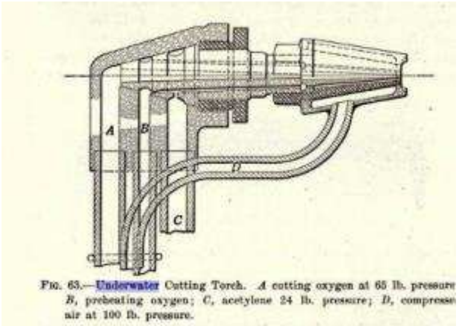
The United States production of the first underwater torch returns to Eugene Bournonville.
In 1904 he receives two welding torches from Edmond Fouché that he will use to repair some of its machines then a little later he interested himself in the patent filed in the USA by the Belgian Felix Jottrand on a blowtorch model that used a jet of pure oxygen to cut steel (53) and finally in 1906 Bournonville began to manufacture its own torches under the AIRCO name.

Figure n° 12: Davis Bournonville cutting torch (54)



Around 1916 basing himself on the German underwater torch he devised a special hood that can be adapted over the tip of a regular cutting torch.
During a test made at Puget Sound Naval Shipyard in Bremerton with this oxyacetylene cutting torch a diver was able to make a circular cut of 48 cm (19 inch') in 6 minutes at 6.6 meters deep (55).

Figure n° 13: Sketch of the Bournonville special hood (56)



Subsequently between 1917 and 1922 other US manufacturers also adapted their cutting torch to the underwater environment.

Figure 14: Diver using an oxyacetylene gas burning torch in 1919

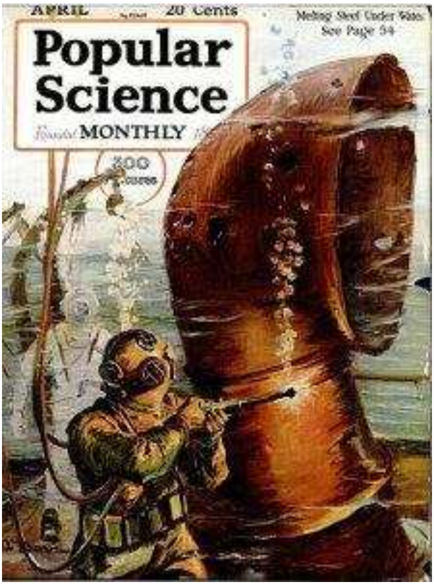
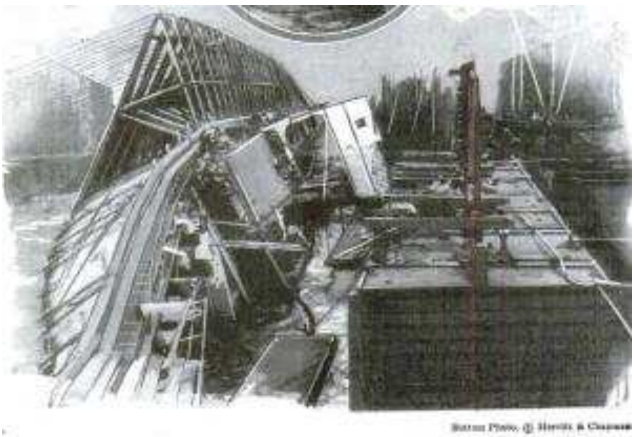


Photo n° 25: Schrader underwater torch (no information available) (57)

One of the first companies that started to use this tool (without specifying the brand) was Merritt - Chapman & Scott from New York.
Their divers began to use it on small jobs like for instance the cutting of steel wire entangled around the propellers.
Then in 1918 one of the first large projects where mention was made of the use of the submarine torch was the salvage of the *S.S St. Paul* which sank for an unexplained cause and turned over on its port side in the mud in the Port of New York on 25 April of that year (58).
To be able to refloat the ship by pumping it empty the divers had to close off nearly 500 openings of all kinds, evacuate the 2,000 tons of mud that had accumulated in the wreck and cut Ø 450 mm openings in each of the steel bulkheads to drain the compartments.

Photo n° 26 The St Paul in the port of New York (59)

Figure n° 14: Erecting of the steel legs (60)

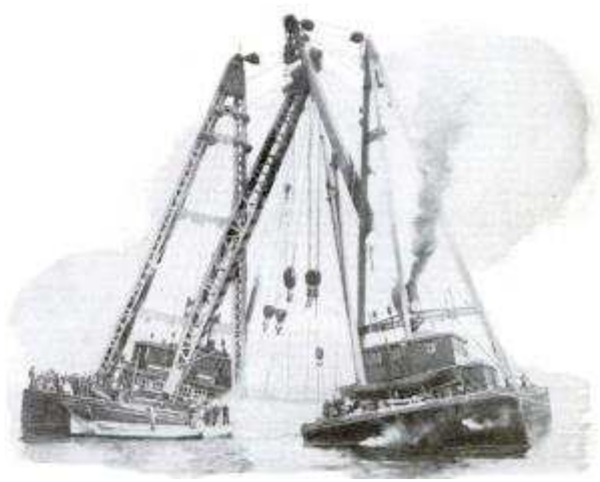


Then after came the digging of 6 tunnels under the hull to pull the lifting slings.
These were made by the help of water fire hose, but apparently it was not an easy job for the divers because nearly one week of work was needed per tunnel.
The greatest difficulty of this job was not the patching or the pumping, but getting the ship upright again.
To solve it the salvage engineers erected 21 great steel legs shaped like the letter A along the starboard side.
The turning sequence will last about a week. It will be followed by a few hours of pumping and finally September 28, 1918 the ship resurfaced.
Other similar interventions take place without that the torches evolve in design then in 1925 the United States Navy meets a disaster.
During the night of 25 September, one of their submarines the *S-51* was rammed while navigating at the surface by the steamer *S.S City of Rome* and sank in less than one minute.
Ten men managed to jump into the water of which only three will be saved.
The next afternoon i.e. fifteen hours after the collision a first team of divers from the Navy arrived on the scene and immediately dived on the wreck that lies in 39 meters of water.
Unfortunately, despite their repeated blows on the hull no return signal will be heard.
The 23 men still on board are reported dead.

Photo n° 27: USN diver going down on the *S-51* (61)

Since the announcement of the accident two large derrick barges of a private company, the *Monarch* and the *Century* are mobilized and sent to the scene of the disaster together with the submarine *S-50*.
Once there, the Captain Davis who is in charge of the operation installed an air hose in the gap whereby the S-50 pump air continuously with the slim hope that it can be confined in an enclosed space and thus lighten the wreck.
At the same time two steel cables are passed with difficulty under the submarine on the stern side and on September 30 lifting is attempted.

Photo n° 28: The two derrick barges during their lifting trial (62)



Despite some 400 tons of combined traction the wreck does not move one iota.
The wrecking company's divers are again sent to the bottom to burn small holes with their torch in the upper parts of the submarine to check for air pockets. But the result is negative no bubbles come out of holes, which of course means that the lifting means used are insufficient to lift the weight of nearly 1,000 tons.
Following this failure the work will be interrupted until October 16 (63).
The second phase of the work is entrusted to Captain Ernest King and Commander Edward Ellsberg.
To make this work, the latter prepared the next salvage plan:

Eight submersible pontoons would be sunk in pairs on either side of the submarine, connected by a cradle of heavy lifting chains under the wreck, and then blow with compressed air for a lifting force of 640 tons.
The additional buoyancy would come from sealing and blowing the S-51 undamaged compartments.
In this case a rather simple plan but still requires seven months of actual work to be brought to completion.
This was due in part to the fact that at the time the US Navy divers were inexperienced and only a few had been trained to work at that depth.
They were certainly very aquatic but those who were really able to work under water were really hard to find (64).
On the other hand, when he persuaded his superiors that he was able to do this salvage Ellsberg was convinced that the submarine torch prepared by the marine laboratory would be of great help to him, unfortunately it was not.
To make their own torch, the laboratory based itself on what had been done in France and Germany but from its implementation on site our Commander realized that she was not at all reliable.
In fact, during one of the first pontoon installation a false maneuver had been made and to unlock it a thick steel cable had to be cut.
Normally at the surface, this cut would have taken a few seconds but in substance it had requested no less than 40 minutes of work and six bottles of gases to George Anderson the youngest diver of the team to sever the cable (65).

Photo n° 29: Cdt Ellsberg with his underwater torch (66)

The work was interrupted on December 7 because of bad weather and Cdt Ellsberg took therefore advantage of the three-month of standby to follow an accelerated dive training course while at the same time he began to make some modifications to the existing torch so to make it more efficient.
By testing the one that had used at sea he immediately realized that the flame was not hot enough and thought it was coming from the hydrogen which as reported elsewhere had a lower temperature than acetylene.
Knowing that acetylene could anyway not be used at this depth he tried to experiment with other gases but again he becomes disillusioned.

Result back to the drawing board and re-use of the hydrogen. It was well on the torch he had to work and not on the fuel gas.

Photo n° 30: Cdt Ellsberg during a trial dive (67)

But the development of it was not without risk. So one day he said it would be nice to try a torch with a big mixing nozzle. Jim Frazer, one of his testers went to water and lit the torch. She seemed to burn properly for a few seconds and then all of a sudden the flame was sucked into the torch and went out. Frazer looked at his tool without understanding what had happened, but suddenly he felt that his hand was burning and by reflex threw the torch away from him.

Just in time because it exploded in the tank.

Ellsberg knew that he was to return to a smaller tip.

Sea trials followed those in the tank and gradually the new tool was perfected.
Yet a problem remained.
To obtain a proper heating flame a correct dosage of the various gases had to be send to the mixing nozzle and the diver could only do that by adjusting the length of each gas bubble before the ignition to obtain the following values:

- length of the air bubble: 3 inches (7,6 cm)
- length of the hydrogen bubble: 3 inches (7,6 cm)
- length of the heating oxygen bubble: 2,5 inches (6,3 cm)

Needless to say, the setting was quite laborious. Our designer imagined therefore a rather simple but effective system that would allow the divers to easily adjust the length of the gas bubbles with a removable adjustment bar they had to place in front of the nozzle (68).
The trials sessions followed each other and the torch was getting better but the flame extinguished still quite often. Ellsberg knew that it probably came from the air bubble. He finished his adjustment by altering the path of the air bubble so that its flow became parallel to the flame and not cross which sharply reduced the extinction of the torch.
Finally at spring after weeks of laborious work Jim made a final test during which he cut a big plate of 4.2 meters in 10 minutes, the underwater gas burning torch was ready just in time to resume work.

Photo n°31: Diver Kelley J.R with the Ellsberg torch (69)

Thanks to its tool the cutting divers would now be able to remove the various elements that hindered and perform the cutting of many vents in the lower portion of the submarine which aim to ensure the evacuation of water during inflation of watertight compartments.

Photo n° 32: The divers Francis Smith and Jim Frazer (70)

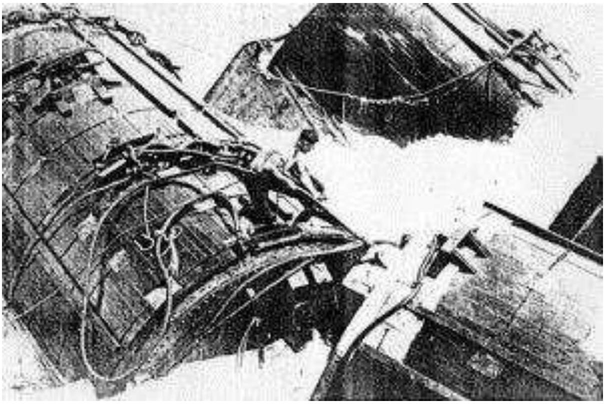
Besides the development of the underwater torch another interesting tool for divers was invented on this site. Indeed, to link the starboard and port pontoons together, various tunnels had to be dug under the wreck of the S-51. Unfortunately for our divers the ground on which the submarine laid was made by extremely hard clay and was very difficult to break through.
The first tunnels were made using a 2.5 " (Ø 65) fire hose equipped with a conventional lance like the one used by firefighters. But the problem with such type of tool and that each diver knows, is that the operating pressure cannot be very high because otherwise it is impossible to keep in place.
As a result, the first tunnel took almost six weeks to be realized what was obviously much too long. Luckily in

may a new nozzle designed and made by Machinist's Mate (Second class) Waldren was now available.
In the nozzle there were 6 jets, 1 large ahead and 5 smaller ones radially astern.
It was found that the jet arrangement abolished the reaction which previously had made it impossible for the diver to hold the 2.5-inch hose with any special pressure; further, the radial jets enlarged the hole cut by the forward jet and shot the material cut loose astern at considerable speed.
With this new invention the passages under the wreck could now be done in more or less two days.

Photo n° 33: Waldren's special balanced hose nozzle (71)

A first refloating attempt took place on 22 June, but because of bad weather the team was forced to flood the pontoons and let the wreck go back on the bottom.

Phot n° 34: Diver Wickwire clearing air hose prior to flooding the pontoons (72)



Finally, work was successfully completed on 5 July 1926 and the submarine was towed to a Navy dry dock.

Photo n° 35: Towing of the *S-51* (73)

Soon after its invention, the firm Craftsweld Equipment Corporation began manufacturing the Ellsberg torch and for many years they supplied the gas burning torch with teams of skilled divers to complete cutting works all over the world (74).

Photo n° 36: First underwater gas burning torch manufactured by Craftsweld (75)

It was perhaps such a team that in 1937 defeated a cutting record during the construction of N.Y.C Marine Parkway Bridge.
On this site, the divers had managed to cut at 9 meters deep no less than 2118 sheet piles (14 cofferdams) in the space of 40 days, an average of almost 53 piles / day which was really not bad (76).
Given the increase of these underwater cutting works contracts various other US manufacturers started also to make their underwater cutting torch on the basis of which

was designed by Cdt E. Ellsberg and therefore unlike some Europeans torches (French and German) all these American torches would remain faithful to the use of an air shield protection.

Figure n° 16: Detail of the American underwater torch (77)

Fig. 5 Example of an oxy-hydrogen gas cutting torch

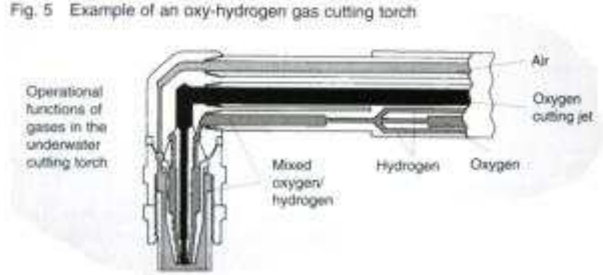


Photo n° 37: Some of the American oxyhydrogen cutting torches (78)

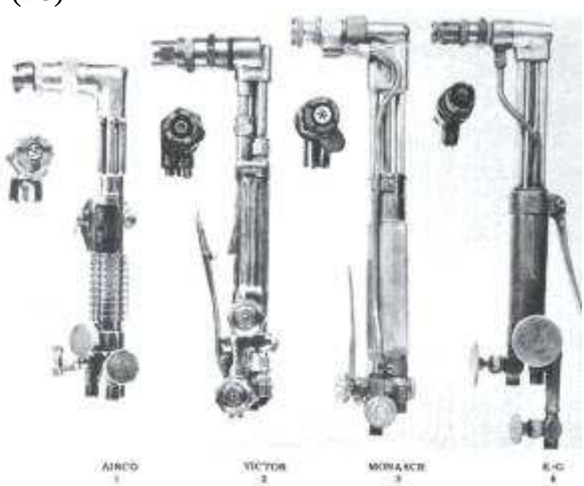


Photo n°38: Airco torch (79)

Photo n° 39: Monarch torch (80)

Photo n° 40: Victor torch (81)

Photo n° 41: KG torch (82)

All these torches were used extensively in Pearl Harbor and also in other ports for the cutting of the wrecks but apparently the US Navy divers were not fully satisfied with it.
For them they were not only poorly adapted to work in wrecks and sometimes difficult to implement, but especially dangerous to use inside the wreckage.

Indeed, it must be remembered that all these torches (except Picard) required if they were to be lit under water cold preset and therefore a more or less important part of unburned and highly explosive gas escaped the torch and could become trapped in one or other enclosed space. Therefore in 1942 for this kind of work the US Navy began to replace the oxyhydrogen torch by the oxy -Arc.
The inshore commercial divers will continue to use the oxyhydrogen torch until the middle of the fifties and then as everywhere in the world these have gradually been replaced by the oxy-arc cutting method.

It is difficult to say who made the first underwater gas burning torch in England. What is certain is that in 1919 two underwater oxyacetylene torches arrived in England following the acquisition by the Maritime Salvors LTD Company from New Haven of two salving vessels the *Restorer* and *Reliant* brought to the US Navy. The trademark of these torches is not clear but they were part of the equipment and items sold with boats (83).
In the early twenties, Siebe Gorman began designing an underwater cutting torch and to do so the firm decided to test several including the second generation Picard AD-8 cutting torch which was tested in November 1924.

Photo n° 42: Cutting test with the 2nd generation Picard AD-8 torch in the Siebe Gorman tank in 1924 (84)

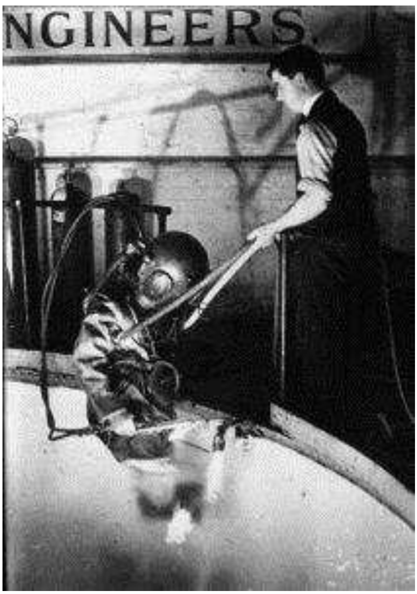


Photo n° 43: Cutting test with the 2nd generation Picard AD-8 torch in the Siebe Gorman tank in 1924 (84)

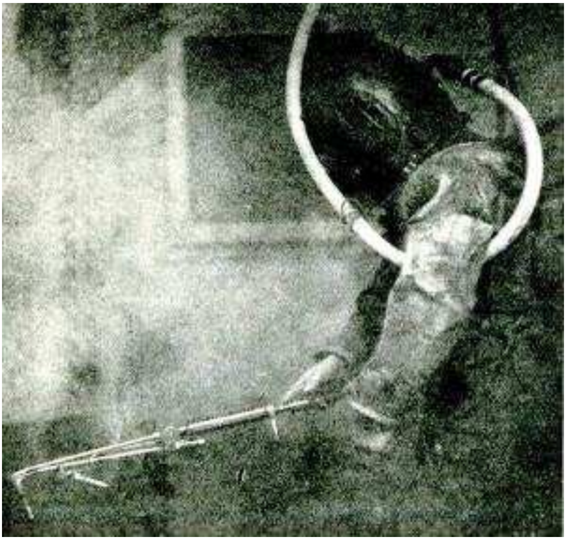
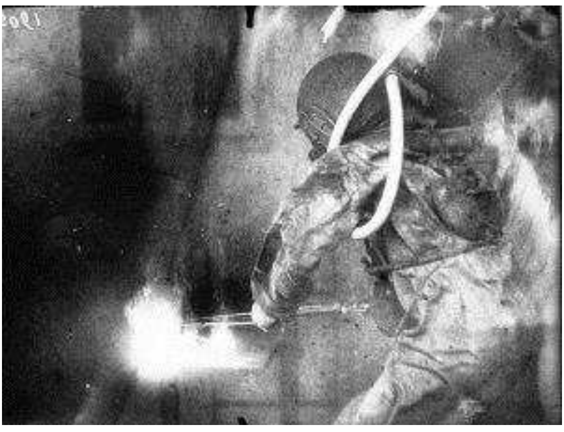
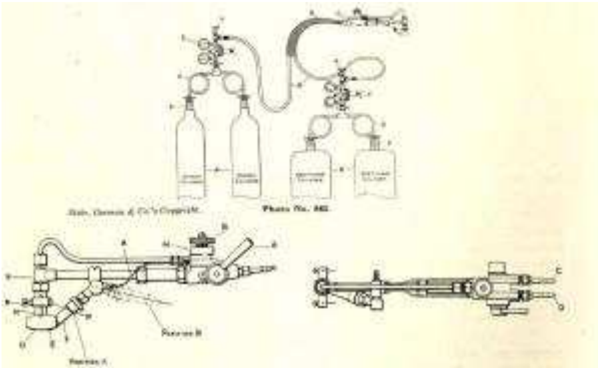


Photo n°44: Cutting test with the 2nd generation Picard AD-8 torch in the Siebe Gorman tank in 1924 (84)



Apparently the French torch seduced since the model they will create incorporates their principles that is to say, the combustion chamber and the pilot flame.

Figure n° 17: Sketch of the first Siebe Gorman underwater burning torch (85)



In 1933 another oxy-hydrogen torch is marketed by the firm Underwater Cutters LTD (86) and in 1938, an article published in "The Electrical Journal" (87) mentions that this torch was used to cut 30 meters of sheet piles at 3 meters depth.

Photo n°45: Underwater Cutters LTD torch (88)

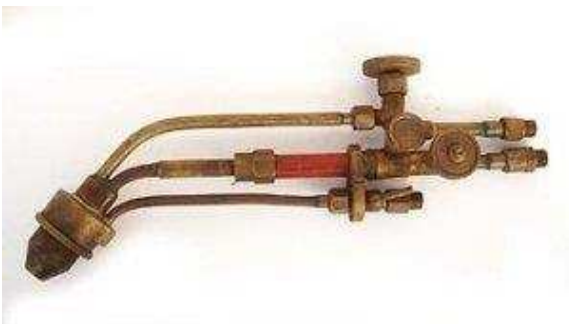
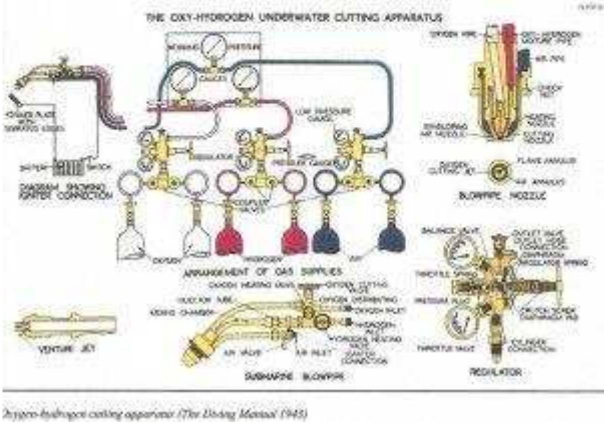


Figure n° 18: Underwater Cutters LTD arrangement (89)



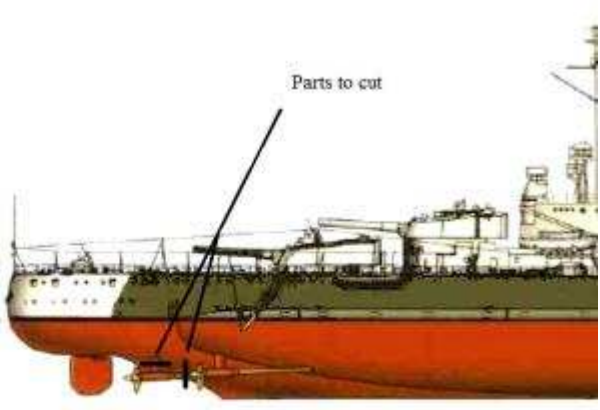
Then comes the torch made by B.O.C & Siebe Gorman. It was a very powerful torch with which the diver could have a cutting speed of 60 cm per minute.

As can see from the photo n° 46, the company has removed the pilot flame and the combustion chamber she had used on her first torch and this time uses the principle of the air bubble as used on US torches.

Photo 46: B.O.C & Siebe Gorman torch (90)

A first mention of the use of this torch is reported in an article describing one of the most famous oxy-hydrogen cutting in history (91).
This one takes place in 1944 on the British warship *H.M.S Valiant*.
This battleship which was engaged in the battle against the Japanese fleet had suffered some damage that had forced her to go into dry dock in Ceylon, but following a false move during the dry setting the dry dock breaks and sinks.
Fortunately, the *H.M.S Valiant* remained afloat but during the sinking the end of the dock severely damaged one of her rudders two of her inner screws as well as the cast iron A frames holding them to the hull.
As there were no other dry dock installation likely to receive a vessel of this size in the Pacific it was decided to send her to Alexandria.
Despite her damage, the battleship could still navigate but only at the reduced speed of 8 knots because the vibrations generated by the inertia of the two central propellers were enormous.
Arriving in the Suez Bay, Commander in Chief Sir John Cunningham called one of his good acquaintances the Lt Commander Peter Keeble, a salvage expert an experienced diver and asked him how to eliminate this problem. It's simple; Peter Keeble replied cut and drop the defective parts on the harbor floor.
Cunningham did not take long to decide and gave Keeble a week to perform this job (92). Him in turn contacted the petty officer Nichols another underwater work specialist, and between them they will undertake this cutting job which is far to be simple.

Figure n°19: Stern of the *H.M.S Valiant* (93)



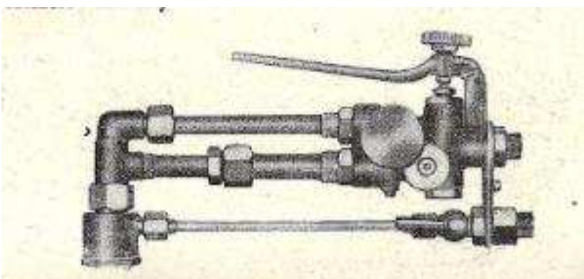
It must be said that the total weight of each items to be removed weighted around 26 tons.
During 2 days Nichols beefed up the existing torch and gave it an awesome strength. Then once ready he volunteered to do the first dive. Sitting astride on the starboard shaft he began the cutting at 1.5 m from the gland. Four hours later he is forced to come to the surface because of a technical problem. He then wanted to go down again despite a burned thumb but his chief took over and finally 6 hours later the first shaft was through.
A little bit too long we may think?
Certainly not if we know that these shafts were 47 cm (18, 5 inches) in diameter.
It remained to cut the A frame that in section were 107 cm (42 inches) wide and 36 cm (14,5 inches) thick.
Nichols cut the first side of the port A frame in 4 hours.
Keeble cut the other side for about 70 cm (27 inches) and then stopped when he realized that the cut began

widening. For security it was decided to cut the remainder of the metal with a plaster charge of 7.5 kg.
Bang! The entire starboard assemblage fell on the harbor bottom. It remained to do the same thing on the other propeller which took about the same time.

Figure n°20: Removal of the starboard side (94)

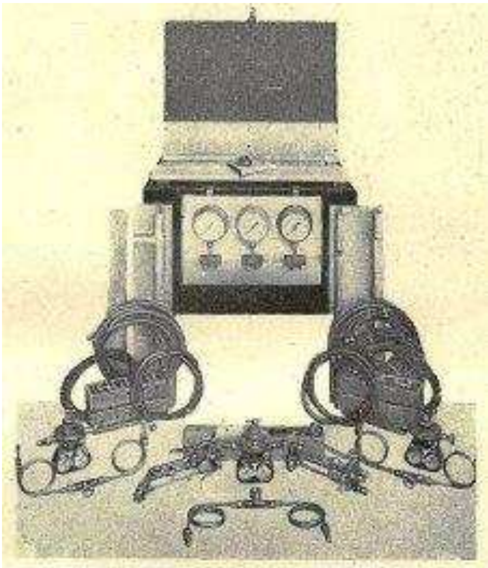
Finally thanks to the cutting the vibration completely disappeared and the dry docking wasn’t necessary anymore.

Figure n° 21: British Gas and Torch (95)



55. ábra. British Gas and Torch típusú vízalattvágó pisztoly

Photo n° 47: B.G.T underwater torch equipment (96)



British Gas & Torch Co
underwater torch equipment

As shown in Figure n° 21 a submarine oxyacetylene gas torch was also manufactured by the British Gas and Torch Company from Camberley but no reference is found regarding the date of manufacture.

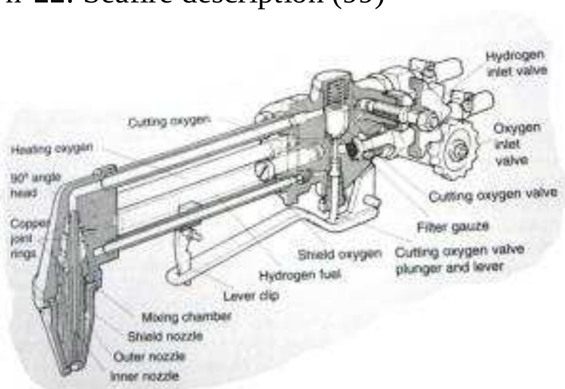
1945 saw the arrival of the Seafire (97).

It is a small oxy-hydrogen torch where the diameter of the mixing nozzle is reduced which has the advantage of using significantly less gas and makes it very convenient for small cutting jobs.

Photo n° 48: Seafire torch (98)

The handle comprises two valves for the supply of the heating flame and a trigger for the cutting oxygen supply. The head is connected to the handle by 4 tubes. The top tube that leads the cutting oxygen, the lower tube the shield oxygen, the left tube the hydrogen fuel, and the right tube the heating oxygen.

Figure n°22: Seafire description (99)



The head is provided with an outer removable nozzle in which the flame burns.
The particular design of the chamber allows an additional supply of oxygen to the base of the flame, thereby promoting combustion. The mixture of the two gases is done in the same nozzle of the torch.
Two models with head orientation at 45 ° or 90 ° are available.

Photo n°49: Diver with a Seafire torch (100)

And finally in 1968 (101) we find the Vixen Kirkham M2, which was the last torch being manufactured by our English friends.
As can be appreciated, with the exception of the locking system of the trigger this torch resembles the model of the Seafire.

Photo n°50: Vixen Kirkham M2 torch (102)

Other countries also had their torch, but like everywhere else these have gradually been abandoned in favor of the electric cutting.
One of the main reasons is due to the fact that learning this technique is longer and more difficult.

Photo n° 51: Loosco Dutch torch (103)

Photo n° 52: Hungarian torch from the twenties (104)

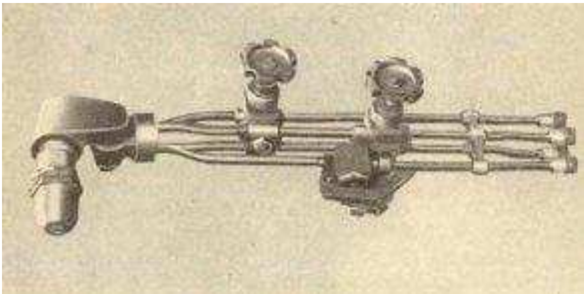
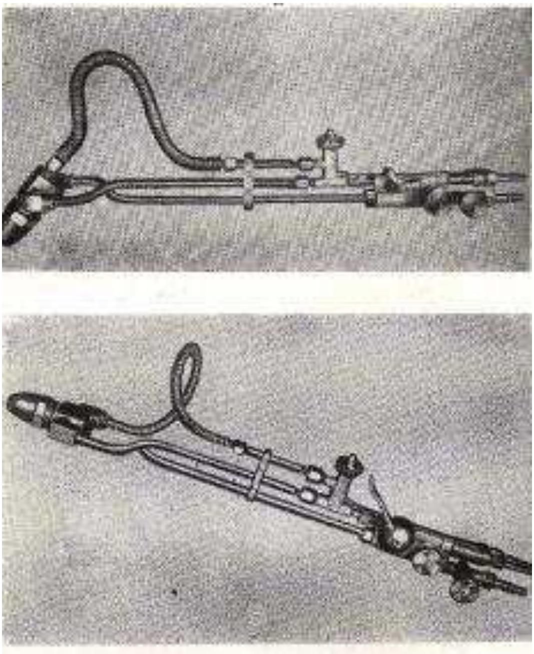
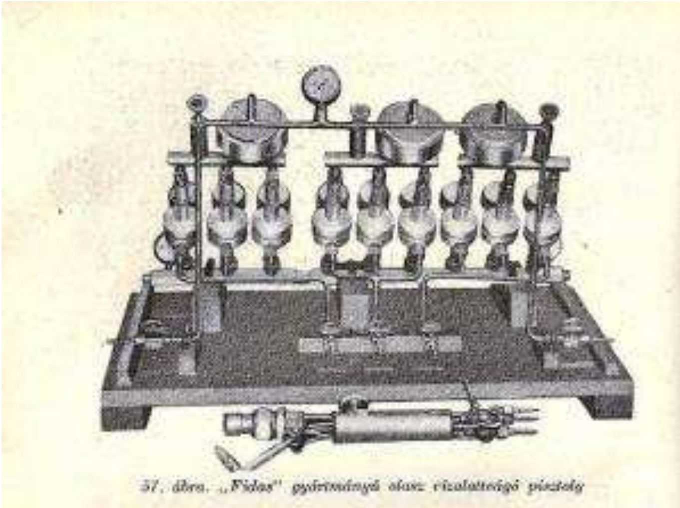


Figure n° 23: Hungarian torch (105)



54. ábra. Varga típusú [illegible] pisztoly, [illegible]

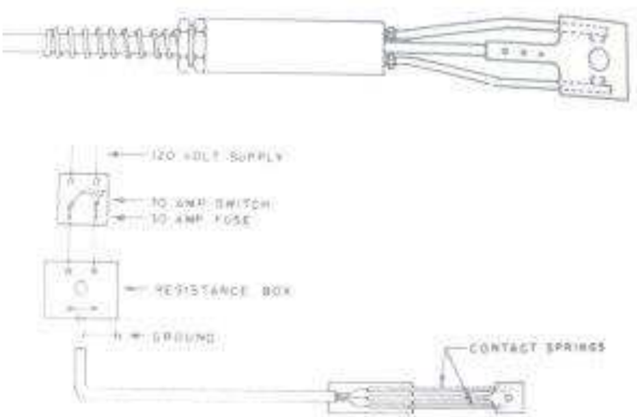
Photo n° 53: Italian torch with the automatic gas control unit (106)



The problem with the underwater gas burning torches is that they sometimes need to be turned off (or sometimes go out from themselves) for a few minutes.
If the diver is working in shallow water, this does not pose much problem because all he has to do is ascend a few meters to reignite.
But this can quickly become annoying or impossible to do on deeper sites.
As we have seen, Mr. Corné Mr. Picard and the Fabbrica italiana d'apparecchi per saldatura, Milano had solved this problem by inventing the pyrotechnic igniter and the pilot flame.
Elsewhere the electric ignition was privileged.
In the early twenties (1920) two ignition systems appeared:

The American system that worked from a 110 volts DC power source and the English system that was rather using a 12-volt battery.
The implementation was more or less identical.
When the diver wanted to light his torch, he first settled the length of the gas bubbles and then once done asked for juice.
This depending on the system caused a spark which in turn lit the torch.
Once it burned correctly the current was cut at surface and the cutting could start.

Figure n° 24: American ignition system (107)



Underwater torch lighter (diagram of connections).

Figure n° 25: English ignition system (108)

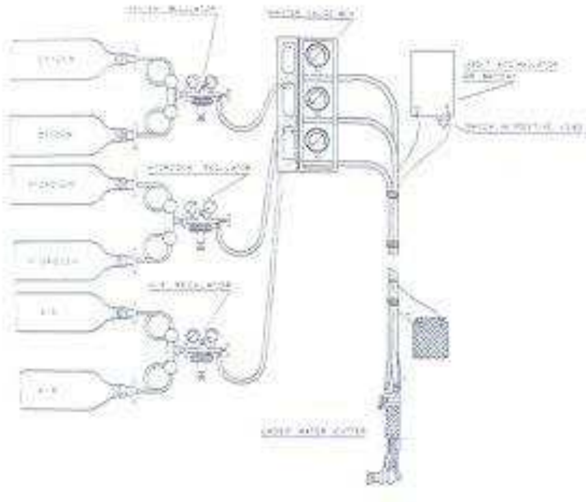


Photo n° 54: Modern ignition system (109)

As seen through the first three articles, underwater cutting torches helped make huge service and have greatly facilitated the work of divers.

They were intensely used until the fifties then gradually abandoned in favor of new cutting processes easier to use.

Photo n° 55: PVL torch (110)

Photo n° 56: Cutting course with the PVL (111)

Currently, there is only one (real) underwater gas burning torch on the market: The PVL a Dutch manufactured torch that uses MAP gas or other by product.
The torch is designed around the mixing nozzle of the P9 Picard torch making it therefore an EXCELLENT tool whose performances are identical to its model of reference.
Apart from this Dutch torch some (rare) manufacturers still offer the possibility to use their common torch under water by adapting a special cap on their head.

Photo n° 57: Pyrocopt combustion chambers (112)

Photo n° 58: Petrogen cutting torch (113)

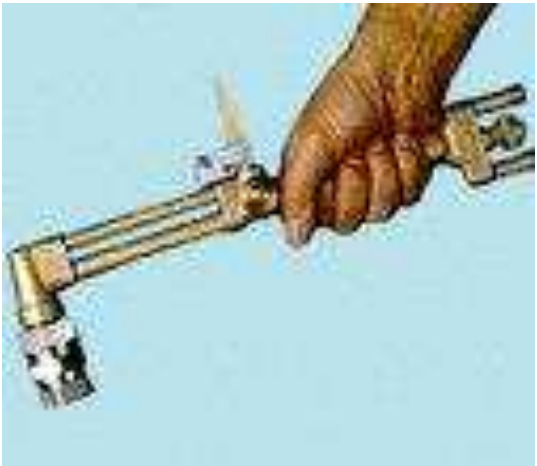


Photo n° 59: Harris underwater cutting adapter (114)

The second method of cutting under water to have emerged uses the principle of arc welding.

Here again, this invention is due to the genius of a few great men.

The first is simply the English physicist Sir Humphry David (Edmund's cousin) who in 1813 managed to create an electrical arc under water.

It will then be necessary to wait until 1890 to see appearing a first patent for a process of arc welding.

The problem is that this first method uses bare electrodes without coating and therefore the arc is very unstable and the welds of mediocre qualities.

Fortunately ten years later the first coated electrodes are invented thereby bringing the first welding jobs.

Very quickly during these works welders are going to realize that by increasing the current intensity it was then possible to cut or rather melt thin sheets.

Nevertheless, it will again be necessary to wait until the middle of the First World War to see someone use this process under water.

The first under water metal-arc cutting essays with a welding rod seem to have begun simultaneously in France, the United Kingdom and in the United States.

In France tests are performed under water in 1917 by the Soudure Autogène Française Company with two types of electrode: small diameters steel electrodes and large diameters carbon electrodes.

But the generators that are used in those days in France are not powerful enough and the tests are inconclusive. As a result on the French side the electrical cutting trials will not resume before 1924 (115).

The British Admiralty seems to have had more success with this process since the Deep Diving and Submarine Operations book from Siebe-Gorman mentions that its divers used it during World War I (116).
At the American side it is to the firm Merritt-Chapman & Scott that returns the merit to have developed this system that will also be used on the *S.S St Paul* in addition to the gas burning torch.

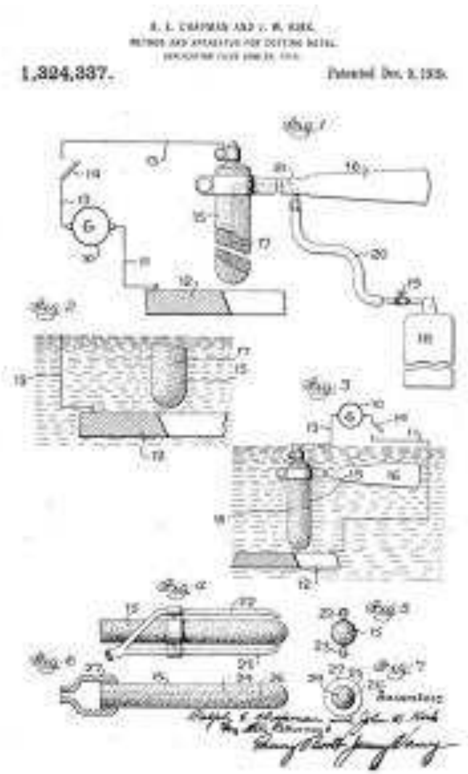
Photo n° 60: Diver with cutting torch (117)

From June 1918 R. E. Chapman and J. W. Kirk applies for a patent for a method of cutting under water by means of the intensity of an electric arc.
For that purpose, the inventors plan 3 manners to cut the steel:

- By means of the only heat generated by the electric arc of a carbon electrode.

- By means of a carbon electrode perforated by 3 holes allowing the passage of a flux of oxygen.
- By means of a carbon electrode provided by two small pipes allowing the passage of a flux of oxygen.

Figure n°26: description of the process (118)



In practice we will later see that only the use of the hollow electrode will be favored.
This patent will be followed a little later by another one also filed by Chapman concerning this time the electric cutting torch which is used by its divers.

Figure n°27: Sketch cutting torch (119)

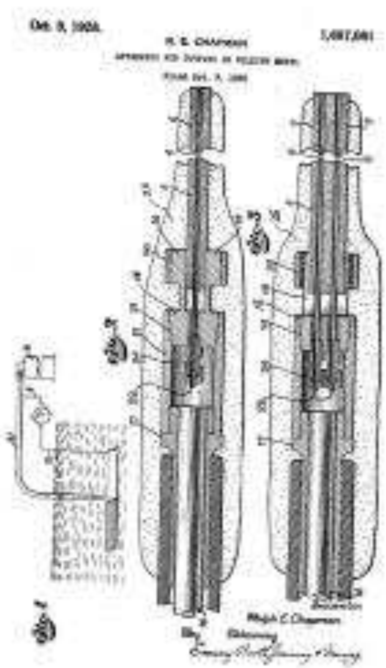
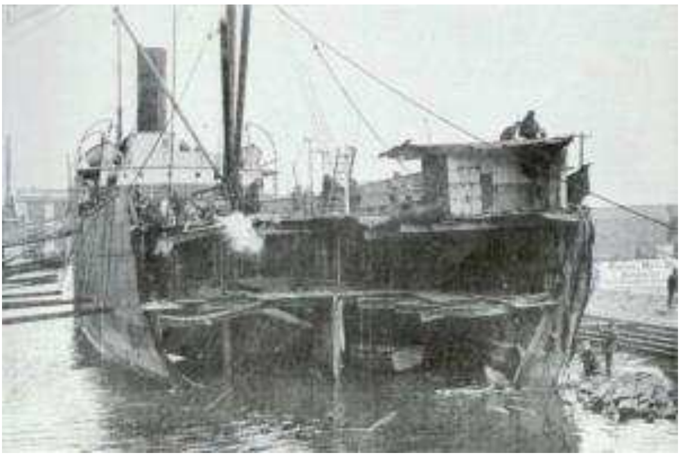


Photo n° 61: oxy-arc cutting torch (120)

Photo n° 62: Merritt-Chapman & Scott cutting equipment and training tank (121)

To train its workers to this new technique a training tank is installed within the company and very quickly the divers will adopt this technique to make some difficult cuttings.
One of the first practical uses will be done in 1919 on the freighter *Lord Dufferin*. It collided with the steamer *AQUITANIA* and to prevent it from sinking the ship had been stranded on the Ellis Island (island of the Statue of Liberty).
About twenty meters from its stern had been partially ripped off and to allow its dry-docking, the divers had to cut by oxy-arc about 8 tons of wrinkled sheets.

Photo n° 63: *Lord Dufferin* in dry dock (122)



Another great performance realized by the guys of this company took place in New York in February 1922.
At that time a dredge accidentally pierced a 36 inches drinking water pipeline feeding Stade Island one of the New York districts.

Photo n° 64: Cutting training (123)

The repair planned to remove the damaged section and replace it with a steel spool piece.
Several working days were necessary to clear the damaged part of the pipe which rested under a thick layer of mud and thus enable divers to start cutting. But the job is not simple because despite the mud removal some sections of the pipe must be cut from the inside which one can imagine was far from comfortable with a Mark V helmet on the head.
Furthermore, the main was made of thick (80 mm) cast iron which we know is not readily oxidized.
Despite these difficulties the divers finally managed to complete this work within 9 days during which they

plunged 24h / 24h and cut not less than 10 linear meters of pipe (124).

Photo n° 65: Removal of the damaged section (125)

And to end we can still mention the cutting realized by John Tooker in also some difficult conditions of around thirty piles that were protecting one of the Texas bridge piles on the Atchafalaya River, Melville which had been torn away and twisted by a big timber fender pier adrift.

Figure n° 28: Detail of sheet piling (126)

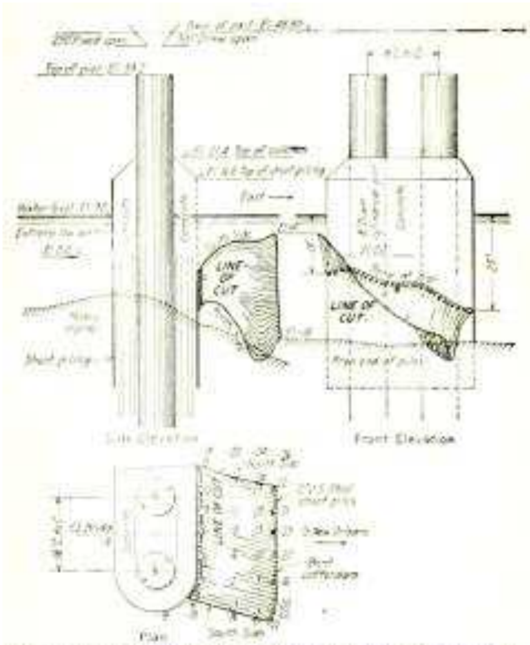


FIG. 1—PIER ELEVATIONS SHOWING BENT COFFERDAM

The work that began November 17, 1922 had required 114 hours of diving among which 67 hours were devoted exclusively to oxy-arc cutting (127).
Becoming aware of the capacities of this electrical cutting tool the US Navy will also develop a first oxy-arc cutting torch. Unlike the Chapman and Kirch torch which we recall is straight, the US Navy one is square and can work with an electrode pointing at 90 °. Among those who participated in the design and the trials we find in particular the Chief Petty Officer John Henry "Dick"

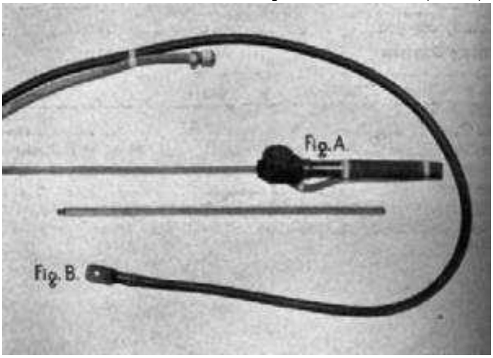
Turpin, who was one of the first African American Navy divers.

Photo n° 66: The diver J. H. Turpin (128)

Thanks to this torch the Navy divers will be able in 1927 to intervene effectively in the refloating work of another submarine the S-4, in which no less than 564 dives of any kinds will be realized (129).
In France in 1924, the Société de la Soudure Autonome Française resumes under the direction of Mr. Lebrun the essays of oxy-electric cutting she had interrupted in 1917 and on June 10, a diver managed using a coated iron tube

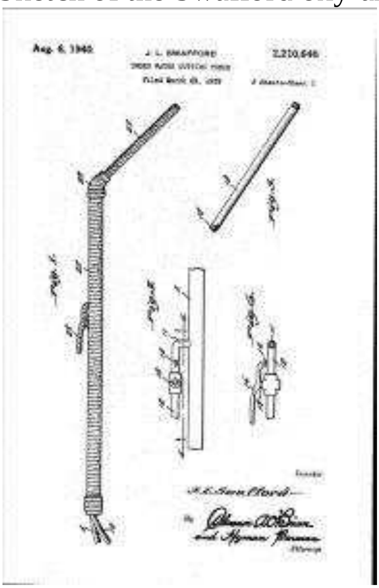
(4mm inside diameter and 8 mm outer diameter and 80 cm length) to cut a sheet steel section of 20 mm in thickness thanks to a series of contiguous holes (130).
The literature does not specify the type of coating, but it's a safe bet that it was adhesive tape because it (the coating) protected the cutters who worked barehanded from the effects of the alternating current (130).
Given the success of the trials it was this technique which was going to be used a few days later to continue the cutting tests on the *Tubantia* which we remember had been interrupted following the explosion of the flexible hoses (see article 2).
This time a diver managed thanks to 6 iron electrodes to cut a length of 1.2 meters plate in one hour of time.
The straightness of the cut had been assured thanks to the implementation of a wooden guide painted in white (130).
As shown, the electrodes used during the French trials were in iron and not in carbon but it is nevertheless this last type of prismatic electrode 30 cm long breakthrough by 2 holes for the arrival of oxygen that will continue to be used by European diving companies into the forties.
By 1932 another cutting method by means of electrode 8 to 10 mm in diameter (without oxygen) will be developed by Mr. Sarrazin but it will be very little applied because its implementation required an operating current of about 1000 amps (131).
In 1935 Siebe-Gorman also describes an oxy-arc torch in its manual. As we can see on the photo 67 it is also a linear shape.

Photo n° 67: Siebe-Gorman oxy-arc torch (132)



In 1939 the American Swafford applies for a patent for a new torch but it seems that this model was never marketed.

Figure n° 29: Sketch of the Swafford oxy-arc torch (133)



On the other hand, towards the same time the same Mr. Swafford also manufactures a cutting electrode composed of a brass tube of Ø 9,5 x 350 mm in which are either welded a small square electrode or 3 steel rods. In order to be properly insulated the electrode it is protected by 3-5 wraps of insulating tape.
Later, this electrode shall contain 7 steel rods and will be used during a few years in the US Navy as it will still be mentioned in the various Manuals until 1948.

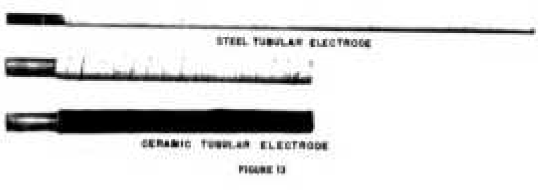
Figure n° 30: Sketch of the Swafford electrode (134)

It will be necessary to wait until 1940 to see a real evolution in the design of electric cutting.
At that time the department of the United States Navy decided to adapt existing materials in the need for the time.
The modernization of this equipment will be realized at the US Naval Engineering Experimental Station located in Annapolis, Maryland and the material will then be tested by the Experimental Diving Unit and Deep Sea Diving School in Washington as well as at the US Naval Training School located at Pier 88 in New York.
It is moreover this number of quay that will give its name to this new oxy-arc torch.

Photo n° 68: The Pier 88 cutting torch (135)

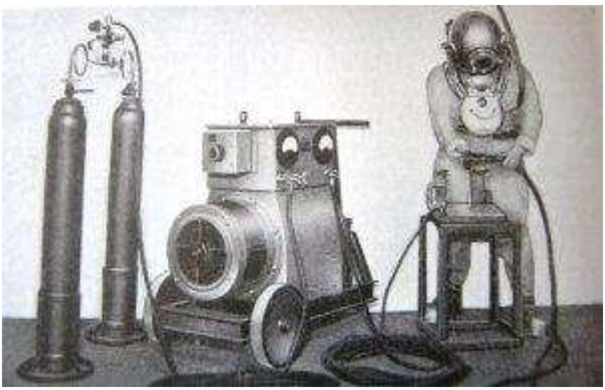
From that time also the big carbon electrodes are gradually going to disappear in favor of new finer tubular electrodes. Two new types of hollow electrode will then be available: The ceramic electrodes and the steel tubular electrodes covered with a coating.

Photo n° 69: Models of electrode (136)



With this new equipment, the American divers are going to be able to work more effectively on the diverse ships which were sunk by Japanese aircraft.
At Pearl Harbor, not less than 20,000 hours of diving will be needed to refloat most ships among which numerous hours were dedicated to cutting (137).
What is extremely surprising is that since the advent of electric cutting until the late forties a lot of cutting was also made with alternating current (138).
In spite of the inconveniences and the risks of this type of electric supply the only additional precaution that were taken by the divers with regard to direct current consisted to better insulate the inside of the helmet by covering for example all metal parts which might to touched (139).
What is on the other hand to notice is that from the very beginning, it was recommended to turn off the electric current during cutting stops and changes of electrodes (see Chapman and all patent process).

Photo n° 70: Siebe-Gorman cutting set (140)



In Europe also the oxy-arc cutting begins to get modernized after the Second World War.
If England and to a lesser extent in Italy they continue to favor the use of carbon electrodes until the late sixties.

Photo N° 71: Diver using an Italian torch (141)

In France, Belgium and probably other countries we begin to quickly use the steel tubular electrodes "Oxycuttend" manufactured by the company Arcos and the pink electrodes of Craftsweld. These two cutting rods were covered with a rutile coating which had the advantage to generate an extremely stable arc.
On the other hand this coating degraded rather quickly in the water and it was therefore better to protect the electrodes with insulating tape.

To avoid this inconvenience Arcair launches on the market in 1971 the SEA-CUT.1, an electrode composed of a mixture of carbon and graphite which does not contain more than a simple plastic coating.

Photo n° 72: SOGETRAM diver doing some cutting training (142)

Each type of electrodes available had good cutting performance, but also some disadvantages. The big advantage of the carbon and the ceramic electrodes was their burning time which was generally 10 times higher than that of steel electrodes (143). They were also a little shorter what facilitated the work in confined spaces. On the other hand these electrodes broke very easily and the kerfs were rather narrow. Thereby they become less efficient than the plates became greater than 19 mm.
In the years that followed various oxy-arc cutting torches will be marketed everywhere (ARCOS, BECKMAN, CRAFTSWELD, ARCAIR, BROCO).

Figure n° 31: Sketch of the Craftsweld torch (144)

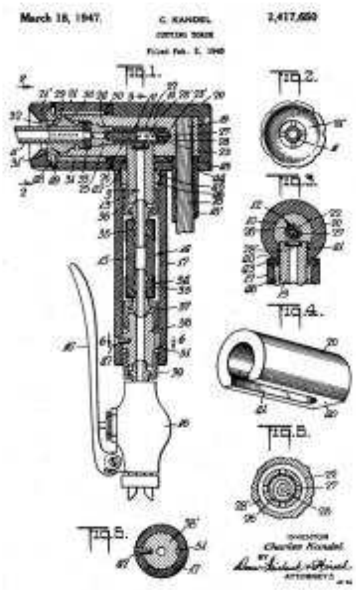


Photo n° 73: Beckman cutting torch (145)

Photo n° 74: Russian cutting torch (146)

Between 1975 and 1978, basing probably on the principle of the thermal lance cutting (see below) as well as on what Swafford had invented in 1939, the Broco Company is developing the first ultra-thermic electrodes.
These are constituted by a fine steel tube 0.7 mm in thickness in which are crimped 7 metal wires of Ø 2.4 mm. Among these one is in a different alloy which allows the maintaining of an exothermic reaction after the cut of the electric current.

Photo n° 75: Electrodes Broco (147)

This electrode has a number of advantages compared with the steel tubular electrode such as that of requiring only a low current intensity (150 Amps) to work and thus a less heavy generator can be set up on construction sites. Another undeniable advantage of this type of electrode is due to the fact that thanks to her exothermic reaction it can cut a larger number of materials that are oxidizing or not. Its implementation is also easier because thanks to the fact that she can burn almost any material the cleaning of the surface to be cut needs no longer be as neat and finally learning how to use it is easier than that of cutting with steel tubular rods.

Photo n° 76: Cutting with an ultra-thermic electrode (148)

As a result, this type of ultra-thermic electrodes is fast going to dominate the market and its principle will rapidly be adopted or copied by other manufacturers or even private entrepreneurs who are going to produce in their turn this type of electrodes (Comex pro, Magnumusa, Divex, Arcair, HBS and many others).
As mentioned a little earlier, the inventors of this new ultra-thermic electrode were probably inspired by another process of cutting: The thermal lance.
It consists of a steel tube of about 3 meters long with diameters ranging from 13 to 21 mm packed with alloy steel rods. It was invented in the 1930s by the French company Air Liquide, which was itself based on the invention of Ernst Menne German who in 1901 developed an oxygen lance for opening furnace taps in steel blast furnaces (149).
Thanks to its high combustion temperature thermal lance can pierce virtually any type of material. Regarding its use in water, it begins just after the Second World War where it is mainly implemented to create boreholes in the cement or the concrete that filled the holds of some wrecks.
By 1968 the American Marine discovers that this type of oxy-lance is used in Europe and thinks that the process could be used in some salvage operation and therefore asks the Battelle Memorial Institute to conduct an investigation on the risks incurred by the divers (150).
The result of the study was clear: process too dangerous to be used under water because of the high risks of explosion.
Despite these risks, certain diving company will nevertheless use the thermal lance in the end of the 70s

for the opening of cavities in the reinforced concrete structures of some offshore platforms (151).
Currently, the thermal lance does not seem to be more used than by small companies not always aware of the risks or for the cutting of big piece when no other cutting mode is possible.

Picture n°77: Cutting of a pipe using a thermic lance (152)

It is then the turn of Reginald Clucas to arrive on the market with a new product.
Probably that this one has in the circle of acquaintances divers who told him about the underwater electric cutting and limitations bound to the electrode burning time. He imagines therefore a system that will allow divers to cut much longer without having to continually change rods and which is also less bulky than long thermal lances.
As a result, in 1968 he launches on the professional diving market a thermic cutting cable for whom he is

going to borrow the first name of his daughter Kerie (153).

Photo n° 78: Kerie Cable reel (154)

The operating principle of the Kerie cable is similar to the thermal lance but contrary to the metallic tubes containing alloy threats, the system consists of an outer sheath of plastic material in which a plurality of multistrand high carbon steel wires forming a hollow core to allow the passage of oxygen are set.
The ignition of the cable is done either by means of a torch flame or electrically with a current of 12 volts.
The cables are supplied in lengths of 15 and 30 meters and in three dimensions 6, 9 and 12 mm.

Figure n°32: Principle of implementation of the Kerie cable (155)

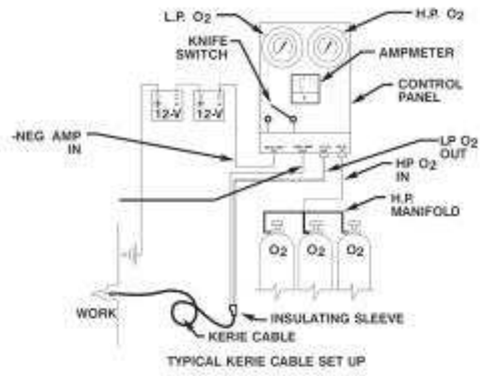
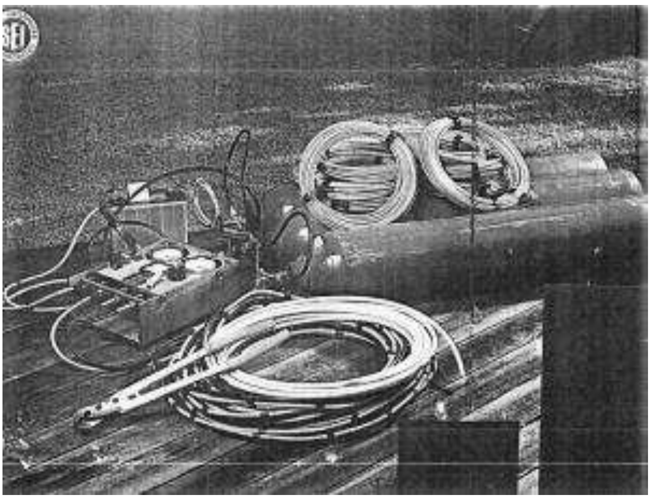
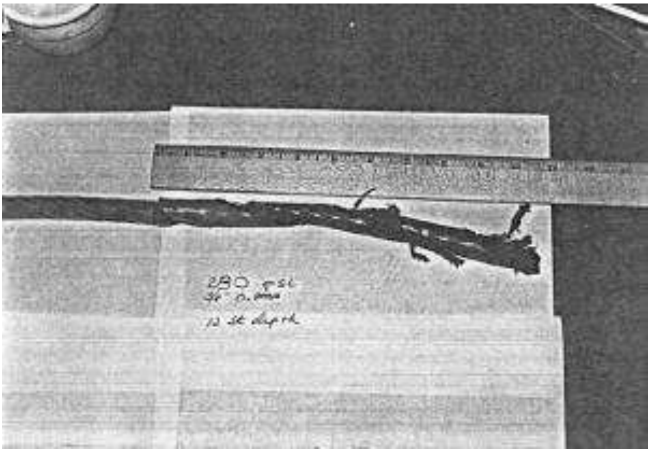


Photo N°: 79: Kerie Cable Set (156)



The burn rate is about 60 cm per minute what gives it a burning time of approximately 50 and 25 minutes by cable.
Although its principle of operation resembles that of the thermal lance, its melting temperature is however much lower (2700 °) what only makes possible that the cutting of ferrous metals. One big problem with this cable (especially the first generation) was due to the fact that sometimes the plastic sheath was consumed faster than the metal core of the cable which was particularly annoying during cuttings without visibility and more than one diver did burn his hand.

Photo n° 80: Defect of functioning (157)



This is probably one of the reasons why this system has never really breakthrough and somewhat fell in oblivion for nearly 3 decades. Today, this problem appears to have been solved and the new system seems to be adopted by several navies and companies.

Photo n° 81: Diver using the Kerie cable (158)

In 2004 we see the arriving of the Swordfish rod from the Speciality Welds society (159).

Photo N° 82: Result of a Swordfish cutting (160)

This new electrode with a high content of iron oxide sold in diameter of 4 mm and 5 resumes the principle of the metal-arc cutting method (without supply of oxygen) used during the early electrical cuttings that is to say that the steel is not oxidized by an oxygen jet but is simply melted by the heat of an arc of about 400 amperes.

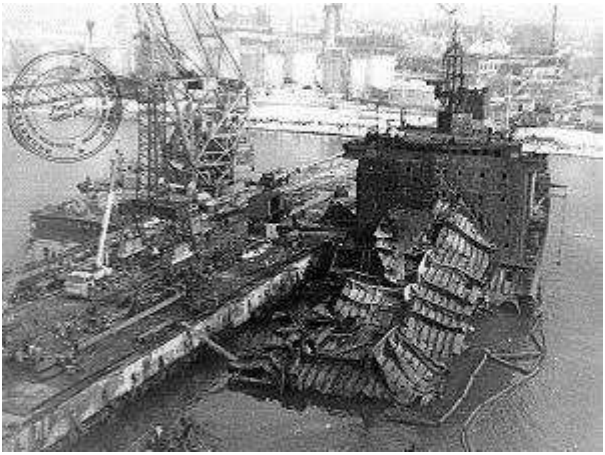
The latest thermal cutting method at disposition of the divers is that of the plasma arc.

Photo n° 83: Plasma arc torch and its control panel (161)

It was developed in the fifties but at that time it is not yet widely used because of some double arcing phenomena that damaged the electrode and cutting nozzle and it will be necessary to wait from then on until 1963 to see a real start in the surface cutting (162).
Fairly quickly the French company SOGETRAM discovers this process and decides to test it in the dive pool on Garenne sur Eure. The trials will however be

quickly stopped because the vibrations and explosions generated by the tool during the cutting sequences were such that the staff feared the breaking of the portholes (163).
It will then be necessary to wait until 1985 to see the underwater arc plasma reappear in the former Soviet Union where this technique will be used together with the oxy-arc on the cutting job of the tanker Ludwig Svoboda that exploded in the port of Ventspils (164).

Photo n° 84: Wreck of the Ludwig Svoboda (165)



One of the problems of the implementation of the underwater arc plasma is bound to the fact that this process runs at 120-200 V arc voltage and has an open circuit voltage of 250-400 V what exceeds very widely the 30 volts recommended by most regulations (166).
Nevertheless from the beginning of this 21nth century the British company Air Plasma Ltd decides to adapt one of their systems for under water use and managed to

eliminate electrical hazards for the divers. Their torch will be used the first time in March 2005 on a project of Mermaid Offshore Services in South Korea on which the divers will cut a series of holes of varied shapes and sizes in a steel sheet 32 mm located at the base of a platform (167).
The same torch will also be used in Canada in 2006 for the underwater cutting of 1500 m of sheet piles (168) and more recently in the United Kingdom to that of a curtain of about 800 m (169). Unfortunately no feedback is available concerning the possible difficulties met during the cutting of the locks and therefore it is a safe bet that only flat parts have been cut by the torch.

Photo n° 85: Cutting trial with the underwater plasma torch (170)

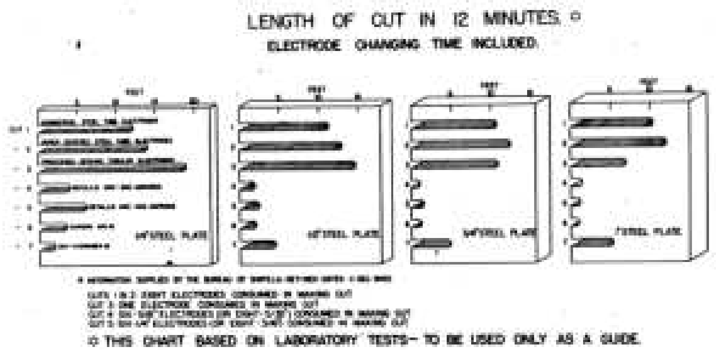
One of the advantages of the plasma arc is that the cutting generates relatively little debris and thus this cutting method is also used in nuclear power plants for

the dismantling of some submerged structures. In most cases, the torch is remotely manipulated from the surface, but recently the divers of an American company specialized in this type of works cut out all the internal components from four steam generators (171).
But apart from these few particular applications there is very little echo's concerning other types of underwater cutting work using this method.

Conclusions:

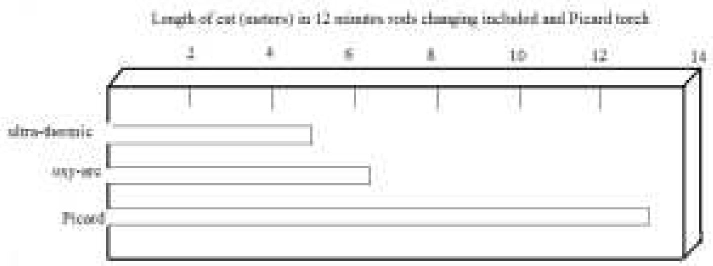
As we have seen through these five articles, as well as through the information of Figure n° 33 which represents the cutting speeds achieved during some tests performed in December 1940, the various tools were relatively productive and allowed to perform tasks that without them would have been impossible to make.

Figure n° 33: Length of cut made in 12 minutes using various cutting processes (172)



Today because of its ease of learning one favor in particular the cutting with ultra-thermic rods. Yet in the point of view of cutting speed per hour, if we except the plasma arc which is currently only used for specific applications and can cut the rate of 3 cm / sec (108 m / h) (173), the undisputed champion for most cutting operations in civil engineering still remains the underwater gas burning torch because used in good conditions and by some competent diver it can reach the speed of 66 m / h (174). It is followed rather far by the oxy-arc cutting (30, 5 m / h) (175) and the ultra-thermic cutting (24, 5 m / h) (176).
Referring to Figure 33, it is surprising to notice that the cutting speed mentioned for the oxy-hydrogen cutting is so low (7, 5 m / h) as it does not correspond to the reality of the time when speeds were rather situated around 36 m / h (177). It is therefore likely that this test was realized by a diver non-specialized in this type of cutting.

Figure n°34: Extrapolation Figure n° 33 to actual performance (174 ,175, 176)



Despite the efficiency of these tools it is clear that both in civil engineering and offshore, thermal cutting operations have greatly diminished.
This is due to several reasons. On shore where these tools were primarily used for cutting of sheet piling it is partly due to the fact that first the steel prices increased sharply and secondly powerful hydraulic extracting tools were created during these last years which have therefore allowed the removal of the piles in their entirety.
In offshore, this mode of cutting also tends to be replaced by methods less risky for divers. Indeed, regardless of the method that is used it always generates a more or less large quantity of highly explosive gas which if they are confined in an enclosed area near the cutting area may explode violently under pulse of incandescent slag.

Photo n° 86: Diving helmet having suffered the effects of an UW explosion associated with cutting (178)

This risk is moreover very real because since the invention of the first underwater torch dozen of divers have unfortunately lost their lives by cutting (179).

The problem is that because of this decrease of cutting work the experience is lost and the new divers hardly have the opportunity to practice.

Even in the commercial diving schools this technique is often approached only in a succinct way by teachers who themselves do not always properly master this process. Yet an effort should be made in improving this teaching because even if less used it is almost certain that during still quite some years thermal cutting will remain a valuable tool for the diver.

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My special thanks go to David L.Dekker and Lévai Miklós for their information supplied in the references n° 84, 85 (David) and 95, 96, 104 -106 (Lévai).

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