

Guide for the Implementation of Operational Control Procedures in Underwater Cutting and Welding Activities

José Fco. Solano^{1,a*}, Sergio Martín-Béjar^{1,b}, Juan M. Cañero-Nieto^{1,c}, and Lorenzo Sevilla^{1,d}

¹Dept. Civil, Materials and Manufacturing Engineering, Escuela de Ingenierías Industriales, Universidad de Málaga, Andalucía Tech, Campus de Teatinos, 29071 Málaga, España

^ajsolano@uma.es, ^bsmartinb@uma.es, ^cjmcanero@uma.es, ^dlsevilla@uma.es

Keywords: Operational Procedures, Oxygen-arc Cutting, Underwater Welding, Professional Diver, Underwater Risks.

Abstract

Professional diving is an occupation that includes a wide spectrum of different activities, but with the same common denominator: its performance underwater. It is carried out in both fresh and salt waters and encompasses such disparate tasks that professional diving is currently present in numerous productive sectors: hydrocarbon extraction, offshore platforms, port maintenance, public works, civil engineering, infrastructure hydraulic, power plants (hydroelectric, thermal and nuclear), shipbuilding, underwater construction, aquaculture, ship and boat salvage, NDT filming and reporting, teaching and training, and scientific research (geological, biological, archaeological, etc.).

It is also characterized by being one of the most dangerous professions and presenting very specific risks, derived from the workplace in a hyperbaric environment, combined with to other hazards of the work activity similar to those of the ground workers.

The objective of this study is to analyze procedural models based on the UNE_EN_ISO 45001:2018 Standard, applied to the execution of thermal cutting and underwater welding works. In order to carry out this work safely and in the most effective way, it must be systematically analyzed, generating procedures and work instructions based on the tasks considered critical, and essential knowledge for all personnel who perform them. Such procedures and instructions should be based on a systematic analysis of the steps taken to perform each task, including the risks involved and the safety measures to be taken to control, reduce or, where appropriate, eliminate them.

Introduction

In order to perform a job safely in the most efficient way, it must be analyzed in a systematic way, leading to the development of procedures and work instructions. Initially, the corresponding procedures and work instructions will be drawn up for the tasks that are considered critical, knowledge of which will be mandatory for all the personnel who carry them out. Said procedures and instructions are systematic analyzes of the steps to be taken to carry out a task, as well as the risks that they imply and the safety measures that must be taken to control, reduce or, where appropriate, eliminate them [1].

A good identification of hazards prior to carrying out the dives and the application of operational control procedures that control the risks at admissible or tolerable levels is the objective of this work.

The hazard identification and risk control processes should be documental and should include the following elements [9]: identification of hazards, evaluating of risks in the underwater cutting and welding activities, application of preventive measures in the place where the underwater cutting and welding works are carried out, identification of any additional risk control measures needed and evaluation of whether the risk control measures are sufficient to reduce the risk to tolerable level.

Methodology

The General Risk Assessment Method, starts from a classification of work activities, developing a posteriori all the necessary information related to each activity. Starting from this base, the variables are then analyzed, identifying the dangers, estimating the risks and finally evaluating them, to determine if they are tolerable or not.

Identification of Hazards and Evaluation of Risks

The process of identification of hazards and risk assessment in underwater cutting and welding operations must be carried out by a technician in occupational risk prevention with sufficient knowledge of the risks of underwater work. The following Table 1 indicates the general risks in the practice of professional diving.

General risks in the practice of professional diving	
Oxygen Toxicity	<ul style="list-style-type: none"> An underwater welder who uses the wrong concentration of oxygen during dives is at risk of oxygen toxicity. Symptoms include tingling, spasms, vertigo, nausea, and tunnel vision.
Gas Toxicity	<ul style="list-style-type: none"> Nitrogen Narcosis: Divers show poor judgment and may become euphoric. Carbon dioxide toxicity is an accumulation of carbon dioxide in the blood that can cause: headaches, shortness of breath, dizziness, vomiting and flushing, Carbon dioxide becomes toxic when a diver's breathing rate does not increase enough during exertion, or enough to move denser air through the breathing apparatus. CO2 poisoning: The air supplied to the diver comes from a compressor that may be faulty. Symptoms of carbon monoxide poisoning include nausea, headache, weakness, clumsiness and confusion, seizures, loss of consciousness, or coma.
Effects of Extreme Pressure	<ul style="list-style-type: none"> As the diver lowers the atmospheric pressure increases one atmosphere for every 10 meters of depth.
Arterial Gas Embolism	<ul style="list-style-type: none"> Excess pressure forces gas bubbles into the arteries of the heart or lungs: symptoms include tiredness, lack of coordination, difficulty concentrating, tremors, and nausea. Decompression sickness-Type I. The pressure of the water expels nitrogen from the bloodstream into bubbles that accumulate in the joints. If a diver slowly returns to the surface, the body will naturally reabsorb these bubbles. But go up too fast and the nitrogen bubbles will expand instead, causing fatigue and pain in your muscles and joints. Known as The Bends, the extreme cases resemble a stroke. Decompression sickness-Type II. With symptoms beyond the curves, decompression sickness affects neurological function, including vision, balance, memory, and causes bizarre behavior. In severe cases, shortness of breath can be followed by cardiopulmonary failure.
Drowning	<ul style="list-style-type: none"> In the water any disease or underwater welding accident can cause drowning. Welders can have a failure in the diving equipment or become entangled in underwater structures or suffer an accident due to the terrain. If the water moves with pressure variations the underwater welder will encounter pressure hazards due to that differential.
Hypothermia	<ul style="list-style-type: none"> Even if special thermal suits are used, prolonged exposure to low temperatures can cause hypothermia. Early symptoms include: chills, exhaustion, confusion, loss of coordination, memory loss, slurred speech.
Health Issues	<ul style="list-style-type: none"> Underwater welding can be strenuous and put a lot of strain on your body.

Table 1: General risks in the practice of professional diving (Source: Author)

Main Hazards and Preventive Measures Underwater Cutting and Welding Operations

But in addition to the occupational risks derived from work in an inhospitable environment such as underwater, the risks derived from underwater cutting and welding operations must be taken into account:

- Underwater welding. These operations can be performed in three types [4] [7]:
 - Wet soldering: It is one in which the welder has direct contact with the water.
 - Dry solder: Hyperbaric welding, when used in a dry environment,
 - Automated underwater welding: Is does not require the direct participation of professionals.

- Underwater cutting. The oxyacetylene flame resulting from the combustion of pressure gases has the advantage of being able to stay under water; this is a quality that allows cutting within the same liquid; it was enough just to find a way to separate the water from the end of the nozzle; that is to say from the point of birth of the flame to ensure its stability. This was achieved by adapting to the torch a compressed air pipe that ends under a small bell that surrounds the nozzle and whose edge slightly exceeds it; the compressed air also has the mission of separating the water from the portion of the plate that the dart has to heat, before the oxygen jet jumps to cut it. In Figure 1, diver shows a classic diver performing underwater cutting operations [3][6].



Figure 1: Classic diver in underwater cutting operations (Source: Author)

The Table 2 shows the specific risks in the underwater cutting and and welding operations, as well as their potential effects on the diver's body and the preventive measures necessary to alleviate said effects.

Hazards	Causes/Effects	Preventive measures
EXPLOSIVE GASES	Gases produced by underwater cutting are rich in oxygen and hydrogen and will explode if trapped and ignited. Underwater explosion.	<ul style="list-style-type: none"> ▪ Start cutting from the highest point and work your way down when cutting thick material. ▪ Gases can be vented to the surface with a vent tube (flex hose) secured in place from the high point where gases would collect to a position above the waterline. ▪ When working below a sea chest, gas can be vented by briefly opening an internal valve.
ELECTRICITY UNDERWATER	Electrical contact of current can cause thermal burns. Severe electrical shocks may cause cardiac or respiratory arrest in divers. Can cause loss of control, panic, or injury due to involuntary muscle contraction. physiological damage.	<ul style="list-style-type: none"> ▪ Inspect before beginning the cut to see how the cutouts will fall and if there are flying debris, wires, or other objects that could obstruct the lines or cause a part to wobble unexpectedly. ▪ Be very careful when cutting very tight steel cables. ▪ Before cutting, make sure that the umbilical and diving equipment are not in the path of the slag from the cutting operation. ▪ Avoid cutting materials above the diver's head, as molten material can damage the diving helmet, suit, and umbilical. ▪ Never leave or carry an electrode holder while it is on and never change an electrode while it is on. ▪ The diver should never allow any part of the body or equipment to contact grounded work when the safety switch is closed.

<p>ELECTRICITY UNDERWATER (continuation)</p>		<ul style="list-style-type: none"> ▪ Care should be taken with large loose metal items carried by the diver to ensure they do not come into contact with a live electrode or the work. ▪ The power source used for underwater cutting or welding: Use only DC welding power. ▪ Do not use torches and electrode holders that have not been specifically designed for underwater applications. ▪ Inspect the welding equipment and verify its insulation ▪ A positive acting non-fused current interrupter switch, rated 400 amperes, must be provided in the welding circuit. ▪ All parts of the cables that are intended to be submerged must be completely insulated and watertight. ▪ It is extremely important that diving clothing provide maximum protection against electrical shock and arc flash eye injury.
<p>CUTTING UNDERWATER WITH THERMIC LANCE (BURN BARS).</p>	<p>This process produces large quantities of hydrogen gas. When combined with oxygen, these concentrations are highly explosive and will produce random explosions of some magnitude.</p>	<ul style="list-style-type: none"> ▪ All materials used in the Thermica lance must be kept away from oils and grease. ▪ Thermal lances or burn rods should not be used by divers underwater or by surface personnel cutting below the waterline while the diver is in the water. However, during situations where it would be impossible to place a diver in a cutting position and where cutting can be performed from the surface, the thermal lance can be used with extreme caution.
<p>CONDITIONS WHICH CONTRIBUTE TO MAKING UNDERWATER WORK DIFFICULT</p>	<p>There are many variables that make underwater cutting and welding work difficult. These are also related to the environment; adverse currents, unstable feet, low visibility (black water), dangerous animals and low temperatures.</p>	<ul style="list-style-type: none"> ▪ Careful analysis should be done before beginning underwater cutting to know how the cut parts will fall and if there are any projections, wires or other objects that could obstruct the lines or cause a part to sway unexpectedly. ▪ Caution when cutting very tight elements. ▪ Before proceeding with the cut, it must be ensured that the umbilical and the diving equipment are not in the path of the slag from the cutting operation. ▪ Avoid cutting overhead if possible, as falling molten material will severely damage the diving helmet, suit, and umbilical. ▪ The diver should never allow any part of the body or equipment to contact grounded work when the safety switch is closed. ▪ Care should be taken with large loose metal items carried by the diver to ensure they do not come into contact with a live electrode or the work.

Table 2: Main hazards and preventive measures underwater cutting and welding operations.

(Source: Author; Note: Adapted from Example P. By, D. Of, N. Sea, and S. Command, 'UNDERWATER CUTTING & WELDING MANUAL', no. September 1995, 2002 [3].)

Operational Control in Underwater Cutting and Welding Activities

The development of this activity is included in the procedure for the operational control of underwater activities welding and cutting operations involve dangerous situations for divers: currents, oxygen and hydrogen-rich gases that will explode and high electrode tip temperatures. It is practically impossible to control 100% all risk situations and scenarios that may arise during the course of the work [1]. But through the design and application of operational control procedures (8.1 UNE-EN-ISO 45001:2018 Standard), we can work in working conditions that contemplate the different possible scenarios in order to reduce the risks of divers and mitigate their consequences in the event of an accident [8][9]. The Figure 2 shows some examples of operational control that companies must implement operational control procedures that guarantee safety in underwater cutting and welding operations.

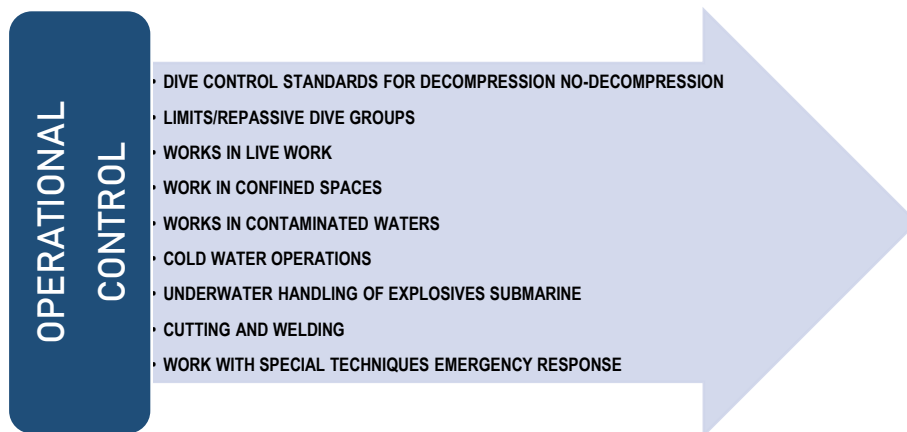


Figure 2: Operational control in the practice of professional diving (Source: Author)

Safety Pre-meetings

Communication between the different levels of the company plays an important role in ensuring that any diving operation is carried out correctly and in safe conditions. For this reason, preliminary meetings will be held when carrying out work that involves a certain risk. Said meeting will take place between the different levels of the line responsible for the work, generally the Site Manager, the Diving Team Leader and the Prevention Technician are the agents involved. Operational safety is considered the responsibility of the supervisor. The development of this activity will be included in the Procedure for preventive planning of the underwater works to be carried out. Through the preventive planning of the works, the preventive action in the operations is integrated into the model, taking into account all the agents involved and the Head of the Diving Operations Team being its catalyst [1]. The Figure 3 represents the importance of coordinated planning of the work y all the agents that participate in underwater activities.

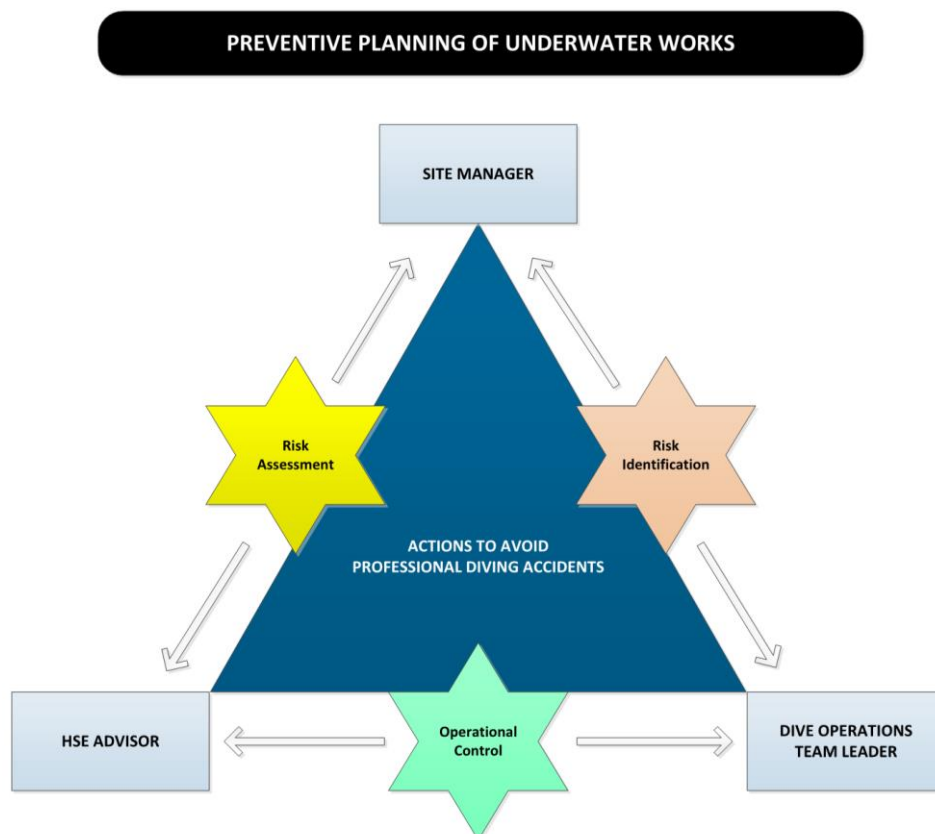


Figure 3: Preventive planning of underwater works (Source: Author)

The performance of the professional diving work will be directed by the Dive Operations Team Leader, who will be responsible for the evaluation, planning, supervision and on-site control of the diving operation. The team leader will be appointed by the diving company, leaving a written record. The Team Leader will be a diver with the appropriate qualification to carry out the operation to be carried out. The Team Leader of the Diving Operations Team will approve the diving plan, prepared by the HSE Advisor based on the risk assessment of the diving operation to be carried out.

In underwater cutting and welding work, the corresponding operating instructions must be available that specify who must carry out the task, what it consists of and how it must be executed, when and with what expected result. There will always be a boat on the surface to help and assist divers during their dives. The boat's crew will monitor the bubbles coming from the divers' respiratory equipment at all times and will be informed, as far as possible, of the approximate duration of the dive. The crew of the boat will be alerted to pick up a diver who comes to the surface with any problem in the shortest possible time [2]. In figure 4, The classic diver, with his team of diving assistants prior to carrying out a dive.



Figure 4: Classic diver before doing a job (Source: Author)

The Royal Decree 550/2020, of June 2, determines the safety conditions of diving activities on safety standards for the exercise of underwater activities are established as regulations. Professional divers must cover the aforementioned sheets, in a mandatory manner, being signed by the Team Leader and with the stamp of the company. In the latter case, they will constitute the justification of hours of work under water. In the case of diving with a mixture of gases other than nitrogen and oxygen, the regulatory sheets mentioned in the previous paragraph will be used, with the appropriate modifications and, if necessary, a new one will be created where all the detailed information of the immersion. Model of «Diving sheet with air or mixture of nitrogen and oxygen» and «Calculation of successive immersion» must be used to control each individual or collective immersion, carried out at any depth and with any diving equipment. Have an "Equipment Registration/Control Book", which specifies the facilities and equipment available to the entity to carry out said activity, as well as the controls carried out on said equipment. These underwater work control sheets, together with the equipment control sheets in the aforementioned Equipment Record/Control Book form the "diving record book", whose sheets will be covered by the chief of diving equipment that controls the immersion, with your signature and seal of the company [1].

Safety for Contractors/Subcontractors

For the hiring or subcontracting of certain tasks to personnel from external companies who carry out their work facilities, controls must be established to guarantee not only the safety of workers and own facilities, but also the safety of subcontracted external workers is indicated in art. 24 of the Law of Prevention of labor risks and the Royal Decree 171/2004 [1].

Periodic Surveillance of Workers' Health

For the exercise of professional underwater activity, which approves the safety regulations for underwater activities, includes the obligation of professional divers to carry out a specialized medical examination on an annual basis in order to continue developing their professional activity. Any person who undergoes a hyperbaric environment must previously undergo a specialized medical examination. Periodic examinations will be mandatory to gain access to any title or certificate that enables you to undergo a hyperbaric environment, apart from the initial [1].

Preparation and Answer to the Emergencies

When developing an emergency and evacuation plan, the specificities of this type of work activity must be taken into account the potential emergency situations and will be identified [2]. The first rule that must be taken into account is that any incident suffered by a professional diver in the 24 hours after a dive must be considered a dysbaric accident. Only a specialized doctor should rule out this type of pathology, after the worker is admitted to a Hyperbaric Medicine Center, since in most cases they require recompression of the injured person. The above standard implies that an emergency and evacuation plan must provide for the evacuation of the injured diver to the Hyperbaric Medical Center closest to the place of work. Any diving operation must guarantee the existence of a multiplace decompression chamber, which makes adequate treatment possible, within a maximum period of two hours and recommends the presence of a decompression chamber in the workplace when working at depths greater than 50 m [7].

Safety Inspections and Preventive Observations

Periodically and in accordance with preventive planning, the company will carry out inspection visits to the facilities and equipment to detect unsafe conditions or unsafe acts that may result in harm to people. These will be carried out by groups that will control the implementation of the corrective and preventive actions proposed in previous inspections. A rigorous and systematic monitoring of corrective and preventive measures will be carried out, as well as repetitive anomalies to identify causes and critical points of the company and eliminate them satisfactorily [2].



Figure 5: Classic diver working (Source: Author)

Notification, Investigation and Analysis of Accidents and Incidents

The purpose of the notification, investigation and analysis of accidents and incidents is to adopt the necessary measures to prevent their repetition by obtaining objective data that allow the facts to be defined and the basic causes that originated them to be established. Accidents and incidents will be analyzed as a whole to detect the critical points of the organization and the repetitive basic causes, making a rigorous and systematic follow-up of the corrective and preventive measures. Statistical controls and monitoring of occupational accidents in the company will be carried out. The methodology and scope of the investigations will be defined in a notification procedure, investigation and analysis of accidents and incidents. Table 3 content of the diving accident sheet [1].

1. Name of injured person
2. Diving qualification
3. Diving specialty
4. Type of equipment used: Autonomous/Semi-autonomous/Classic
5. Breathing medium: Air/Oxygen/Mixed
6. Make and model of equipment
7. Did you go with a partner? Partner's name and certification/Diving specialty
8. If alone: (YES/NO). Was he/she attached to the surface by guide. Did he/she carry a telephone? Name, certification and diving specialty of helper
9. Diving area: Geographic location/Depth/Visibility/Water temperature/Weather conditions. Day or night?
10. Dive data: Depth/Time at the bottom/Decompression
11. Work
12. Supporting vessel (YES/NO). Type of vessel
13. Type of accident suffered: Death/Injuries/Pressure attack/Medical report summary
14. In case of pressure attack or embolism: Chamber to which you were led/Name, qualification and diving specialty of the person in charge of the treatment
15. General remarks

Table 3: Model of diving accident report

Individual Protection Equipment

The existing risk conditions and the operations carried out in the different jobs will be studied. Once it has been concluded that the only way to reduce risk exposure at that time is the use of personal protective equipment. In compliance with Royal Decree 773/1997, of May 30, on minimum safety and health provisions relating to the use of personal protective equipment by workers. This equipment will be provided by the employer, combining safety with the best comfort conditions and complying in any case with current legislation. A procedure will be established for the use of this equipment [1]. Welding produces short wave ultraviolet rays that can cause erythemous action and inflammation of the conjunctiva. To avoid this, protective glasses with filter lenses that comply with DIN 6 to 15 must be used depending on the intensity of the arc [4].

Conclusions

The implementation of operational control procedures requires motivated professionals with a high level of participation from the entire organization, therefore adequate and personalized dissemination of the objectives and goals should be the first action to be taken. This informative phase must be done through the elements of consultation and participation that the occupational risk prevention law makes available and where suggestions play a fundamental role for the subsequent success of the development of the preventive policy, thus achieving the active involvement and assumption by all of the preventive policy to be followed.

The specific training regulated for the exercise of the profession contains the fundamental subjects and the diving techniques necessary for the exercise of the activity. Health surveillance and the protocols for its periodic follow-up are considered fundamental for the verification of the fitness of the professional diver prior to carrying out the work.

Operational control, establishing specific methodologies and programs for the reduction and control of risks derived from underwater activities. Through the use of procedures and work instructions, the implementation of good operational practices that guarantee the safety and health of professionals in the sector exposed to risk is proposed.

Acknowledge

The authors thank University of Malaga-Andalucía Tech Campus of International Excellence for its economic contribution on this paper.

References

- [1] J. Solano Martos, Modelización para el estudio, análisis y prevención de riesgos intrínsecos en sectores singulares. Tesis doctoral. Universidad de Málaga, (2011).
- [2] J. Solano., E. Maeso, Modelling for implantation of the systems preventive management in the singular sectors. 7th International Conference on Industrial Engineering and Industrial Management. XVII Congreso de Ingeniería de Organización. Valladolid, July 10-12, (2013).
- [3] P. By, D. Of, N. Sea, and S. Command, 'UNDERWATER CUTTING & WELDING MANUAL', no. September 1995, 2002.
- [4] K. Verma and H. Garg, 'Underwater Welding-Recent Trends and Future Scope', Int. J. Emerg. Technol., vol. 3, no. 2, pp. 115–120, 2012.
- [5] E. F. Alajmi and A. A. Alqenaei, 'Underwater Welding Techniques', vol. 7, no. 2, pp. 14–17, 2017.
- [6] U. C. Explosions, 'Underwater Cutting Explosions', HERMANS, F. (2021). Underw. Cut. Explos., no. May, 2021.
- [7] L. Orr, 'Underwater welding', Shipp. World Shipbuild., vol. 207, no. 4229, pp. 38–39, 2006.
- [8] ISO 45001:2018. Occupational health and safety management systems. Requirements with guidance for use (2018).
- [9] British Standards Institution: BS-45001-0:2018. Part 0: General guidelines for the application of ISO 45001. British Standars Institution. Londres, (2018).