Guidelines for

Oxy-Arc Cutting

International Marine Contractors Association

www.imca-int.com

IMCA D 003 Rev. 1

September 2011

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IMCA promotes improvements in quality, health, safety, environmental and technical standards through the publication of information notes, codes of practice and by other appropriate means.

Members are self-regulating through the adoption of IMCA guidelines as appropriate. They commit to act as responsible members by following relevant guidelines and being willing to be audited against compliance with them by their clients.

There are two core activities that relate to all members:

- Competence & Training
- Safety, Environment & Legislation

The Association is organised through four distinct divisions, each covering a specific area of members' interests: Diving, Marine, Offshore Survey, Remote Systems & ROV.

There are also five regional sections which facilitate work on issues affecting members in their local geographic area – Asia-Pacific, Central & North America, Europe & Africa, Middle East & India and South America.

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Appendices

1 Introduction

Oxygen-arc cutting is defined as an oxygen cutting process in which metal is severed by means of the chemical reaction of oxygen with the base metal at elevated temperatures. The heat of the arc brings the metal to its kindling temperature and then a high velocity jet of pure oxygen is directed through a tubular cutting electrode at the heated spot. The metal oxidises and is blown away. The tip of the electrode, which is exposed to both heat and oxidation, is consumed in the process and needs to be replaced by the diver at regular intervals.

Typically oxy-arc cutting is utilised to cut steelwork in the underwater environment, some examples of which are described in the following bullet points:

- structure removal;
- removal of redundant steelwork from a worksite to provide access for installation activities;
- removal of damaged tubulars and caissons;
- cutting of seized bolts subject to removal or replacement;
- major abandonment operations.

Divers who perform underwater cutting and welding should have greater skill and stamina than those doing the same work topside. The success and speed of operations depend upon the conditions under which the diver must work because the underwater environment imposes numerous limitations and restrictions on the operator and equipment. The diver is often restricted to working for only a short time on the bottom, particularly at deeper depths. The use of correct techniques and equipment becomes extremely important in terms of work accomplished per hour. Diving apparel, great depth, adverse currents, low temperature, lack of visibility and unstable footing are all factors which make underwater cutting and welding difficult.

The oxy-arc cutting process generally utilises a consumable metal/alloy cutting rod with an internal bore for oxygen, inserted into the cutting torch, which is supplied with a high volume of oxygen and an ignition source. The ignition source found at most dive sites is a welding generator which supplies a dc electrical current to the hand-held cutting torch through an electrical supply cable, with an associated electrical ground cable attached to the worksite to complete the circuit.

Once contact between the cutting rod tip and the workplace is completed, in association with high volume oxygen flowing through the cutting rod, ignition occurs with temperatures in excess of 10,000° Fahrenheit/ 5538° Celsius at the tip, which in the case of exothermic rods will continue to burn as long as the oxygen is supplied or until the rod is consumed. In the case of ultrathermic rods, once ignited, the dc electrical power supply can be isolated and the cutting rod will continue to burn until the oxygen supply is cut off, with little loss of cutting efficiency. When applied safely, oxy-arc cutting provides an effective and versatile method of cutting at subsea worksites.

1.1 Scope

This guidance addresses the basics of oxy-arc cutting. It includes general points that should be considered when deciding if oxy-arc cutting is the correct solution and it places great emphasis on safety, risk assessment, planning and general equipment maintenance. The risk assessment covers underwater explosions. These have occurred in industry and some explosions have been fatal. They occur due to the simultaneous presence of explosive gases (e.g. oxygen and hydrogen), heat (from the electrode) and possibility of gas build-up. This document is an update of IMCA D 003.

1.2 Objectives

The objectives of this guidance are as follows:

i) provide guidance to improve the safety and efficiency when conducting oxy-arc cutting;

ii) place greater emphasis on the risk assessment process prior to commencing job;

iii) provide operational considerations associated with oxy-arc cutting;

iv) provide preventative maintenance guidance for equipment associated with oxy-arc cutting.

2 Glossary of Terms

A number of specialised terms are used in this document. It is assumed that readers are familiar with most of them. However, a number of them, although in use for many years, could be misunderstood. These terms are defined below to ensure that readers understand what is meant by them in this document.

ac	Alternating current
AJC	Abrasive water jet cutting
dc	Direct current
ECG	Electrochemical grinding
ECM	Electrochemical machining
FMEA	Failure modes and effect analysis. This is a methodology used to identify potential failure modes, determine their effects and identify actions to mitigate the failures
FMECA	Failure modes, effect and criticality analysis
HAZID	Hazard Identification
HIRA	Hazard Identification and Risk Assessment
JSA	Job safety analysis. Also called SJA (safe job analysis), JHA (job hazard analysis), TRA (task risk assessment)
MOC	Management of change. This is a process that needs to take place to revise an existing approved design/fabrication or work/installation procedure
Pyromechanism	A mechanical cutting method that uses a charge of pyrotechnic fuel in lieu of hydraulics to activate the mechanical striker
PFM	Principal failure mode refers to the most commonly observed combinations of failure modes (combinations of failure and cause)
Rectifier	A device that transforms an alternating current into a direct current
Risk assessment	The process by which every perceived risk is evaluated and assessed. As part of the process control measures to be established to prevent harm before an operation commences should be identified. The findings and actions will be documented. A risk assessment is part of the risk management process

3 The Selection of Subsea Cutting Methods

3.1 Cutting Methods

Many subsea cutting methods are available but diving contractors are likely to employ simple, proven and robust equipment. More specialist techniques may be used for completing uncommon tasks or when the contractor believes the increased complexity and difficulty of operation of a certain method is outweighed by its potential advantages, especially for large volume, repetitive work.

When confronted with an underwater cutting operation, the planning team should review the advantages and disadvantages of all forms of cutting (mechanical, explosive and electrochemical and thermal) prior to identifying the appropriate method to use.

♦ **Mechanical**

  There are many forms of mechanical cutting and the underlying factor when reviewing this option is availability. Examples of mechanical cutting are chain feed cutters, orbital pipe cutters, pipe saws, casing cutters, hydraulic shear cutters, pyromechanism, hydraulic hand tools, hole saws, wire saws and abrasive water jet cutting (AJC). Most mechanical cutting mechanisms can be called 'cold cutting' which may be the only safe option in certain circumstances.

  The main advantages with using a mechanical form of underwater cutting are the operation is normally conducted remotely and as such there is decreased risk to diver and the finish is generally very clean. There is also no oxygen, heat source or uninsulated electricity involved. The main disadvantage is the cost and availability of the equipment and time involved for the process.

♦ **Explosive**

  Underwater cutting can be achieved using low or high explosives using bulk, collision or shaped charges or shockwave refraction tape.

  The main advantage is the extremely rapid cutting and multiple simultaneous cuts can be achieved and the major disadvantage is the operators require a very specific skill set to use this method.

♦ **Electrochemical**

  Electrochemical machining (ECM) and electrochemical grinding (ECG) work is a process that has been described as reverse electroplating. Electrochemical grinding is a process that removes electrically conductive material by grinding with a negatively charged abrasive grinding wheel, an electrolyte fluid, and a positively charged work piece. Materials removed from the work piece stay in the electrolyte fluid. Electrochemical grinding and electrochemical machining are similar but a wheel is used instead of a tool shaped like the contour of the work piece.

  The main advantage is it is very versatile and cuts all steels at the same rate irrespective of hardness. The main disadvantage is the electrical power source needs to be very stable.

♦ **Thermal**

  There are four available forms of thermal cutting: arc, oxy-fuel, oxy-arc and plasma arc. Arc cutting (e.g. Swordfish) uses electricity as the cutting medium and does not require a surface supplied gas source. Oxy-fuel cutting (e.g. Sea Fire) uses a combustible fuel like acetylene or hydrogen and oxygen. Oxy-arc cutting includes tubular steel cutting, exothermic (Sea Jet, Aqua Exo) and ultrathermic cutting (e.g. Broco and Kerie cable) and involves the use of oxygen and electricity. Plasma arc cutting uses argon, hydrogen or nitrogen (or a mixture) and electricity.

  The main advantage with thermal cutting is the equipment is readily available and decreased time to completion. The disadvantages are the increase risk to the diver of explosion due to the use of compressed gas (mainly oxygen and hydrogen), electricity and flame. There is an increased level of competence required for the operator. This document only covers oxy-arc cutting.

There are two main safety factors to be considered when carrying out subsea cutting operations. The prime consideration needs to be to ensure the safety of all personnel involved in the operation (surface and sub-surface). The divers are at the greatest risk throughout the operation and most effort needs to be concentrated towards ensuring their safety.

However other personnel like diving tenders and topside support staff should not be ignored. The second consideration is to minimise the risk of damage to adjacent structures and surface support vessels as such damage is also likely to cause risk to personnel.

The reliability of any cutting process is always important especially when the process is deployed at the maximum diving depth. Poor reliability leads to considerable loss of production time and, in a subsea environment where divers' time is at a premium, substantial increases in operating cost may be incurred by it. In addition there may also be direct implications on the safety of personnel. The cutting methods that employ simple, proven and robust equipment, purpose designed for use subsea, are likely to be favoured.

The safety implications of a particular cutting method need to be considered using a combination of past experience and professional judgement. The major risks inherent with subsea cutting operations have been identified as:

- steam or gas explosion caused by thermal techniques or by igniting trapped flammable material;
- electrocution from power source;
- failure of gas hose (under pressure) giving 'line whip' and fire risk;
- injury by falling or moving equipment;
- collapse of damaged or weakened members;
- injury through diver interactions;
- damage to diver's life support system;
- flooding of air filled spaces.

3.2 Flow Charts for Different Cutting Tasks

When planning jobs or when confronted with non scheduled tasks that require underwater cutting, the following flow charts may provide some guidance options available in lieu of automatically deploying oxy-arc cutting gear. Although much of what the flow charts cover pertains to removal of an offshore installation, the contents may be useful when applying it to alternate applications (ref. HSE OTH 349).

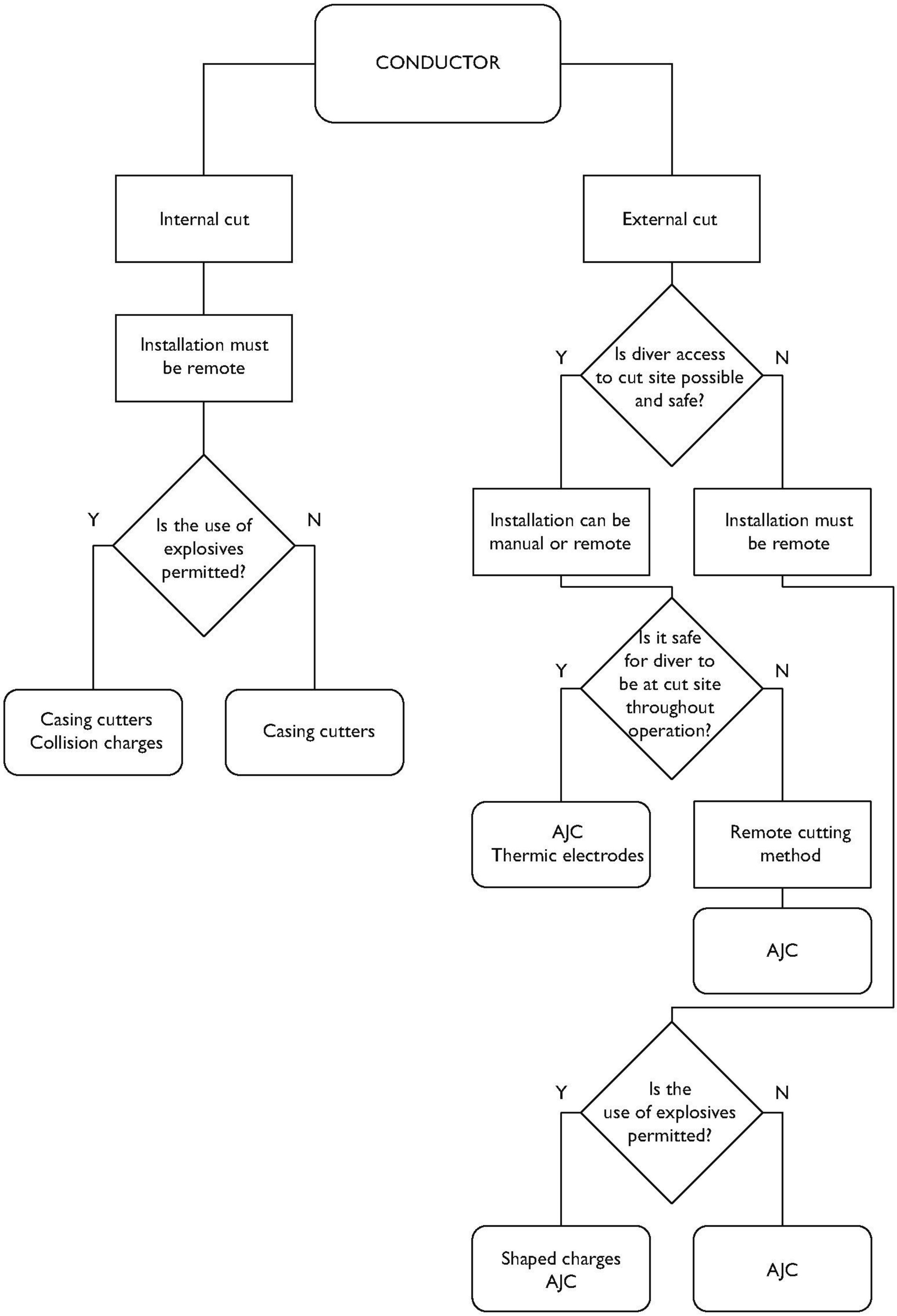


Figure 1 – Conductor cutting flow chart

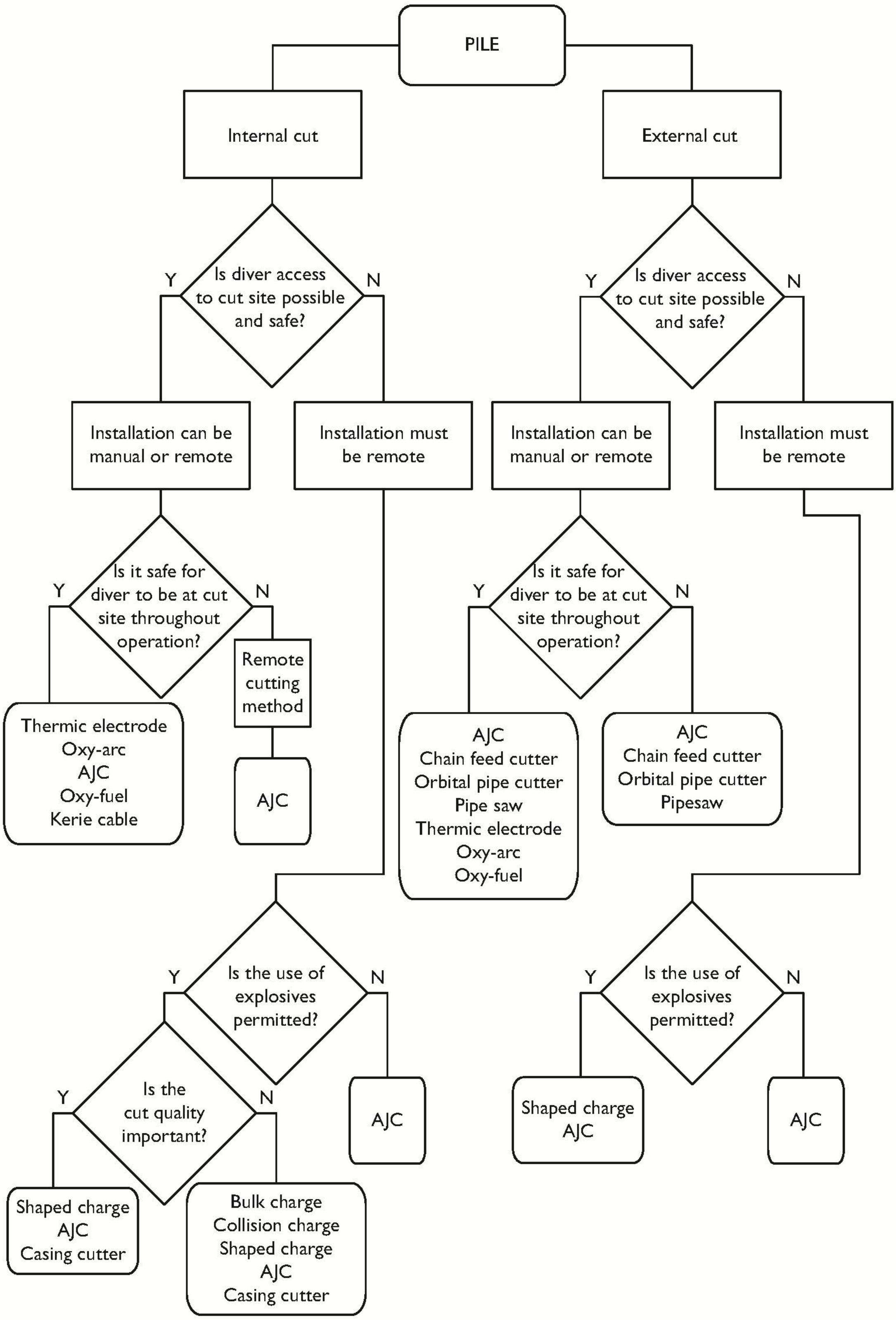


Figure 2 – Pile cutting flow chart

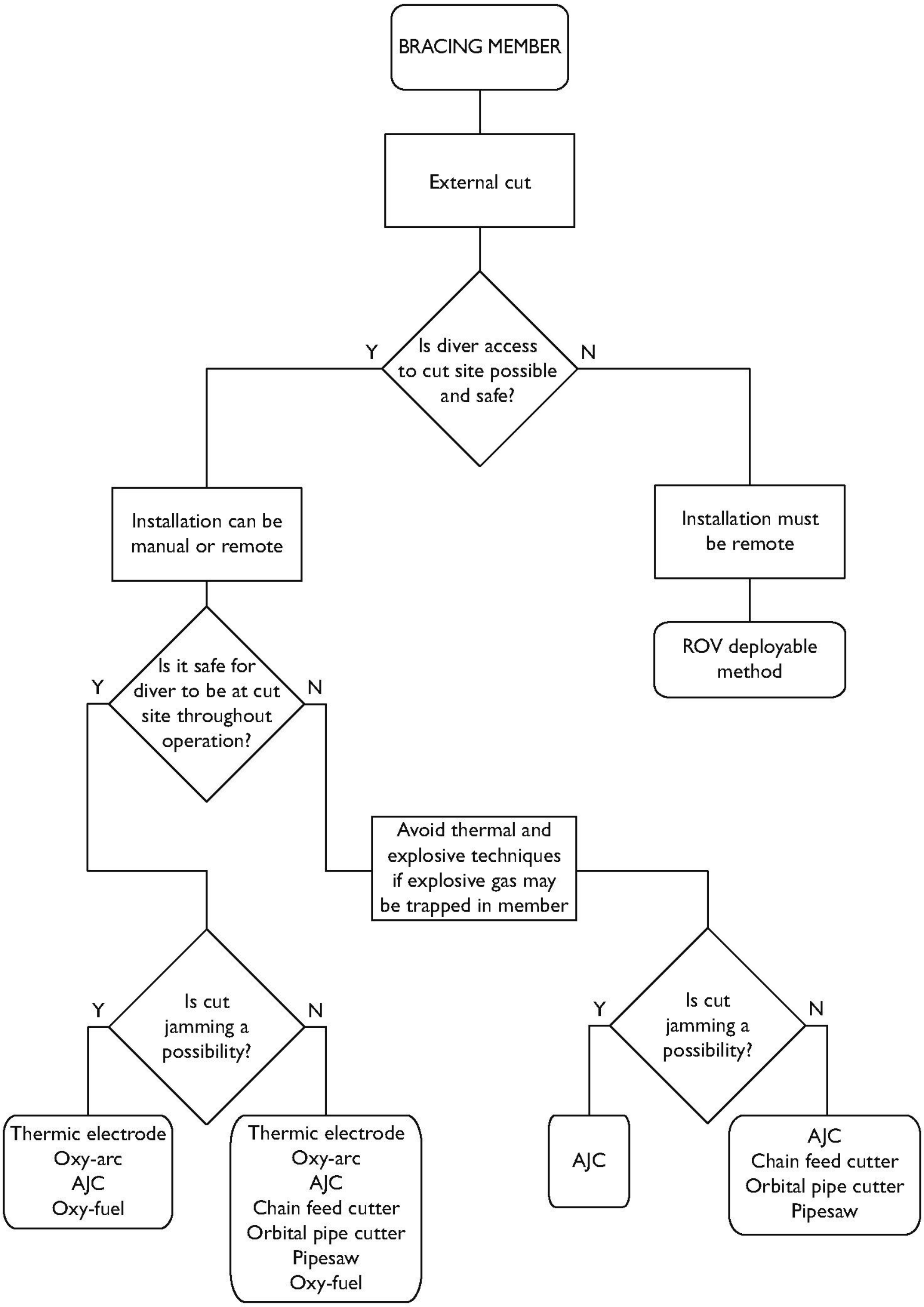


Figure 3 – Bracing member cutting flow chart

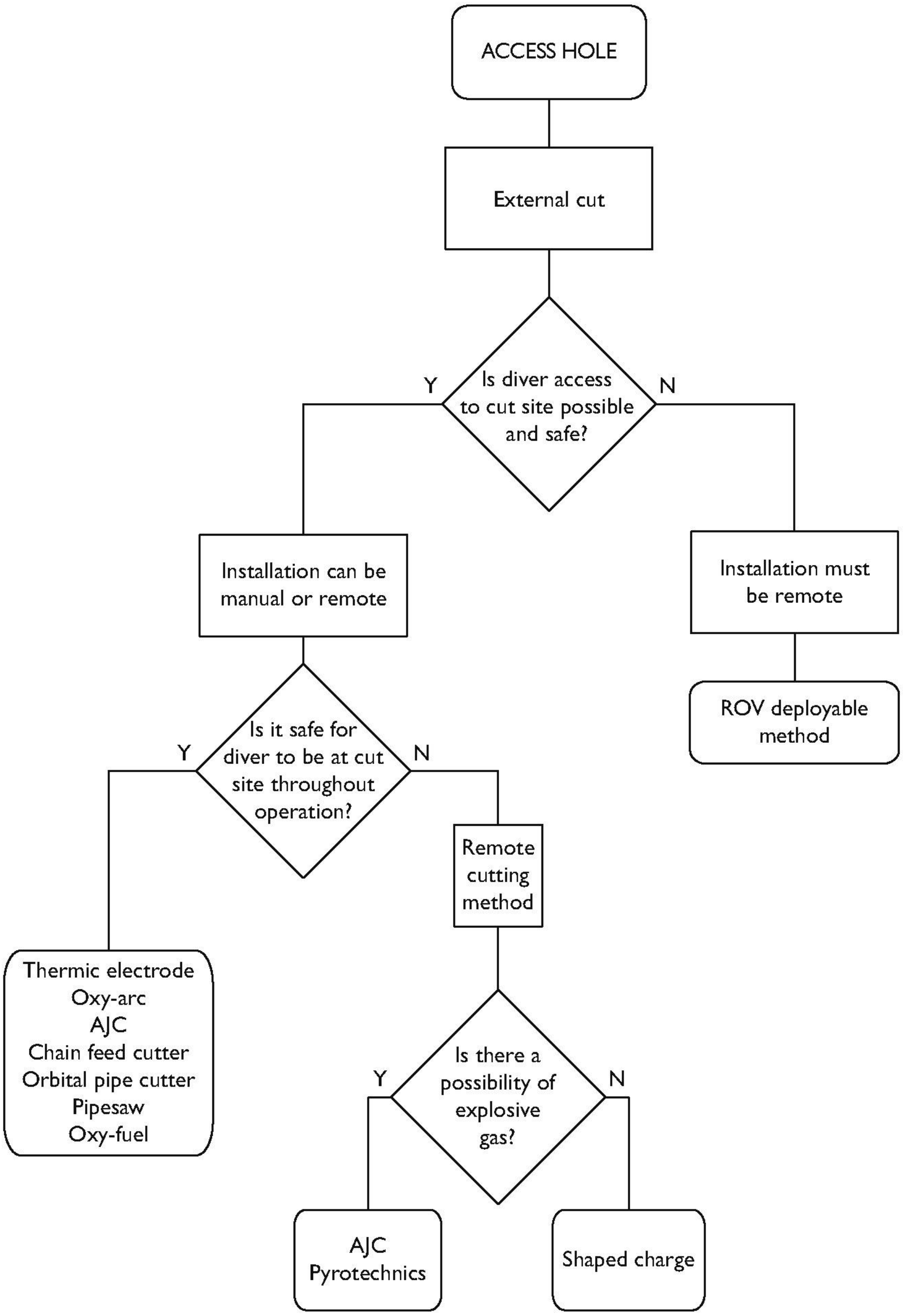


Figure 4 – Access hole cutting flow chart

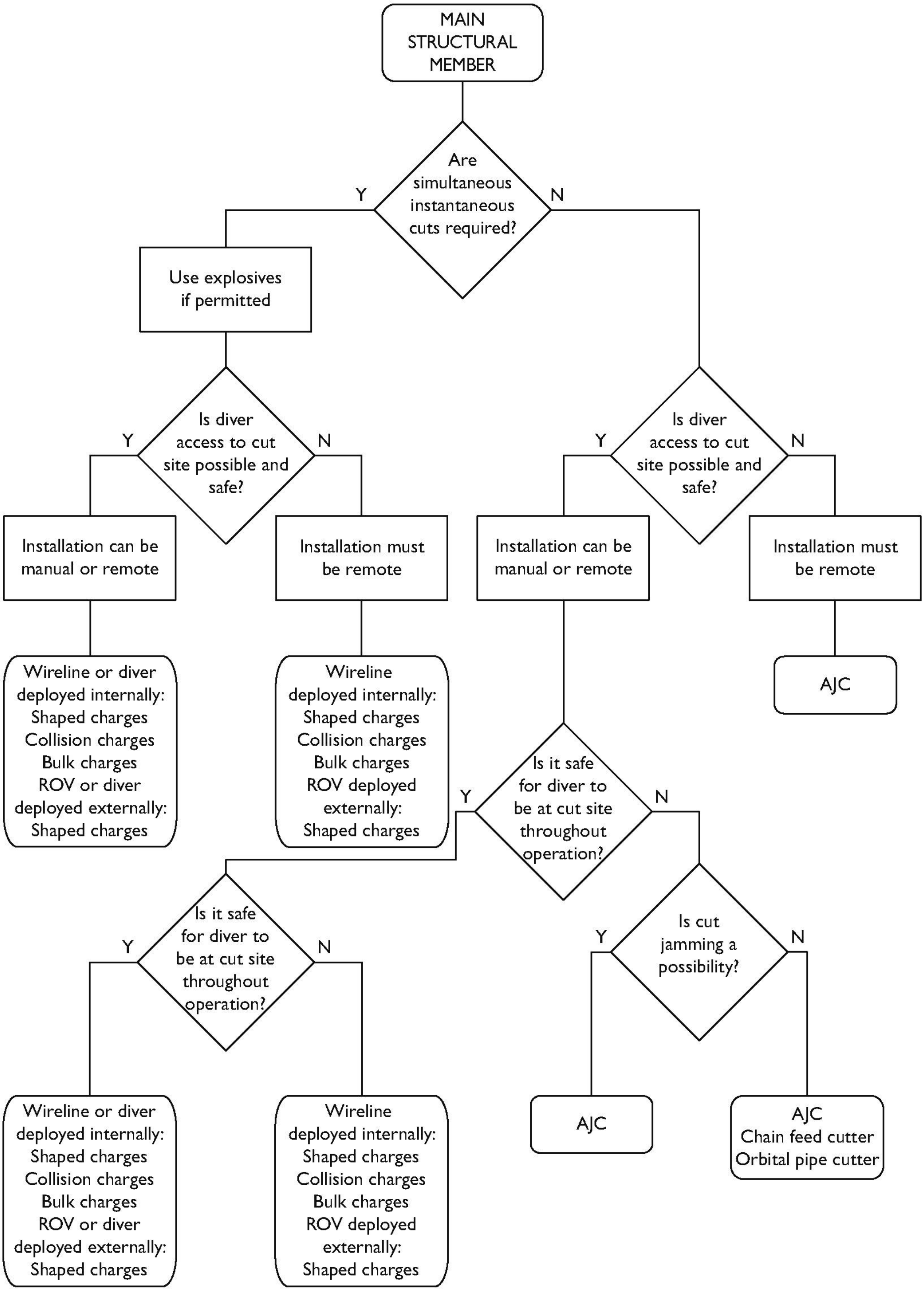


Figure 5 – Main structural member cutting flow chart

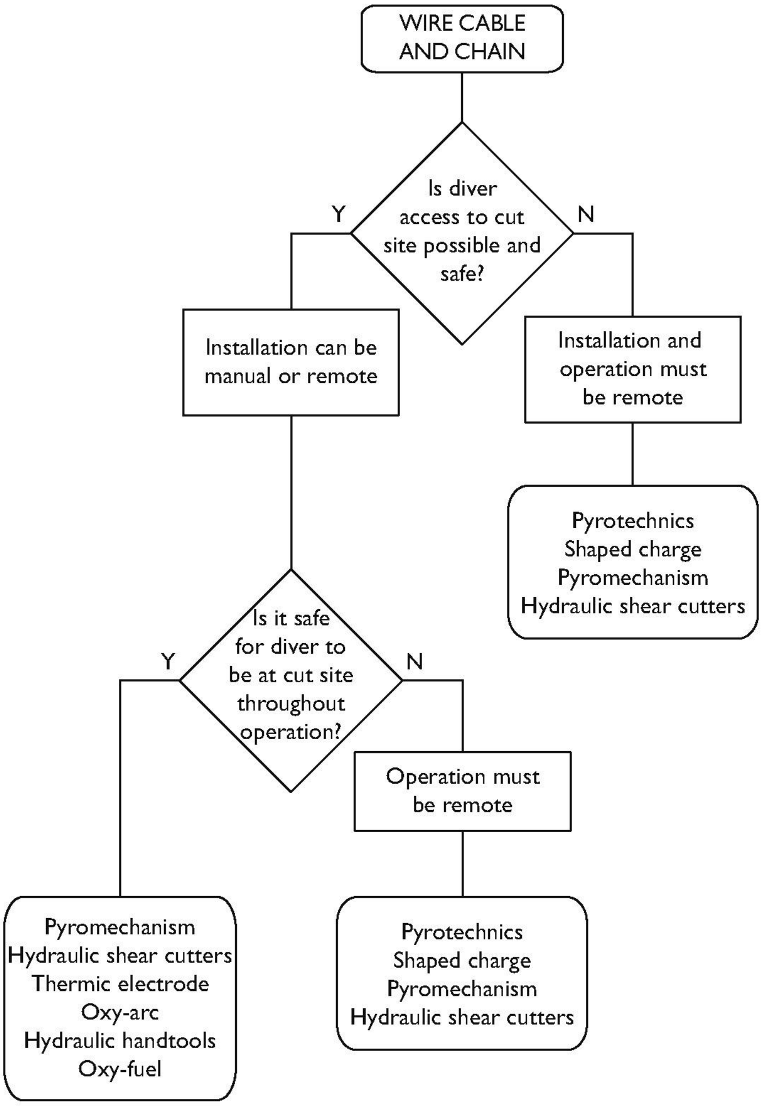


Figure 6 – Wire cable and chain cutting flow chart

3.3 Risk Assessment Process

The diving contractor should have a risk management process in place which addresses the project lifecycle and should include the following.

3.3.1 Onshore

- Risk identification meetings (HAZID or HIRA) prior commencement of the development of step by step work procedures;
- Final risk assessment (HAZID or HIRA) when the step by step work procedures have been finalised;
- Risk assessments of mobilisation/demobilisation plans and the contingency and emergency plans. The risk identification and assessments (HAZIDs and HIRAs) will need to identify site-specific hazards, assess the risks and set out how these can be mitigated or controlled. The persons responsible for any actions will also need to be identified.

The meetings should be attended by experienced diving contractor, engineering and offshore personnel as well as experienced client personnel.

3.3.2 Mobilisation

- Mobilisation and familiarisation of the offshore personnel.

3.3.3 Offshore Operations

- A job safety analysis (JSA) should be completed prior to initiating the work. With the work procedures in place on the vessel/fixed/floating structure, all relevant persons responsible for the work should discuss the potential hazards and precautions to be taken. If the JSA reveals significant unanticipated safety risks then offshore acceptances should be withheld pending revision of the work procedure to address the safety concerns. Approval for the revision needs to be given by all parties concerned, onshore and offshore. Management of change procedures need to be followed (see Appendix 1, ref. IMCA S&L 001);
- A toolbox meeting should be held at the start of each shift or prior to any high-risk operation, where the diving supervisor and/or the diving supervisor's delegate and shift personnel discuss the forthcoming tasks or job and the potential risks and necessary precautions to be taken;
- Dive plan. This should be used for each dive to brief the divers. It should contain the tasks to be carried out, hazards, risks and precautions to be taken.

The diving contractor's responsibilities include provisions to ensure that a risk assessment has been carried out. Risk assessments will normally have been carried out for all the routine diving procedures and the results included in the company manual. The project manager, diving superintendent and diving supervisor are likely however, to be involved in carrying out site- or task-specific risk assessments.

The basis of risk assessment is task analysis, sometimes called job analysis or job safety analysis. The aim is to break each task down into steps and identify the significant risk associated with each step. Procedures are then devised to reduce or remove the risk.

Due to its very nature, oxy-arc cutting operations should always be considered as a hazardous activity and control measures arising from thorough risk assessments may reduce the probability of injury or damage. As such, all other cutting options available should be reviewed prior to opting for an oxy-arc solution.

The risk levels to divers associated with the presence of oxygen, electricity and diving related environmental conditions such as limited visibility or access etc. emphasise the need to always look at alternate options prior to committing to the use of oxy-arc cutting.

If cutting using oxy-arc is to be used then it should be as part of the project onshore risk assessment and be classed as 'safety critical' tasks in all associated procedures. Prior to commencing the offshore task, an onsite job risk assessment should be conducted, with all relevant personnel.

The following table identifies some key words to be considered when conducting a risk assessment on oxy-arc operations.

Guideword	Rationale
Annular cavities	Consideration to be given to the potential for annular cavities to be blocked and unable to free vent escaping gases.
Arcing	Consideration should be given to the potential for electrical arcing during initial ignition of the cutting system. Electrical cables should be visually examined to ensure they have not been abraded and in contact either subsea or on surface.
Blowback	These are spontaneous explosions of varying intensity that happen at times at the cutting point. Most are of minor intensity, possibly due to hydrogen formation or oxygen explosion. Good cutting technique and diver positioning alleviate most of the potential discomfort.
Client approval	Any client prohibition on the use of oxy-arc cutting operations should be discussed at an early stage in the programme.
Cutting guide	Consideration should be given to the use of cutting guides by the diver to define his working area and assist in guiding of the required cut.
Diving bell	The possibility of unconsumed gas contaminating the bell atmosphere needs to be taken in to account with the diving bell position adjusted to ensure gas plumes are clear.
DP system	When conducting operations from a DP DSV, consideration should be given to the waste gas and its potential to interfere with the vessel hydroacoustic position reference system. Oxy-arc umbilical management needs to focus on deployment and proximity to thrusters.
Enclosed space	Special attention and consideration is to be given to operations that involve cutting into enclosed spaces where gas entrapment can occur. It is of paramount importance to initially cut a vent hole that allows gas escape and no accumulation to occur that creates the potential for an explosion.
Flash back	To prevent oxygen ignition propagating into the equipment causing damage and the potential for an explosion, flash arresters are incorporated into the system. These require to be periodically examined as part of a planned maintenance programme.
Hydrocarbon residue	Consideration should be given to the potential for hydrocarbon residues to be present, either within enclosed spaces or captured under structures or comingled within the seabed.
Pressure differential	Consideration should be given to the potential for a pressure differential when cutting into enclosed spaces, particularly on tubulars or pipelines.
Platform risers/ caissons	When conducting operations on platform substructures, consideration should be given to any potential for unconsumed oxygen to accumulate within riser/caissons and the management of this by the platform.
Protection	Although the oxy-arc process cuts through most materials, consideration should be given to protecting adjacent steelwork with appropriate material to prevent accidental contact with ignited rod or from molten slag.
Securing load	Consideration should be given to the potential for the cut section to drop and subsequently injure the diver or damage infrastructure.
Vent hole	An exit hole to allow unconsumed and waste gas to escape from the worksite locale. Particularly important when burning into enclosed spaces such as tubular members and steel sections. A vent hole needs to be higher than the planned cut position and capable of venting any build up of gas during the cutting process. During the risk assessment for this requirement, consideration should be given as to whether the initial cut should be performed utilising 'cold cutting' techniques or whether it would be acceptable to use the oxy-arc equipment due to the potential for an explosion occurring during cutting of the vent.

3.4 Management of Change

Each diving contractor should have in place a management of change (MOC) procedure which describes what actions need to be taken if there is a need to revise an existing approved design, fabrication or work/installation procedure and how to manage change associated with unplanned events that may arise during the offshore works. Normally a formal review of the change should take place to ensure that safety is not compromised.

When an offshore risk assessment is required senior personnel – typically the diving superintendent/ offshore manager, vessel master, diving supervisor, project engineer and client – should carry out this risk assessment. The contractor's management of change procedure needs to describe clearly the process to be followed, including the requirement for offshore and onshore reviews and risk assessments and who needs to give approval offshore and onshore both from the contractor and the client, for any revision or change.

An example of a management of change process is found in Appendix 1 (IMCA S&L 001 provides further guidance on management of change).

3.5 Failure Mode, Effect and Criticality Analysis (FMECA)

Failure mode, effect and criticality analysis (FMECA) on oxy-arc cutting has identified the following principal failure modes (PFM) (ref. HSE OTH 349).

i) Failure: Blowback — Cause: Spontaneous combustion of trapped oxygen;

ii) Failure: Blowback — Cause: Steam explosion;

iii) Failure: Loss of power — Cause: Poor electrical connection;

iv) Failure: Hose/umbilical breaks — Cause: Failure of couplings;

v) Failure: Failure to strike arc — Cause: Poor ground conditions.

4 Oxy-Arc Cutting Operations

4.1 Operational Considerations

Oxy-arc cutting requires the combined use of both electricity and oxygen, both of which require the need for appropriate control measures to be in place to ensure a safe place of work for the diver.

- **Electrical power supply**

  A number of considerations are required when using electricity within the subsea environment, not least the hazard to the diver from electric shock. IMCA D 045/IMCA R 015 – *Code of practice for the safe use of electricity under water* – provides guidance when using electricity under water:

  – All oxy-arc operations require a direct current (dc) generator capable of supplying at least 150 amps at the electrode (up to 400 amps when using steel tubular electrodes). Electrical protection provided by rubber gloves is a necessity for oxy-arc cutting operations as well as adherence to operational procedures;

  – Control of the electrical supply to the diver requires the integration of either a double pole manual knife switch or electrical circuit breaker (single pole and suitably rated at 600 amp minimum) in the lines, directly under the control of the diving supervisor. If a knife switch is used, then it needs to be insulated or shielded to protect the operator from arcing;

  – Electrical polarity – To ensure correct operation of the cutting torch the electrical supply from the dc generator is required to be connected correctly, ensuring the electrode (consumable rod) is negative and the earth connection positive;

  – Electrical grounding – Prior to commencing oxy-arc cutting the diver is required to connect the ground cable via a G clamp to the conductive, ferrous material to be cut, thus providing an electrical circuit through contact with the cutting rod. To limit the potential for electrical shock, the diver should not, at any time, position himself between the ground and the cutting rod to avoid becoming part of the electrical circuit.

- **Oxygen supply**

  A number of considerations are required when using oxygen within the subsea environment:

  – A large volume of oxygen is consumed when performing oxy-arc cutting operations. The oxygen should be delivered to the worksite via a subsea umbilical which incorporates both the electrical supply and ground cables together with a single diameter oxygen hose. Control of the oxygen supply delivery pressure is via an oxygen rated, high flow regulator capable of delivering 1.98 m^3/min (70 cfm) at a pressure rate of 6.21 bar (90 psi) above the pressure at the diving worksite due to the water depth;

  – Oxygen partial pressure increases in relation to the water depth and strict control of the diver's environment (diving bell) to prevent contamination of breathing mixtures is required to be in place. Oxygen venting from the oxy-arc burning operation should at no time compromise the diver's life support system;

  – Oxygen entrapment at the work site can have serious consequences as it creates the potential for an explosion. This explosive force is exacerbated proportionally as depth increases. Prior to any operations taking place, a full assessment needs to take place to ensure no gas pockets can build up, whether due to the structure configuration, voids or underneath steel plates resting on the seabed floor. See comments on vent holes above;

  – Oxygen and oils or grease should not be mixed, as hydrocarbons can ignite almost spontaneously in the presence of oxygen. All equipment should be cleaned to the required standard for oxygen service. Topside pressure testing of the oxygen hose should never be conducted utilising the vessel's compressed air system due to the possibility of hydrocarbon contamination from oil residue. IMCA D 031 – *Cleaning for oxygen service: Setting up facilities and procedures* – provides guidance on cleaning equipment to be used in oxygen service;

  – A flashback arrester and Monel screen should be incorporated within the cutting torch, to protect the diver and inhibit damage to the cutting torch through oxygen explosion. This should be checked as part of an ongoing maintenance programme to ensure no corrosion damage has occurred through electrolysis and no clogging has occurred to reduce oxygen flow;

  – A flashback arrester in combination with a pressure relief valve is required to be incorporated into the oxygen rated, high flow regulator on downstream (low pressure) side of the surface oxygen gas quad. Oxy-arc burning operations should not be conducted without these safety features incorporated;

– Oxygen purity for all underwater oxy-arc cutting should be 99.5% or greater to ensure cutting efficiency.

♦ **Utilisation**

The following should be considered regarding the operational use of the cutting torch:

– Oxy-arc cutting operations within the splash zone should be avoided, as the diver could become exposed to the air/water interface, and he would be at risk of severe electric shock if only partially immersed in water;

– The cutting operation should be halted when the cutting rod has been consumed to within 75mm of the cutting torch. The diver should release the trigger, halting oxygen flow to extinguish the cutting rod. Failure to halt operations may cause damage to the cutting torch, including electrolysis to the flashback arrester;

– A suitable cutting visor should be utilised to protect the diver's eyes during cutting operations;

– Surgical under-gloves can be utilised in addition to the primary rubber gloves to help prevent electric shock.

4.2 Equipment

Oxy-arc cutting equipment spreads may comprise the following major items as shown in Figure 7:

- welding generator capable of supplying a minimum of 150 amps;
- topside double pole knife switch for breaking circuit or circuit breakers;
- oxygen rated high flow regulator capable of supplying 70 cfm (1.98 m^3/min) of oxygen. A flashback arrester and pressure relief valve should be incorporated into the regulator on the downstream (low pressure) side;
- underwater burning umbilical typically consisting of:
  - oxygen supply hose of appropriate rating
  - electrical earth/ground cable c/w G clamp
  - electrical power cable
  - cutting torch.

In addition to these principal items of equipment, the diver should be provided with the following to perform the oxy-arc burning operation:

- consumable cutting rods;
- welding visor to attach to diving helmet;
- spare collets and washers for torch;
- rubber gloves;
- surgical under-gloves.

Note: Control of the electrical ignition source is from dive control with either a manual knife switch or electrical circuit breaker operated by the dive supervisor.

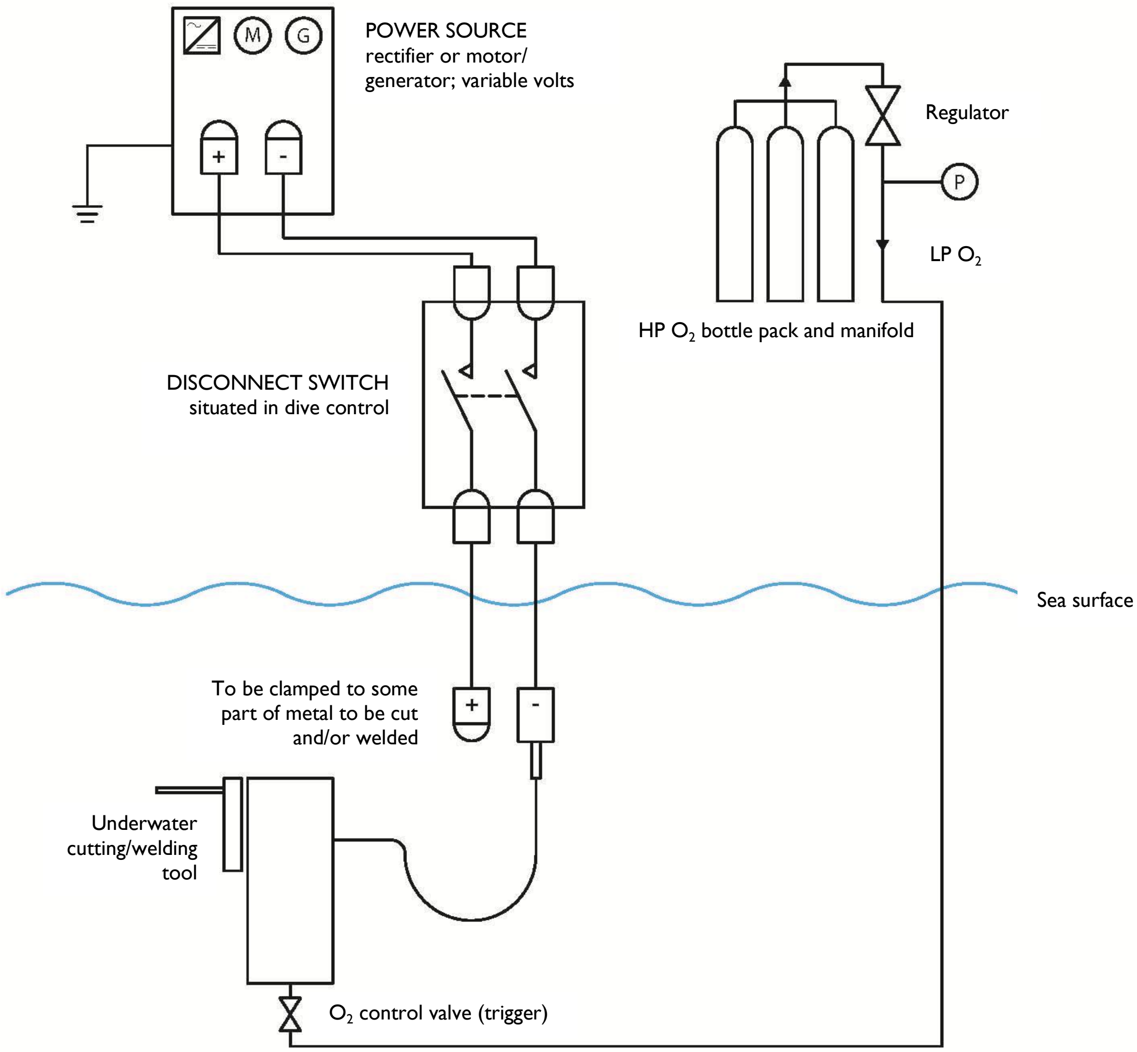


Figure 7 – Diagrammatic representation of standard oxy-arc set up

There are two main types of rod used in oxy-arc cutting – steel tubular electrodes and exothermic rods.

- **Steel tubular electrodes**

  Steel tubular electrodes have the following advantages:

  i) the cutting technique is simple and readily mastered;

  ii) metals up to 50 mm in thickness can be cut;

  iii) cutting is performed rapidly;

  iv) neat, trim, narrow cuts are produced;

  v) the power required is within the capacity of a 400 amp welding power supply.

  The disadvantages of the steel-tubular electrode are:

  i) the burning time of the electrode is short (approximately one minute);

  ii) it produces a narrow gap which may be difficult to locate in poor visibility conditions;

  iii) the higher amperage requirement deteriorates the electrode holder more rapidly than the exothermic process.

♦ **Exothermic (or ultrathermic rods)**

Exothermic electrodes have the following advantages:

i) the cutting technique is very simple and readily mastered;

ii) they will cut thin metal when the power is off;

iii) cutting is performed rapidly;

iv) they will cut all ferrous and most non-ferrous metals;

v) they are applicable to all metal thicknesses;

vi) they will burn through concrete, rock, coral, marine growth and other non-conductive materials when the power is off;

vii) the power required is within the capability of a 200 amp welding power source;

The following are disadvantages of exothermic electrodes:

i) a larger volume of oxygen is required than with steel-tubular electrodes;

ii) burning time of the electrode is short; 45 to 55 seconds;

iii) contact with the work is not required to sustain ignition, thus electrode waste can occur.

4.3 Settings and Consumption Rates

The consumption rate of oxygen is dependent on the depth of the worksite and the flow rate utilised to optimise the burning technique. The greater the volume of oxygen delivered to the cutting rod the faster it is consumed, with the optimum delivery pressure at the cutting rod of 6.21 bar (90 psi) above the working depth. Always use manufacturers' recommended guidance to establish settings and consumption rates (e.g. Broco Inc.'s Underwater Cutting Operating Instructions – see Table 1).

(Photograph reproduced with permission from Divex)

Oxygen Delivery Pressure Setting for Depth		
Depth		Pressure Gauge Setting
ft	m	psig
33	10	108
40	12	112
60	18	123
80	24	134
100	30	145
120	37	155
140	43	166
160	49	177
180	55	188
200	61	199
220	67	210
240	73	221
260	79	232
280	85	243

Note:

1. Calculate regulator gauge pressure setting as follows: For every 10 ft of hose required, add 1 psig to the 90 psig necessary at the tip. This compensates for friction line losses. Additionally, add 0.445 psig for every foot of working depth.

Setting Amperage for Cable Length and Size				
Length of Power Cable (supply to work distance)		Amperage Setting for Cable Size		
ft	m	#1/0	#2/0	#3/0
150	46	155	152	150
200	61	157	154	152
250	76	159	156	154
300	91	161	158	156
350	107	163	160	158
400	122	165	162	160
450	137	167	164	162
500	152	169	166	164

Note:

1. The increase in amperage compensate for resistance losses. For greater lead lengths, add 2 amp per 50 ft to settings.
2. #1/0 cable size = 50 mm^2
   #2/0 cable size = 70 mm^2
   #3/0 cable size = 90 mm^2

Table 1 – Example of a manufacturer's settings and consumption rates – Broco Inc. Underwater cutting operating instructions

4.4 Deployment

Unless the equipment is incorporated within diving related equipment on a permanent platform, such as on a diving support vessel, the oxy-arc cutting systems may be supplied to the vessel on a handling rack. Due to the weight of the electrical cables, the subsea umbilical may have D rings spliced at 15m intervals to allow the deck crew to support the weight of the umbilical. Depending on the depth/location of the worksite, this could be achieved by attaching with running shackles to a down line (positioned midwater) or chained to a deployment tugger wire and clump weight (at the seabed).

Sufficient cutting umbilical should be available to allow the diver to reach the worksite, without having to disconnect from the down line/tugger wire.

Care should be taken on the vessel to ensure that the oxy-arc cutting umbilical is not deployed over sharp edges that may result in damage or that the oxygen hose does not become crimped if a hold back rope is utilised to tie off the umbilical.

The oxy-arc cutting umbilical should be treated with the same level of respect as would be given to a diver's umbilical.

4.5 Operating Mode

Whether conducting oxy-arc cutting operations, an offshore (onsite) job risk assessment is to be conducted on the vessel prior to commencing the task.

4.5.1 Procedural Steps

The following steps have been identified and should be considered when developing the company's specific procedures for undertaking oxy-arc cutting operations:

- Project team to complete the offshore JSA and relay its findings to all relevant parties;
- Project deck crew to complete a surface preparation checklist (example in Appendix 2);
- Project diving team to complete a subsea preparation checklist (example in Appendix 3);
- Deploy divers/remotely operated vehicle (ROV) to locate and assess the worksite;
- Positively identify and mark the subsea component to be cut. Second diver or ROV to validate location;
- Diver/ROV to undertake an assessment of the worksite for the potential for gas entrapment, either within cavities or overhead. Pneumofathometer to be used to assess the location of gas discharge and direction of the plume relative to diving bell;
- Positively identify the position of any vent holes required and mark accordingly. Second diver or ROV to validate location and dive supervisor and client's representative to confirm agreement;
- Divers and supervisor to agree whether to cut vent holes with oxy-arc;
- If required, diver to secure the intended component to be cut to ensure that, once severed, no movement will have the potential to injure the diver or damage equipment or assets;
- Dive supervisor to confirm that dc power supply is isolated, prior to oxy-arc cutting equipment deployment;
- Dive supervisor to confirm that the oxygen supply is isolated at the regulator topside, prior to oxy-arc cutting equipment deployment. Note: the oxygen line should be left 'charged' to required pressure for working depth to inhibit water ingress into the hose;
- Deploy oxy-arc cutting equipment, D rings spliced onto the subsea umbilical should be utilised to support the weight, if possible. Depending on the depth/location of the worksite, the subsea umbilical can be supported with running shackles attached to a down line (midwater) or chained to a deployment tugger wire and clump weight for seabed operations;
- Ensure sufficient spare length is available to allow the diver enough slack in the cutting umbilical at the worksite;
- Diver to manoeuvre the cutting umbilical to worksite and secure sufficient length to conduct the cutting operations;
- Deck crew to secure oxy-arc umbilical on deck ensuring oxygen hose is not crimped;
- Diver to identify the ground cable, intended connection point and remove any paintwork/clean area to bare metal for G clamp connection. Ideally connect to redundant steelwork or component to be cut to ensure any potential for arcing does not damage existing assets;
- Diver/dive supervisor to confirm that ground connection position does not position the diver between the earth and the cutting torch to limit the potential for electric shock. Connect earth/ground G clamp;
- Install protection, if necessary, to avoid accidental damage during cutting operations;
- Install cutting guide, if necessary, to aid the cutting operations;
- Once the diver and the dive supervisor are in agreement that cutting operations can commence, deck crew to de-isolate the oxygen supply at the regulator and ensure the low pressure gauge reading is 6.21 bar (90 psi) above the diver's working depth pressure;
- Diver to insert cutting rod into torch, ensuring it is fully inserted and is bottomed out on the neoprene washer, prior to tightening cutting torch head;
- Diver to test flow oxygen through cutting torch. A visual indication of good flow is to hold the cutting torch horizontal and have a minimum gas jet length of 300 mm (12 in) emitting from the cutting rod;

- Diver to position himself, slightly offset and comfortable for the full range of the intended cut without any further movement required;
- Diver will request the electric power to be turned on, usually on the command 'make it hot', whilst fully flowing the oxygen supply and contacting the cutting rod on to the cut position, making the electrical circuit;
- On cutting rod ignition, diver to request the electric power to be turned off, usually on the command 'make it cold'. In the case of exothermic cutting, the rod will continue to burn as long as the oxygen supply is flowing;
- During oxy-arc cutting operations the second diver or ROV should be positioned to allow observation of the working diver during cutting operations;
- Proceed with cutting operation until cutting rod has been consumed, leaving a 75 mm (3 in) stub. Lift off and close oxygen supply allowing rod to extinguish;
- Tap cutting rod stub on to cut position as visual observation of no electrical power supply and remove cutting rod stub;
- Diver to check cut for any bridges across cut path. Hacksaw blade or 6 mm welding rod to be passed along cut path to confirm fully severed;
- Insert new cutting rod. Continue process until cutting operations is complete;
- On completion of the cutting operations the dive supervisor will request the deck crew to turn off the dc generator;
- On completion of the cutting operation the dive supervisor will request the deck crew to isolate the oxygen supply at the regulator and turned off at the supply quad;
- Recovery of the subsea umbilical is to be a reverse of deployment, with the deck crew recovering the equipment to the deck and the diver ensuring that the equipment is removed from the worksite and clear to the surface;
- Once the equipment is recovered, deck crew will vent down any residual pressurised oxygen in the umbilical.

4.5.2 Post Use Maintenance

- Disconnect cutting torch and install temporary cap on oxygen hose;
- Wash cutting torch with fresh water and allow to dry;
- Disassemble the torch head and inspect for any signs of corrosion, clogging or screen burn out. Replace items as necessary. Disassembly and reassembly should be as per the manufacturer's instructions;
- Always store the cutting torch and remaining rods in a dry, oil free environment when not in use.

Note: It should be reiterated that good preventative maintenance practices should ensure less operational downtime.

5 Troubleshooting

5.1 Electrical Supply

Generally the exothermic cutting rod requires approximately 150 amps at the cutting torch to ignite under the flow of oxygen. If using steel tubular electrode the amperage will be higher. The required amperage at source to perform the task is very dependent on cutting umbilical length. It is important to ensure the correct tools are available for the job.

The inability to create an arc strike when contact is made between the cutting rod and the worksite may be due to one or more of the following factors:

- Is the dc generator operating and umbilical connected?
- Is the amperage setting appropriate (utilise tong tester on output if available)?
- Is the polarity correct (negative to cutting torch)?
- Is the earth/ground connection clean and attached? This should be checked by the diver.

If necessary the diver can attach a test plate directly into the G clamp on the earth/ground and test the system.

When the polarity of a welding generator is uncertain (e.g. the terminals are unmarked or not legible), it will be necessary to determine the polarity before proceeding with cutting (or welding) operations. Personnel performing this test need to be properly insulated from the current.

The procedure for testing is as follows:

- With the power source dead, connect the ground and welding leads to the terminals;
- Attach a small plate to the ground cable and place a cutting rod in the cutting torch;
- Immerse the plate and tip of the cutting rod in a container of salt water and hold them about 50 mm (2 in) apart;
- The supervisor should energise the torch ('make it hot') and one of the following will occur:
  - a heavy stream of bubbles will rise from the cutting rod tip. This indicates straight polarity, that is: dc, electrode NEGATIVE (-)
  - if bubbles appear from the plate, switch off the current and change the lead connections to the opposite terminals. Repeat the test and label the machine terminals for future reference;
- Once the correct polarity is determined, the ground clamp should be bolted to the POSITIVE (+) lead and the cutting rod holder attached to the NEGATIVE (-) lead.

5.2 Oxygen Supply

Oxy-arc cutting relies on an unobstructed oxygen flow to be most effective. Providing ignition has occurred the root cause of any inefficiency will be due to either the oxygen supply or technique.

A visual indication of good flow is to hold the cutting torch horizontal and have a minimum gas jet of 300 mm (12 in) length emitting from the cutting rod, when fully depressing the torch handle.

If there is a problem with igniting the cutting rod, the following should be checked with regard to oxygen flow:

- Confirm the oxygen regulator is set to the correct pressure rating relative to the diver's working depth. The cutting process requires an optimum setting as per manufacturer's recommendations over the working depth to work efficiently;
- The deck crew should confirm the umbilical is not restricted/compressed at the over boarding sheave or any restraints utilised;
- The diver should remove the rod and confirm the flow rate stream coming from torch, to eliminate the possibility of a blocked rod from the diagnostics;
- The diver should remove the collet and washer and ensure they are in good condition and the washer is not restricting flow;

- The diver should examine the oxy-arc umbilical subsea to ensure no kinks or loops are restricting the oxygen flow rate;
- The ROV should inspect the oxy-arc umbilical for any damage that may result in leakage;
- On elimination of above, the dive supervisor should consider recovering the oxy-arc umbilical to deck to disassemble the torch head and inspect for any signs of corrosion, clogging or screen burn out and replace items as necessary. Disassembly and reassembly should be as per the manufacturer's instructions.

Diver using Oxylance AQUA EXO
(Photograph reproduced with permission from Brian Derby: EPIC Divers)

6 Equipment Certification and Planned and Periodic Maintenance

Guidance exists on the frequency and extent of inspection and testing required of all items of equipment used in a diving project, together with the levels of competence required of those carrying out the work. All of the equipment used in a diving operation will need to comply with at least these requirements. Suitable certificates (or copies) will need to be provided at the worksite for checking.

Diving equipment is used under offshore conditions, including frequent immersion in salt water. It therefore requires regular inspection, maintenance and testing to ensure it is fit for use, e.g. that it is not damaged or suffering from deterioration. Regular maintenance is an important factor in ensuring the safe operation of a diving system.

Diving contractors should give due consideration to recommendations given in manufacturers' maintenance manuals, amount of use, previous operational experience and guidance given in IMCA D 018 – *Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment* – contains the following detail sheets relevant to oxy-arc cutting equipment:

- Detail Sheet 9.1 – Seamless gas cylinder and pressure vessel not taken under water – dry internal service (Appendix 4);
- Detail Sheet 11 – Electrical equipment (Appendix 5);
- Detail Sheet 28 – Umbilical – hose component (Appendix 6).

By placing controls on the maintenance of oxy-arc cutting equipment, the contractor decreases risk to user in a proactive manner.

When cleaning oxy-arc cutting equipment, IMCA D 031 – *Cleaning for oxygen service: Setting up facilities and procedures* – provides guidance for the use of oxygen cleaning equipment.

7 Competence

Oxy-arc cutting requires a specific skill set. The dive supervisor should satisfy himself that the task of oxy-arc cutting is being conducted by suitably trained and competent personnel.

The person carrying out the task should also be confident in their ability prior to performing the task and refuse to perform the task if they are not confident to conduct the task safely.

It is the employing company's responsibility to ensure the selection of personnel for oxy-arc cutting is captured within the company specific competence scheme.

8 References

IMCA D 014 – *IMCA international code of practice for offshore diving*

IMCA D 018 – *Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment*

IMCA D 022 – *The Diving Supervisor's Manual*

IMCA D 031 – *Cleaning for oxygen service: Setting up facilities and procedures*

IMCA D 039 – *FMEA guide for diving systems*

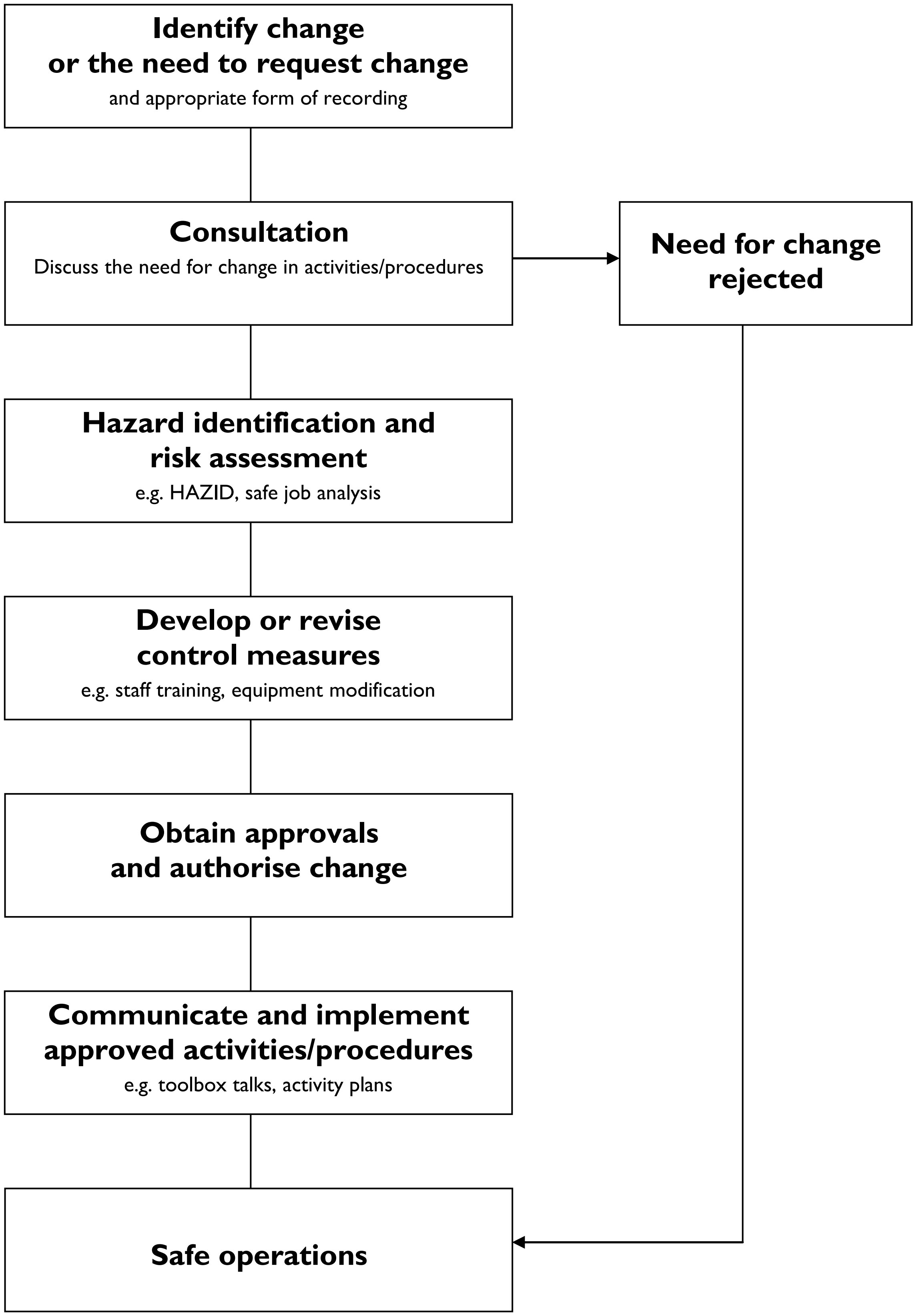
IMCA D 045/IMCA R 015 – *Code of practice for the safe use of electricity under water*

IMCA S&L 001 – *Guidance for the management of change in the offshore environment*

S0300-BB-MAN-010 – *US Navy underwater cutting and welding manual*

HSE OTH 349 – *Evaluation, selection and development of subsea cutting techniques*

Management of Operational Change Process



Surface Preparation Checklist

Item	Requirement	Yes	No	Comments
1	Dive supervisor to confirm he has reviewed the project risk assessment and completed an offshore job risk assessment (JRA).			
2	Dive supervisor to ensure client approval for oxy-arc burning is in place and the relative permits to work (PTW) are in place.			
3	Has the deployment area for the oxy-arc cutting system been assessed and clear of hydrocarbon residues and combustible materials in the event of an oxygen leak or electrical arcing?			
4	Is suitable fire fighting equipment available on deck and adjacent to the oxygen gas quad?			
5	Has a qualified fire watcher been designated to monitor the topside area during the oxy-arc cutting operations?			
6	Has the area been cordoned off suitably to prevent non-essential personnel from being within the vicinity?			
7	Has the oxy-arc umbilical, ground G clamp, oxygen hi-flow regulator and cutting torch been assembled and equipment confirmed as inspected and fit for purpose?			
8	Does the oxygen rated regulator incorporate a flash back arrester and pressure relief valve on its downstream, LP side?			
9	Has the dc generator been set at the correct amperage output and umbilical connected to ensure a negative supply to the cutting torch?			
10	Has the oxy-arc cutting system been function tested on deck? **Note: Hot work permit requirements.**			
11	Has the electrical supply been isolated prior to subsea deployment?			
12	Has the oxygen line been left charged at the correct pressure relative to the working depth and then isolated at the quad, prior to deployment?			
13	Has consideration been given to supporting the burning rig catenary on deployment?			
14	Have spare collets and washers been attached to the cutting torch?			
15	Are sufficient cutting rods of the correct dimensions prepared for the subsea operation?			
16	Have a cutting visor, surgical gloves and rubber coated hot water gloves been provided for the diver?			

Dive Supervisor Signature: ____________________

Date/Time: ____________________

Subsea Operation Checklist

Item	Requirement	Yes	No	Comments
1	Has the diver correctly identified and marked the correct location for the cutting operation and verification confirmed by the second diver or ROV?			
2	Has the diver/ROV fully assessed the worksite for the potential for gas entrapment, either within cavities, structural members or overhead, that would constitute a risk?			
3	Has the diver positively identified the position of any vent holes required and marked accordingly? Second diver or ROV to validate location and dive supervisor and client's representative to confirm agreement.			
4	Have the diver and the supervisor agreed whether to cut the vent holes with oxy-arc?			
5	Dive supervisor to consider diving bell position with regard to waste gas. Diver's pneumofathometer to be utilised to assess gas discharge and position of plume relative to diving bell.			
6	Has the diver assessed whether cut section requires to be supported by rigging prior to any severance to alleviate the potential for injury or damage?			
7	Has the diver identified a position for the earth/ground connection that does not place himself within the electrical circuit?			
8	Has the diver confirmed that the earth/ground connection is to a redundant piece of steelwork and has been cleaned to bare metal?			
9	Has the diver considered the requirement to utilise any protective material in vicinity of the cut that may prevent inadvertent contact?			
10	Has the diver positioned himself such that no molten slag or cut sections can land on himself or his life support umbilical?			
11	Are the divers conversant with the recommended commands with regard to cutting operations?			

Dive Supervisor Signature: ____________________

Date/Time: ____________________

IMCA D 018 – Detail Sheet 9.1

Seamless Gas Cylinders and Pressure Vessels not Taken Under Water – Dry Internal Service

NB *This includes both fixed and transportable gas storage cylinders and tubes and filter housings. It does not include welded pressure vessels or pressure vessels designed for human occupancy*

When new, when first installed or when moved

Note: *All of the "when in service" requirements must also be complied with before the equipment can be put in to service.*

Examination/Test	Category of Competent Person
Manufactured in accordance with a recognised international code or standard and fit for the purpose it will be used for	3 or 4

When in service

Examination/Test	Validity Period	Category of Competent Person
External visual examination	6 months	1, 2, 3 or 4
Thorough external visual examination and gas leak test to maximum working pressure	2½ years	3 or 4
Thorough internal and external visual examination and gas leak test to maximum working pressure. If the competent person deems it necessary, an overpressure test to 1.1 times the maximum working pressure may be required	5 years	3 or 4
Ultrasonic testing of gas cylinders may be performed as an alternative to the 5 yearly internal inspection providing the following prerequisites are met: ◆ Cylinder is within the 2½ yearly external visual inspection as detailed above ◆ Moisture readings taken upon filling and return of the cylinders demonstrate that levels within the cylinder have not exceeded 25ppm (-46°C at 1013mbar) whilst in service[1] ◆ The cylinder is connected to a residual pressure valve (RPV) whilst in service[2] ◆ Cylinder has not been used for compressed air storage due to inherent moisture	10 years	3 or 4

1 *If the moisture level is found to have exceeded 25ppm an internal visual examination in line with the 5 yearly examination will be required.*

2 *In the event that the RPV fails to retain pressure or has visible signs of tampering an internal visual examination in line with the 5 yearly examination will be required.*

References

1. ISO 6406:2005, Gas cylinders – Seamless steel gas cylinders – Periodic inspection and testing, International Standards Organisation, 2005.
2. AODC 010 – *Gas cylinders used in conjunction with diving operations in areas governed by UK regulations*

Notes:

- The ultrasonic testing system used must conform to the requirements of ISO 6406:2005 (section 11.4 – ultrasonic examination);
- In many countries there are detailed national regulations concerning gas cylinders, particularly if these are transportable. Such regulations must be complied with, even if they conflict with or are more onerous than the recommendations given above;
- Hydraulic testing of large storage tubes subject to dry internal service is not recommended as it introduces moisture in to the system which may prove difficult to remove. In such cases pneumatic or gas overpressure testing may be submitted;
- If testing is not hydraulic and the competent person requires it then other testing such as wall thickness measurement or acoustic emission testing may also be required;
- Some national regulations, certifying authorities or gas cylinder codes may give no option but to apply hydraulic overpressure testing;
- In all types of overpressure testing, suitable safety precautions must be taken to ensure the safety of all testing personnel and others.

It is recommended that a pressure leak test is carried out after hydraulic test in order to detect any possible leakage of the pillar valve stem seals prior to return to service.

IMCA D 018 – Detail Sheet 11

Electrical Equipment

When new, when first installed or when moved

Note: *All of the "when in service" requirements must also be complied with before the equipment can be put in to service.*

Examination/Test	Category of Competent Person
In accordance with manufacturer's specification and fit for the purpose it will be used for	3 or 4

When in service

Examination/Test	Validity Period	Category of Competent Person
Visual examination, function test of unit (including protective devices) plus continuity and resistance testing of any cables	6 months	2, 3 or 4

References:

- AODC 035 – *Code of practice for the safe use of electricity under water*

IMCA D 018 – Detail Sheet 28

Umbilicals – Hose Components only

including End Terminations and Fittings but excluding Electrical Components

NB This includes excursion, main bell, wet bell and surface dive umbilicals plus deck hoses and flexible whips

When new, when first installed or when moved

Note: *All of the "when in service" requirements must also be complied with before the equipment can be put in to service.*

Examination/Test	Category of Competent Person
In accordance with manufacturer's specification and fit for the purpose it will be used for	3 or 4
Hydro test at 1.5 times maximum rated working pressure or as recommended in manufacturing code or standard	3 or 4
Pressure leak test then verify internal cleanliness as appropriate to the intended duty	1, 2, 3 or 4

When in service

Examination/Test	Validity Period	Category of Competent Person
Visual examination and function test	6 months	1, 2, 3 or 4
Pressure leak test to maximum rated working pressure	2 years	1, 2, 3 or 4

Notes:

- If excursion, surface dive or gas supply umbilicals are stored for more than six months they should be flushed prior to being re-used.
- In the case of hoses which are likely to be subjected to external pressure (for example gas recovery hoses) then the above internal pressure tests are adequate to test the integrity of end fittings provided the hose was originally designed and type tested to withstand external pressure.