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# Performance of diving equipment

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# RESEARCH REPORT 424

# Performance of diving equipment

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The objectives of the study were:

To examine and test as much as possible of the equipment implicated in accidents / incidents from all sectors of diving, and so increase the HSE knowledge base on diving equipment and the reasons for its failure.

To establish clear guidelines and procedures to be followed when an incident occurs in order to preserve the equipment in its "as failed" state until examined.

To provide reports to OSD on equipment performance and failure modes, for possible feedback to manufacturers, users and Standards bodies.

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**HSE** BOOKS

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# EXECUTIVE SUMMARY


**Objectives**

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2. To establish clear guidelines and procedures to be followed when an incident occurs in order to preserve the equipment in its "as failed" state until examined.
3. To provide reports to OSD on equipment performance and failure modes, for possible feedback to manufacturers, users and Standards bodies.

**Main findings**

A total of 54 incidents were referred to HSL for investigation by a range of enforcement authorities. Ten involved non-fatal occurrences, while the remainder were associated with a total of 46 fatalities. In half of the incidents studied, we have been able to establish with some confidence whether the equipment in use was likely to have been a causative factor; around a quarter were probably directly attributable to equipment faults. In the remaining incidents, information to assist with the enquiries of the relevant authorities has been generated and provided. This information has contributed significantly to the subjective findings of inquests and fatal accident enquiries.

Incidents were analysed for recurring themes related to events, depths, main causes and likely contributing factors. Almost half the regulators tested did not meet the performance requirements of the European standard for diving equipment (EN 250) through lack of maintenance, servicing and cleaning, incorrect set-up, and possible effects of mix and match of component parts. Dive planning and practice were frequently implicated, with bad practice, unsafe behaviour or human error frequently playing a significant part.

**Recommendations**

Non-HSE enforcing authorities currently believe examination and testing of diving equipment to be unaffordable. As a result, important information for inquests and enquiries, and on the performance of diving equipment, may be being missed. A parallel system to that which operates for investigation of road accidents, where funding is provided to allow provision of expert evaluation, should be set up to cover investigation of non-HSE-enforced diving incidents.

EN 250 allows first and second stages to be tested and certified in isolation. The possibility exists for mis-matching of these components when combined after-market, possibly with abnormal lengths or bores of connecting hose, elbows and swivels. The performance of assemblies under conditions of simultaneous main and octopus regulator use, supplied by the same first stage is not directly addressed in EN 250. Information on the significance of these effects is required, either to justify introduction of changes to EN 250, or to provide manufacturers, users and training agencies with information on suitable configurations of equipment.

EN 250 only tests the performance of equipment to a depth of 50m. Twenty percent of incidents studied here involved depths greater than 50m, some by a considerable margin. Action is needed to ensure that users understand that performance of EN 250 equipment deeper than 50m cannot be guaranteed. The value and reliability of simple after-service bench tests of regulators should also be established.

Breathing gas moisture levels produced by compressors require tighter means of control, or the standard requirements must be reviewed to reflect what is adequately safe and achievable.

The findings of this project should be communicated to training agencies and diving organisations, highlighting the following aspects:

- The apparently common practice of divers to undertake dives right up to the recognised limits of safety, or of their formal training and experience, should be actively discouraged. Promote through the training agencies a safe dive programme giving up to date guidance on decompression theory, and the limits pertaining to age, fitness, water temperature, and dehydration.

- The emergency procedures to adopt in the case of negative buoyancy at the surface need to be emphasised more strongly, early on in the formal syllabus, and practiced.

- The emergency procedures to adopt in the case of inversion and positive buoyancy when using a drysuit need to be included in the formal syllabus and emphasised.

- To start the dive with correct amount of appropriate gas for the dive. Including carrying the correct reserve amount as planned for the dive. Further emphasis should be placed on the "Plan the dive, dive the plan" throughout diver training

- The limitations on performance of regulators beyond the 50m maximum depth limit of EN 250 certification, needs to be clarified and communicated to divers.

- The need for regular servicing and maintenance of equipment, by people who are qualified, and licensed to the required proficiency.

# 1 INTRODUCTION

## 1.1 PROJECT OBJECTIVES

While fatal incidents in the commercial diving sector (where Offshore Division (OSD) of HSE enforce) are generally low (2-3 per year), there are annually more than about 20 fatal diving incidents in the UK, either at work where Local Authorities are the enforcement agency, or in the leisure sector where the Police take the lead. Because of this division of enforcement responsibilities for the different sectors, there has been no consistency in the type, methods, or quality of investigations conducted after a diving incident has occurred. Much of the diving equipment used is common to all these sectors. OSD wished to increase their knowledge base on equipment reliability, failure modes and adherence to standards, by having all equipment involved in diving incidents in the UK examined and reported to a constant level.

The principal objectives of the study were:

1. To examine and test as much as possible of the equipment implicated in accidents / incidents from all sectors of diving, and so increase the HSE knowledge base on diving equipment and the reasons for its failure.
2. To establish clear guidelines and procedures to be followed when an incident occurs in order to preserve the equipment in its “as failed” state until examined.
3. To provide reports to OSD on equipment performance and failure modes, for possible feedback to manufacturers, users and standards bodies.

The project began in Summer 1999, with the purchase of the necessary technical test equipment for diving equipment, and commissioning in time to accept equipment for testing in Spring 2000. It continued until September 2003, effectively lasting for three “diving seasons”. (In the event, there was little variation in the rate at which incidents were reported throughout the year.)

## 1.2 PROCEDURE FOR REPORTING INCIDENTS

During the first phase of the work, while the test equipment was being sourced, built and commissioned, a procedure for requesting investigation of diving-related incidents was developed, and promotional material including a request form, was produced (see Annex 2).

Several hundred copies of this form were distributed to the relevant authorities by direct mailing, and issue at relevant meetings / conferences.

In a few cases, incidents which pre-dated this study were included with the agreement of the customer, to assist in resolving areas of uncertainty.

## 1.3 TEST METHODS USED

### 1.3.1 Visual inspection

A vital part of the process for examining and testing of equipment received under this project was a thorough visual inspection of its as-received state. The condition and configuration of the equipment, valve settings, gauge readings, maximum depth indications, connections, dive slate markings and the like were all taken into consideration. Included in the visual inspection was examination of incident descriptions from witness statements and police reports, and where relevant, reports of equipment examinations carried out by other investigators.

### 1.3.2 Gas tests

Contents of gas cylinders, where required, were routinely measured for composition using the following techniques:

| | |
|---|---|
| Oxygen | paramagnetic dipole analyser |
| Carbon Dioxide | infra-red absorption |
| Carbon Monoxide | infra-red absorption or electrochemical cell |
| Oil mist | chemical absorption tube |
| Moisture content | chemical absorption tube, dew point meter or capacitance analyser |
| Helium | thermal conductivity |

Where testing for additional components was required (e.g. suspected organic contaminants) air samples were analysed by gas chromatography, mass spectrometry or infra-red absorption.

The required quality of compressed air for breathing purposes is specified in EN 12021. This stipulates that compressed air for filling of cylinders at 200 bar or above should meet the following requirements for composition (by volume):

| | |
|---|---|
| Oxygen | $21 \pm 1\%$ |
| Carbon dioxide | <500 ppm |
| Carbon monoxide | <15 ppm |
| Lubricants | <0.5 mg $m^{-3}$ |
| Odour and taste | None detectable |
| Water content | <25 mg $m^{-3}$ (dew point less than –51°C at 1 bar) |
| Other contaminants | None present at >10% of the relevant 8h TWA OEL |

While nitrox or trimix blends may have other oxygen concentrations than specified above, levels of the potentially harmful contaminants should remain within the above specification.

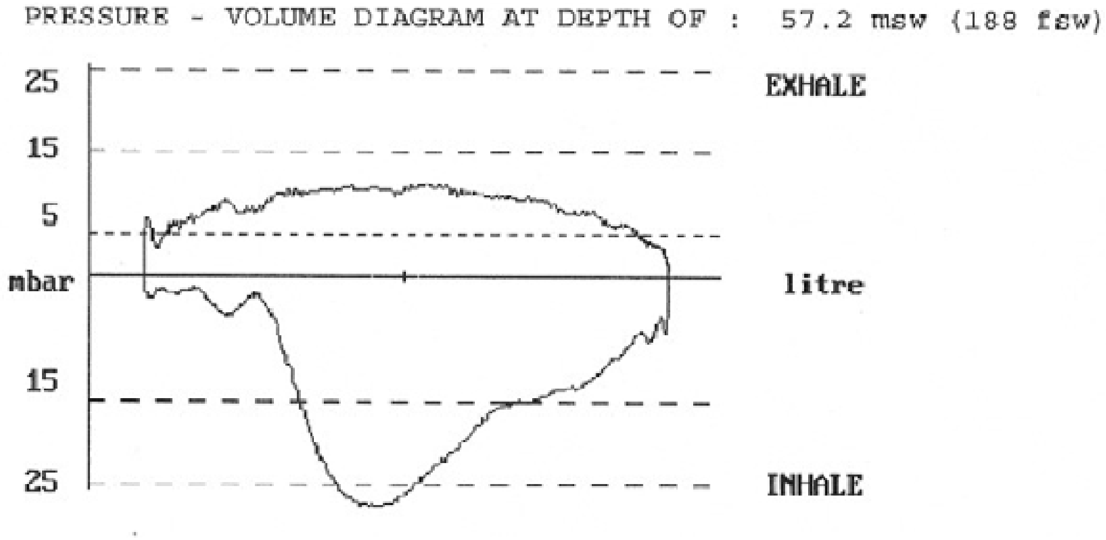
### 1.3.3 EN 250 performance tests

In addition to design and mechanical strength requirements for the complete equipment, performance tests of SCUBA regulators are specified in EN 250. For the purposes of certification, the breathing resistance of the air supply system must be within defined limits for inhalation and exhalation pressures and overall work of breathing, when tested at a breathing rate of 62.5 l $min^{-1}$, submerged in water at a pressure of 6 bar absolute (equivalent to a depth of 50m). These limits are:

| | |
|---|---|
| Work of breathing - | <3.0 J $l^{-1}$ |
| Peak respiratory pressure - | $\pm$25 mbar (inhalation or exhalation) |
| Inhalation work of breathing - | <0.3 J $l^{-1}$ |
| Pressure spikes with no measurable positive work of breathing - | <10 mbar |
| Pressure spikes with measurable positive work of breathing - | <5 mbar |

The important factors of this type of test may be derived from a pressure-volume diagram such as that shown in Figure 1, where the inner set of dashed lines shown at +/- 15 mbar is the Preferred Limits and would be considered comfortable to breathe. The outer set of dashed lines shown at +/- 25 mbar is the Maximum Acceptable Limit above which the diver would find it extremely difficult to breathe. The area bounded by the P-V diagram is also proportional to work of breathing and is a further important measure of how easy or difficult the demand regulator is to breathe from. In this example, the regulator exceeds the 25 mbar limit during inhalation.

**Figure 1. Pressure – volume diagram describing regulator performance**




The equipment necessary to carry out these performance tests is manufactured by ANSTI Test Systems Ltd (Fareham, Hampshire), and generates pressure-volume plots as shown in Figure 1. The test machine is in fact much more versatile than these basic tests require, being adjustable in terms of the breathing rate (to simulate differing work rates), water temperature (regulators are rated for warm or cold water use), ambient test pressure (from surface to the equivalent of ~90m depth) and supply pressure (from 300 bar to zero). Using the ANSTI machine, the various known parameters under which diving incidents had occurred could be recreated in the laboratory, to see if the SCUBA equipment performed normally.

Typically, testing of regulator function took place by attaching it to the ANSTI machine and assessing its performance at a range of simulated ambient pressures (depths) from the surface to the incident depth where this was known. Usually, if the incident depth was less than the EN 250 test depth of 50m, testing was continued to this level to assess conformance of the equipment with the standard. The process would be repeated for a range of breathing rates and air supply pressures from 200 bar downwards, to investigate the effects of depleting cylinder pressures, and work rates in use.

### 1.3.4 Valve function tests

In addition to the valves and regulators directly supplying the breathing function of SCUBA equipment, there are other important valves associated with the control of buoyancy. These are the inflation, deflation and automatic dump valves incorporated into buoyancy control devices (BCDs) and drysuits. Where possible, examination and testing of the function of these valves and connectors was carried out. Of particular importance here is the ability of the valves to open and shut off cleanly when required, and to pass the necessary volume flow rates of air.

### 1.3.5 Dive computer interrogation

Where provided, dive computers worn during incident dives were examined and interrogated. In many instances, interrogation required dedicated computer interfaces to communicate with the dive computers, and to download stored information on dive profiles and other relevant data. Manufacturers of dive computers were approached to obtain these interfaces, and almost invariably provided them to us free of charge, once initial suspicion of our motives had been overcome.

Dive computers were generally of one of two levels of sophistication.

***Dive timers –*** These record basic information of the date, time, duration, maximum depth, water temperature, and any alarm conditions (e.g. ascent too fast).

***Dive computers –*** These record all the above information, plus the full depth / time profile of each dive, up to the limit of the computer memory (typically 37 dives). Alarm conditions can be tied to distinct points in the dive profile.

Both forms can be used to plan dives for depth and duration, and any necessary decompression stops. If followed, these computed dive plans would invariably be safe. If during a dive the plan is not followed, the computer automatically compensates and adjusts the timings and alarms to maintain safety.

Information from dive computers was of particular relevance in correlating with witness statements, interpreting the course of events during an incident dive, and in recreating the prevailing conditions of an incident using the ANSTI machine. In a few cases, errors of programming of the computer may also have been contributing factors towards causing the incident.

### 1.4 INDIVIDUAL INCIDENT SUMMARIES

Annex 1 of this report contains brief summary descriptions of the incidents investigated that enabled the authors to come to the main conclusions of the report. These descriptions have been anonymised. For each incident, full individual letter reports were produced for the organisation originating the request for the work. These contained much more in the way of detail and technical results and discussion than is given in this final report. If individual cases are of interest, we retain separate sub-files on each study, and can provide more specific information on request.

Individual letter reports varied in length from two pages for a simple gas analysis, to 20+ pages of technical description, test results, photographs and discussion for the more complex cases involving testing of several sets of equipment.

Any opinions expressed in these summaries on possible contributing factors to the incidents are those of the authors, based on technical judgement alone, and may or may not concur with the final outcomes of any prosecutions, inquests, or fatal accident enquiries. Outcomes of such legal proceedings have not been included, and are outside the technical scope of the project.

Where reports were provided direct to Coroners, Procurators Fiscal or Police (as in the great majority of the investigations undertaken in this project), these were often required to contain higher levels of explanation and interpretation than necessary for HSE technical experts.

# 2 ANALYSIS OF FINDINGS AND DISCUSSION

## 2.1 ORIGINATING ORGANISATIONS

Requests for investigation of diving-related incident material originated from four basic source types, as detailed in Table 1.

**Table 1. Investigation request originating bodies**

| **Originating organisation** | **Number of requests** |
|---|---|
| HSE | 12 |
| Police / Coroner / Procurator Fiscal | 37 |
| Environmental Health / Local Authority | 3 |
| Other (Solicitor; Icelandic Coastguard) | 2 |
| **Total** | **54** |

## 2.2 BREAKDOWN OF TYPES OF REPORTED INCIDENT

Of the 54 incidents referred to HSL for investigation, ten involved non-fatal occurrences, while the remainder were associated with a total of 46 fatalities. In several cases, the deceased and/or their equipment have not been recovered, so our investigations centred on equipment used by their diving partners, or spare cylinders which may have been filled at the same time as those in use on the fatal dive.

There were a number of recurring themes to the reported incidents, as detailed in Table 2.

**Table 2. Recurring themes in reported incidents**

| **Theme** | **Number of instances** |
|---|---|
| Lone diver, or became separated from buddy | 14 |
| Failed to surface | 10 |
| Observed in difficulty, and blacked out beneath water | 8 |
| Rapid uncontrolled ascent | 7 (including 2 with inversion) |
| Suspected bad fill of air | 5 |
| Free flow from second stage | 4 |
| Trainee diver – panic / inexperience | 6 |
| Unable to establish buoyancy at the surface | 5 |

In the above, “became separated from buddy” refers to the divers losing contact at or prior to the onset of any problems. The heading “failed to surface” almost invariably refers to instances where the diver was alone at the time, or had become separated from their companion(s). The exception here is one case (see annex 1 cases 9 and 18) where neither of a pair of divers returned from a dive. In these cases, there is no further information available on which to classify the type of problem, which the diver(s) may have experienced.

A significant number (12) of the incidents involve loss of control of buoyancy, either positive or negative, with fatal consequences. In instances where positive buoyancy could not be established at the surface, it is interesting to note that no attempts were apparently made to dump weights.

### 2.3 BREAKDOWN OF INVESTIGATIONS UNDERTAKEN

#### 2.3.1 Diving equipment involved

The types and quantities of equipment examined and / or tested under this project are summarised in Table 3. Numbers do not tally exactly with the number of reported incidents because in some cases several sets of equipment were sent for examination, while in others either equipment was not recovered or a full examination was not requested.

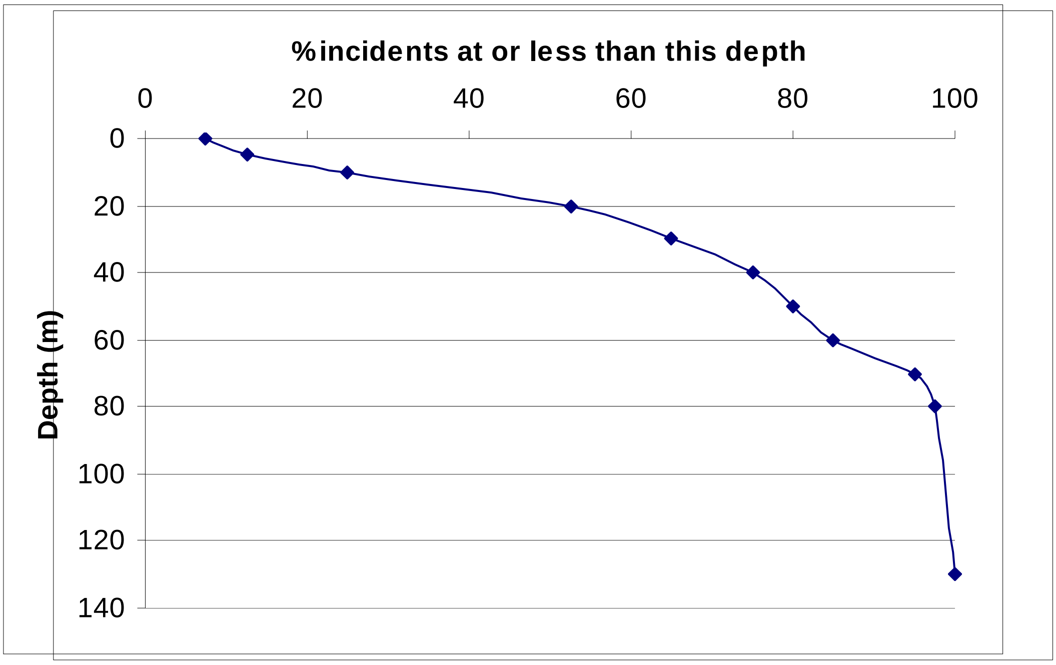
**Table 3. Breakdown of the examinations / tests conducted**

| **Component / equipment** | **Number of examinations / tests** | |
|---|---|---|
| Sets of diving equipment received | 45 (sets include one or more of the following) | |
| | - open circuit air | 35 |
| | - open circuit Nitrox | 15 |
| | - open circuit Trimix | 4 |
| | - Rebreathers | 7 |
| Regulator sets tested | 50 | |
| BCDs examined | 34 | |
| Gas analyses | 65 | |
| Dive computers examined / downloaded | 52 (from 28 incidents) | |
| Incidents with witness statements / reports to be examined | 40 | |

#### 2.3.2 Incident depths

The range and distribution of depths at which the various incidents occurred (where known) was from 0m (surface) to 130m, distributed as shown in Figure 2.

**Figure 2. Incident depth distribution**



Incidents appear to be relatively evenly distributed over the range 0 to 80m, with a single outlier at 130m. Twenty one percent of incidents involved depths greater than 50m, the maximum depth to which EN 250 specifies equipment performance. All but one of these (case 12) were fatalities.

## 2.4 CAUSATIVE FACTORS

### 2.4.1 Identified causes of reported incidents

In only 14 of the cases studied have we confidently identified the probable cause of the reported incident as resulting from equipment faults. Three of these refer to confirmation that suspected “bad fills” of air did in fact have noticeable odour, taste or contamination. The remaining eleven cases are summarised in Table 4.

In several cases, these events on their own need not have led to fatalities, had training and standard emergency procedures been followed. Predominant in this area is the need to maintain close contact with a buddy diver for just these types of emergency, and not to dive alone. However, in the two cases (5 and 11) where a buddy diver was close by and offered assistance, this was not accepted.

The added complication of manifolded twin cylinder sets is apparent here, with two instances where the isolating valve on the manifold was incorrectly set – in one case (11) it was insufficiently open to allow pressure equalisation between the cylinders; in the other case (45) the isolating valve was completely closed. Normal practice would be to dive with this valve sufficiently open to allow rapid equalisation between the cylinders, but able to be closed quickly in the event of a loss of air from one side of the twin cylinder arrangement.

Inability to establish buoyancy at the surface (cases 29 and 38) reflects the inexperience of the divers, students under instruction. While the BCDs were inoperable in these cases, alternative means of gaining buoyancy (drysuit inflation, ditching weights) were not attempted.

### 2.4.2 Probable contributing factors to reported incidents

More tentative identification of factors that were likely to have contributed to individual incidents, or to increase the severity of the consequences, were identified in most cases. Again, these fall under a number of broad headings.

***Out of air*** – In six separate incidents, divers ran out of air and got into difficulties. In two cases, this is explainable by the fact that contents gauges attached to their equipment over-read significantly (by 70 bar in each case). Failure to establish buoyancy at the surface, owing to lack of air with which to inflate the BCD or drysuit, resulted on two occasions.

***Oxygen toxicity*** - Acute central nervous system oxygen toxicity was likely to have been a significant contributory factor in seven separate incidents. Several of these are only marginally above the recommended limits for oxygen partial pressure exposure, reflecting a tendency of some divers to push right up to the boundaries of safety, leaving no margin for error. Others are significantly excessive; apparent failure of the main breathing gas supply, forcing the diver to breathe from an enriched air nitrox mix at an inappropriate depth (cases 31 and 42).

**Table 4. Identified causes of incidents**

| Annex 1 paragraph describing incident | Reported event | Identified cause |
|---|---|---|
| 2 | Failed to surface from 16m | Regulators fail at 16m. Gauge error predisposes to running out of air unexpectedly. Had become separated from party. |
| 4 | Failed to surface from 10m | Regulators on limit of acceptable performance at 10m. BCD not functional or connected. Lone diver. |
| 5 | Free flow from main regulator at 35m, attempted to use spare regulator, panicked and bolted to surface. | Reported free flow could not be reproduced. Spare regulator did not work below 25m. Octopus would have worked. |
| 6 | Valve ignition during nitrox filling | Contamination of valve / whips owing to bad filling practice. |
| 11 | Observed in difficulty at 63m, refused assistance and was lost in stirred-up sediment. | Regulator fails at 64m with air. Twin cylinder manifold valve setting suspect (inadequately open). |
| 13 | Sheared off valve fittings | Inappropriate brass alloy used, with damage to nickel-plating at thread roots. |
| 29 | Student encountered difficulty at the surface and could not maintain positive buoyancy. | Second stage regulator damaged, allowing water ingress. BCD inflator controls broken and ineffective. |
| 38 | Student on a night dive could not maintain positive buoyancy at the surface. | BCD inflator hose not connected. |
| 42 | Free flow at 40m, sank. | Regulator went into free flow at 40m. Possible attempt to breathe from 60% nitrox pony, leading to oxygen toxicity and blackout. |
| 45 | Difficulty encountered at the start of ascent from 44m. Sank. | Twin cylinders isolated by closed manifold valve – gauge attached to unused full cylinder so no indication of contents in the other cylinder. On running out of air, switched to second regulator that could not supply below 25m. |
| 49 | Became entangled and failed to surface from 16m. | Regulator condition so poor through corrosion and lack of maintenance as to be untestable. Blunt dive knife. Lone diver. |

***Nitrogen narcosis*** – This is likely to have been a contributing factor in at least five cases. Individual susceptibility to nitrogen narcosis is believed to vary with time and acclimatisation. In two of the cases considered here (cases 44 and 52), the incident dive was very much the deepest dive recorded in the previous few months.

Even in mild cases, nitrogen narcosis reduces vigilance, judgement, reasoning and dexterity, and may predispose the sufferer towards idea fixation or panic. These effects may help to explain some of the reported behaviours at depth.

***Diving with known faulty equipment*** – There were at least two cases of divers knowingly entering the water with faulty or malfunctioning equipment (cases 24 and 32), which subsequently contributed to their downfall. Other instances where equipment must have been known to be non-functional are dealt with in 2.4.3.

***Uncontrolled positive buoyancy with inversion*** – Two drysuit wearers became uncontrollably buoyant when the legs of their drysuits inflated. Drysuits typically have air dump valves on the arm or upper body. If the legs of the suit inflate and rise, these valves cannot dump air to regain control of buoyancy. Control can only be regained if the legs are physically lowered, or are punctured to release the trapped air. In both these cases, the divers and their buddies expended considerable effort in trying to lower the legs, and did not consider puncturing the suit despite the seriousness of the situation; perhaps a manifestation of the effects of nitrogen narcosis noted above? This eventuality is not addressed in training courses provided by the main agencies.

In neither of these cases was the diver apparently wearing a weight belt. The constricting effect of such a belt may have helped prevent the migration of air inside the drysuit into the leg region.

***External interferences*** – Deliberately attached objects or accidental entanglement played a part in at least three incidents.

- Collected items (scallops) added to the diver's weight in one case (28) where surface buoyancy could not be established, until they were cut away by the diver's buddy.
- A lone diver became entangled at depth and was unable to free himself (case 49).
- Two divers became entangled in the line attached to a marker buoy as it was being deployed from depth at the third attempt (case 52), despite one of them being very low on air, and were dragged rapidly to the surface; possible idea fixation due to nitrogen narcosis?

In a further two cases (9 and 31) it is suspected that entrapment inside wrecks, prompting the diver to remove equipment to try to escape, was involved.

Finally under this heading is one instance (case 48) where during regulator exchanging confusion resulting from another diver's emergency situation, one of two buddy divers mistook his own snorkel mouthpiece for a second stage regulator mouthpiece while at depth.

***Simultaneous main/octopus breathing*** – Of concern are five instances where during or following attempted dual breathing from the same first stage in emergency situations, one diver (usually the one originally in distress) subsequently collapsed or lost consciousness (cases 26, 28, 42, 48 and 54). While the underlying cause of these collapses may be independent of the equipment, this could imply that an inadequate air supply was provided under these conditions of demand. None of the equipment involved exhibited problems when tested according to the requirements of EN 250, but dual breathing is outside the scope of this standard.

### 2.4.3 Detected faults not directly related to the incidents

Incidental findings of the various investigations are significant, even if these factors had no direct bearing on the incidents in question. These provide an insight into the typical levels of equipment condition, maintenance and performance in diving in the UK.

***Cylinder test status*** – Eleven of the 95 cylinders examined during the course of these investigations were found to be out of test date at the time of the incident, according to the prevailing regulations. (Note that the required examination / test frequency has recently changed from 2 years to 2.5 years.) In several other instances, markings denoting past history of examination / test are incomplete; there are apparent gaps in the record.

Two of the expired cylinders were emergency inflation bottles attached to BCDs in separate incidents (cases 3 and 4). These were empty at the time of the incidents, perhaps because they could not be filled owing to expiry of their test date. In one case, had the equipment been functional, a fatality may have been avoided.

In another instance, not only was the cylinder date expired, but it was found to contain air at a pressure slightly exceeding its 232 bar rating.

***Cylinder marking*** – This relates to test / examination marks, oxygen cleaning records, and to temporary marking of cylinder contents for nitrox composition.

- Some of the date formats for test / examination marking do not appear to be to the BS standards in force at the time of the test. Digits denoting year and month appear to be transposed in different examples, leading to possible confusion, potentially for the years from 2001 up to 2012. There is also a suggestion in one case (54) that the date of expiry of test / examination was marked (for oxygen clean status) on a label attached to the cylinder, and not the date on which the test was carried out (i.e. 10 months after the date of the incident).
- Labels and markings denoting the date of oxygen cleaning were frequently found to be damaged or illegible.
- Marking of contents on nitrox cylinders was often incomplete, or confusingly duplicated. In some instances, there was a dedicated label for this purpose which had been completed to indicate one mix, but there was a different mix marked separately elsewhere on the cylinder.

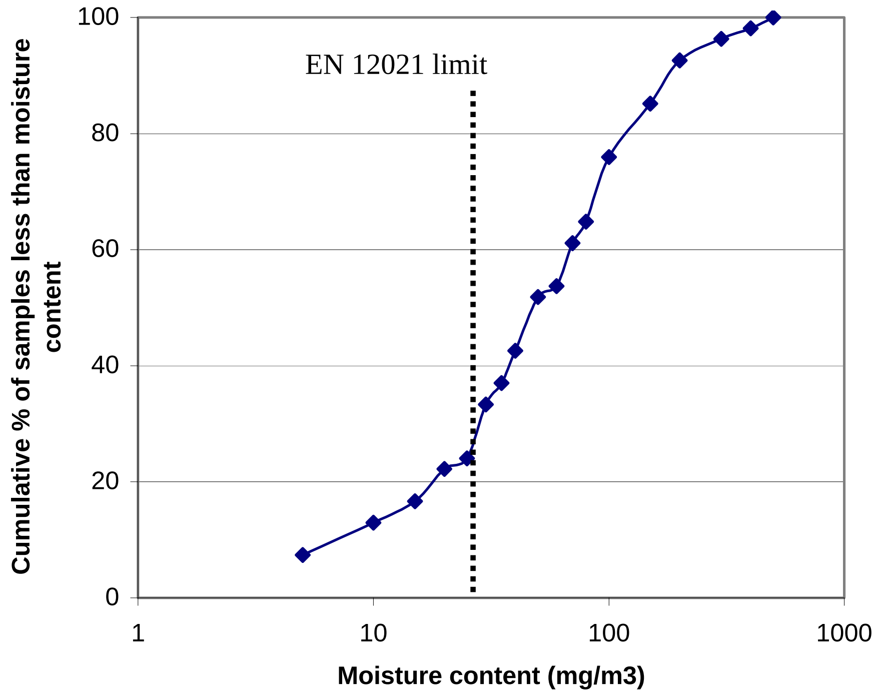
***Cylinder filling practice*** – In several instances, cylinders designated and marked as oxygen clean for nitrox use were found to be filled with air. Connecting such a cylinder to a compressed air filling system would invalidate the “oxygen clean” status of the equipment, potentially leading to an ignition if subsequently exposed to high pressure oxygen. The consequences are likely to be similar to the incident reported case 6 in Annex 1.

Considering the findings on cylinder test status above, whoever filled the expired cylinders was not adhering to the requirement to check their test status before filling.

***Moisture content of compressed air*** – In the 54 cases where the moisture content of air was measured, 41 were found to exceed the limit specified in EN 12021. For filling of cylinders, the moisture content of air should not exceed 25 $mg/m^3$ (equivalent to a dew point measured at atmospheric pressure of -51$^{o}$C). The distribution of measured moisture contents is shown in Figure 3. In practice, it appears that more than ¾ of the air samples tested do not comply with this Standard.

These moisture limits are primarily intended to prevent condensation, corrosion and damage to pressurised storage cylinders, and condensation and freezing in regulators owing to cooling from release of pressure. For the highest moisture content measured here (430 $mg/m^3$), condensation of moisture should not occur at temperatures above –26°C at atmospheric pressure. However, for the same air at a typical cylinder pressure of 200 bar, condensed moisture will be present in the cylinder at the observed water temperatures; condensation will also be present in the medium pressure parts of the system (typically 9 bar) if the temperature of any surface falls below approximately -2 °C. Temperatures close to this latter value can easily be achieved during use, particularly if the equipment is submerged in relatively cold water. The total quantity of water involved is small – in this worst case a total mass of just over 1g, if all the moisture in a full cylinder was condensed out.

**Figure 3. Measured moisture content of air in cylinders up to 200 bar**

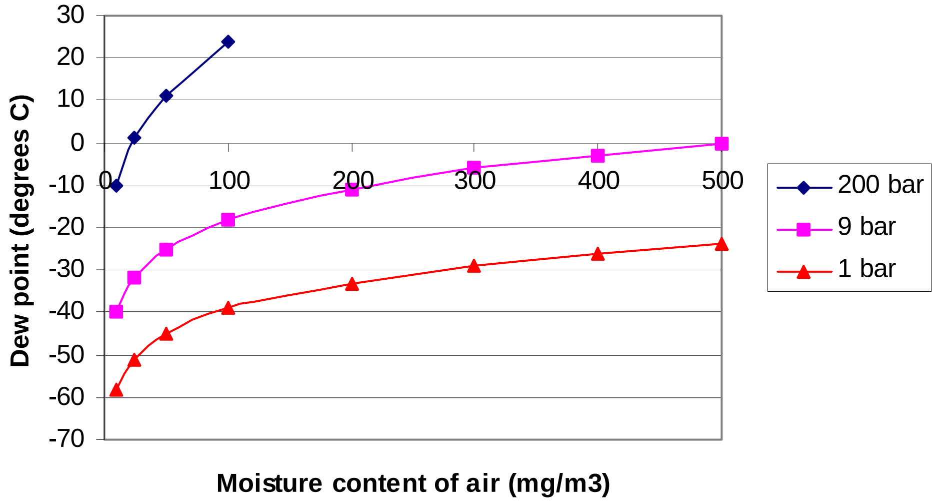



Owing to the moisture content of the air and the prevailing temperatures, approximately 60% of diving cylinders tested would probably have had small quantities of condensed water inside at the time of the incidents. A few may also have been sufficiently wet to allow condensation and freezing in the medium pressure parts of the air supply system (see Figure 4). However, there is no clear link to the reported incidents, other than detection of odour in the wetter samples.

***Regulator performance*** – Out of a total of 60 regulators (first and second stage combinations) tested in the course of this project, 26 failed to meet the performance requirements of EN 250, as described at 1.3.3 above. For two others, while they performed according to the breathing resistance requirements specified, they exhibited faults such that water was introduced into the breathing air. Minor self-correcting free flows were noted in several other instances. The cause of these EN 250 failures was not established in all cases, but evidence pointed to the following probable reasons:

- Lack of correct servicing or maintenance
- Corrosion of metal components through water ingress
- Wear, pitting, scoring or damage of components
- Incorrect set-up of regulators
- Mis-match between first and second stage performance
- Combined component tolerances approaching the service limit
- Icing of regulators
- Mixing of first and second stages from different manufacturers
- Modification equipment (hose lengths and bores, connectors, swivels, and elbows).

**Figure 4. Dew point as a function of moisture content of the air and applied pressure**




### 2.4.4 Elimination of equipment as a cause of incidents

Almost as important as identifying equipment faults as causing or contributing to reported incidents, is elimination of this possibility. In 13 cases, our examination and testing concluded that the condition and performance of the equipment was unlikely to have caused or contributed to the event in question. While the equipment ensemble used may have had faults, these were not relevant under the specific conditions, which applied to the individual incidents. In these cases, causes external to the equipment must apply.

# 3 CONCLUSIONS AND RECOMMENDATIONS

## 3.1 CLEAR UP RATE

In exactly half of the incidents studied during this project, we have been able to establish with some confidence whether the equipment in use was likely to have been a causative factor; around a quarter were probably directly attributable to equipment faults.

In the remaining incidents, where examination and testing of the equipment involved has been possible (i.e. assuming it had been recovered), information to assist with the enquiries of the relevant authorities has been generated and provided. Although this information was inconclusive, it has often contributed significantly to the subjective findings of inquests / fatal accident enquiries, which are inevitable when dealing with uncertain events.

Since the end of the HSE funding for investigation of all diving incidents under this project, there have only been a handful of requests from outside enforcing authorities for investigation of diving equipment. Even for those that have been requested, full examination and testing of equipment is considered too expensive for an individual authority to afford, and only basic testing and examination have been possible. Important information for inquests and enquiries, and on the performance of diving equipment, may be being missed. There are direct parallels here with the system that operates where fatalities are associated with road accidents. Funding is provided to allow provision of expert evaluation of such accidents. For non-HSE enforced diving incidents, there is a compelling case for a similar system to apply.

## 3.2 CONFORMANCE WITH STANDARDS

Over 46% of the regulators tested did not meet the minimum performance requirements of the current standard, EN 250:2000, or had other faults. Principal causes of this poor performance included lack of maintenance, servicing and cleaning, incorrect set-up, and possible effects of mix and match of component parts.

EN 250 only tests the performance of equipment to a depth of 50m. Twenty percent of incidents studied here involved depths greater than 50m, some by a considerable margin. Our studies have demonstrated that it is not possible to extrapolate regulator performance from one depth to another; onset of failure with increasing depth can be sudden and catastrophic. These factors raise three important questions:

1. Is it generally known and understood that performance of EN 250 equipment deeper than 50m cannot be guaranteed?

2. In the absence of sophisticated testing equipment like the ANSTI machine, how reliable are bench tests of regulators in ensuring correct set-up and performance after servicing?

3. Should there be a National body to oversee the standards of regulator servicing similar to the CAA licensing of Aeronautical engineers.

The requirements of EN 12021 for moisture content of compressed breathing air were not met in the great majority of cases. Potential therefore exists for condensation of moisture inside cylinders, with associated corrosion and damage, and for condensation in regulators leading to freezing and failure, although none of the investigated incidents could be attributed to these causes.

Assuming the low moisture levels specified in EN 12021 are in fact necessary (as they would appear to be from a theoretical point of view), better means of control of moisture in the output of cylinder filling compressors appears to be needed. This aspect should already be under control through the requirements of COSHH.

## 3.3 MISSING INFORMATION FROM STANDARD TESTS

In EN 250, first and second stages are permitted to be tested and certified in isolation. This introduces the possibility of mis-matching between components when combined after-market. Similarly, the effects of abnormal lengths or bores of connecting hose, elbows and swivels which may be added after certification cannot be assessed during certification.

The performance of systems under conditions of simultaneous main and octopus regulator use, supplied by the same first stage is not directly addressed in EN 250. This is a foreseeable condition of use, under conditions where more than one life may depend on continued satisfactory performance of the air supply system; both second stage regulator users are likely to be stressed and working quite hard, factors which significantly increase breathing rates. This seems to be a significant oversight in the standard.

Supporting information on the significance and magnitude of these effects is required, either to justify introduction of changes to EN 250, or to provide manufacturers, users and training agencies with information on suitable configurations of equipment.

## 3.4 LESSONS FOR TRAINING AGENCIES AND DIVING ORGANISATIONS

In many of the investigated incidents, bad practice, unsafe behaviour or human error appears to have played a significant part. While it will be impossible to eliminate deliberate risk-taking behaviour, the relevant findings of this project should be communicated to these agencies to encourage them to emphasise the consequences of such actions, and to at least try to prevent them occurring through ignorance. Under this heading, the following aspects should be highlighted:

- The apparently common practice of divers to undertake dives right up to the recognised limits of safety, or of their formal training and experience, should be actively discouraged. Promote through the training agencies a safe dive programme giving up to date guidance on decompression theory, and the limits pertaining to age, fitness, water temperature, and dehydration.

- The emergency procedures to adopt in the case of negative buoyancy at the surface need to be emphasised more strongly, early on in the formal syllabus, and practiced.

- The emergency procedures to adopt in the case of inversion and positive buoyancy when using a drysuit need to be included in the formal syllabus and emphasised.

- To start the dive with correct amount of appropriate gas for the dive. Including carrying the correct reserve amount as planned for the dive. Further emphasis should be placed on the “Plan the dive, dive the plan” throughout diver training

- The limitations on performance of regulators beyond the 50m maximum depth limit of EN 250 certification, needs to be clarified and communicated to divers.

- The need for regular servicing and maintenance of equipment, by people who are qualified, and licensed to the required proficiency.

# 4 REFERENCES

BS EN 12021:1999 Respiratory protective devices – Compressed air for breathing apparatus.

COSHH Control of Substances Hazardous to Health Regulations 2002 Approved code of Practice and Compliance L5 (Fourth Edition) HSE books 2002 ISBN 0 7176 2534 6

BS EN 250:2000 Respiratory Equipment- Open-circuit Self-contained compressed air diving apparatus- Requirements, testing, marking.

BS EN 1809: 1998 Diving accessories-Buoyancy compensators- Functional and safety requirements, test methods.

BS 4001-1: 1981 Care and Maintenance of Underwater Breathing Equipment.

# ANNEX 1

## INDIVIDUAL INVESTIGATION SUMMARIES

**(1) Cylinder contents,**

Work carried out for an Environmental Health Service. During use, a diver experienced problems with symptoms reportedly similar to CO poisoning. Analysis of the remaining cylinder contents, and those of three other cylinders filled at the same time, was carried out.

All four cylinders were tested for the presence of Carbon Monoxide. Two methods were used, an electrochemical cell method and an infra-red method. All four cylinders showed:

- CO levels of less than 0.1ppm
- 20.9 to 21.0% oxygen
- less than 0.03% carbon dioxide
- air at a dewpoint of -45°C or drier.

There was a noticeable odour to the air from the two used cylinders (2 and 3 below). The smell was slightly stronger from cylinder 3. The other two cylinders did not have this odour. This was verified by three different persons who were asked to 'blind smell' the gas from each cylinder.

Air samples from three of the cylinders were additionally analysed for chemical composition as follows:
1. Faber 12L steel white/black - Toluene <5ppb, Acetone <5ppb, MEK <5ppb
2. Heiser 15L steel white - Toluene <5ppb, Acetone <5ppb, MEK <5ppb
3. Faber 12.2L steel yellow - Toluene 10ppb, Acetone 10ppb, MEK 15ppb
(MEK = Methyl Ethyl Ketone)

Toluene is normally present in ambient air from traffic fumes etc. Acetone and MEK are not normally present in ambient air.

Further air samples were taken from the cylinders and analysed using a chemical adsorption method which gives a qualitative result for the gases or compounds present in the sample. The results showed:

- No evidence for the presence of Diphenylamine
- Volatile organic compounds:
  Main components: Methyl Ethyl Ketone (MEK), Toluene, Trimethylbenzenes
  Minor components: C5-C6 ketones/aldehydes, xylenes, C8-C10 alkanes

Some of these components are normally present in air from traffic fumes etc, but the MEK and the C5-C6 compounds aren't usually present and could be from a localised source. The odour of the gas may be from these components. Subsequent visits to the cylinder filling facility revealed design problems with the compressor air intake, and proximity to a printing works.

**(2) Fatality,**

Work carried out for a Police force. This fatality occurred prior to the start of the project, but the investigation was still underway. Initially, reports of the incident and the examination of the equipment by Police Underwater Search Unit (which found no problems with the performance of the various regulators on the diving equipment using standard bench test procedures, but did note an error on the cylinder pressure gauge) were assessed. This assessment concluded that additional tests on the (compressed air) equipment could be informative.

The main regulator tested in this report appeared to be in good condition, but when tested it was found not to comply with the relevant European Standard, EN250. With the venturi device in the maximum position the regulator functioned correctly to a depth of 40m. With the venturi device in the minimum position (as received) the regulator functioned correctly to a depth of 16m with full cylinder pressure and 10m with 50 bar remaining in the cylinder.

The scuba equipment as tested at HSL was found to perform in such a way as to give the very minimum level of performance for the depths being dived (up to 16m) when the incident in question occurred. The likelihood of a diver unexpectedly running out of air would be increased by the high-reading pressure gauge.

**(3) Fatality,**

Work carried out for a Constabulary. One of a pair of compressed air divers experienced difficulties at ~30m, began fitting and was brought to the surface unconscious by his buddy.

The main regulator tested in this report was found to be in good condition, to function correctly and in compliance with the relevant European Standard, EN250.

The cylinder in use was marked as “nitrox”, but appeared to be filled with air. It is considered bad practice to fill nitrox cylinders from an air compressor, because trace oil contamination may be introduced to the cylinder which could cause an explosive ignition if the same cylinder is subsequently filled with a higher concentration of oxygen at a later date. There would be no adverse consequences from this to the diver using this cylinder in this particular instance, as the cylinder contained breathable air. (If the cylinder was filled with 21% nitrox at a nitrox filling facility then this would be acceptable, although the concentration should be measured and marked.)

The BCD emergency cylinder was found to be faulty, but this item was reportedly not used during the incident in question. The investigation concluded that the scuba equipment as tested at HSL would not have contributed adversely in any way to the incident.

**(4) Fatality,**

Work carried out for a Police force. A lone diver failed to surface from a ~10m dive. On recovery, some parts of his diving equipment were observed to be disconnected. The equipment condition and function was examined by HSL.

It seems likely from the evidence (the BCD inflator not being connected along with the inflator mechanism being jammed open by corrosion), that the deceased would not have been able to use the BCD to control his buoyancy. This BCD inflator control should have been serviced and possibly replaced prior to using it for diving. The condition of the emergency cylinder (out of date and empty) and its connector (missing component) suggests that the BCD had not been serviced for a number of years.

There are two possibilities regarding the jammed inflation control; the control may have been stuck prior to the dive and the BCD inflator hose not connected. Conversely the control may have become stuck during the dive, and the diver may have disconnected the hose to prevent an uncontrolled ascent.

In the first instance, (hose not connected) this could only occur if the BCD was partially or fully filled with air when the diver entered the water. It is clear from the witness statements that the deceased floated on the surface for several minutes before diving, this would only be possible with air in the BCD. To descend, the air is dumped from the BCD. If the diver then descended to the sea bed rather than using his buoyancy controls in midwater swimming, he may not be aware of the BCD problem until the time came to ascend again. Without the BCD hose connected the BCD would not inflate. The back up system for this is the emergency bottle which was empty prior to the dive. The only way to inflate the BCD in this instance would be for the diver to inflate it orally by inhaling from his regulator and exhaling into the BCD mouthpiece.

In the second instance, (the control sticking whilst in use by the diver), again this may not become apparent until the diver wished to ascend, at which point the BCD would inflate rapidly and the diver would ascend too quickly. Had this occurred the diver would then have to have the presence of mind to identify the problem, locate and disconnect the BCD inflator within a few seconds. Assuming the diver managed to do this, he would then be in the same situation as described in the previous paragraph with his only option being to orally inflate the BCD.

Whichever of these possibilities occurred, the deceased would have found himself in the same situation, in 10 metres of water with malfunctioning equipment, and compounded by having a regulator which was at the limit of its performance at 10 metres.

A diver getting into difficulty with equipment often experiences increased anxiety during which his or her breathing rate will increase. Both regulators tested in this report fail to meet the requirements of the EN250 standard, however both would be capable of supplying some air at 10m water depth although it may require effort on the diver’s part to do so, possibly further increasing anxiety and thus breathing rate. If a diver becomes sufficiently anxious, panic may occur. A panicking diver can demand air at over 100 litres per minute depending on size and build, making breathing even more difficult. If another problem such as a flooded mask occurred, the diver may not be able to suppress the panic.

It should be noted that the regulator first stage was the main limiting factor on the performance of the regulators tested. The second stage regulators delivered much improved performance when tested with a more capable first stage.

It is apparent from witness statements that the deceased was diving alone albeit with boat cover. All the major (non-technical) diving qualification training agencies strongly advise against this practice, and conduct training courses which centre on the ‘buddy’ system of diving. Diving as a ‘buddy pair’ i.e. two divers diving together increases the safety margin of the dive, as each diver is shown how to give aid to, and receive aid from, the other diver either in the form of an air supply or assistance with malfunctioning equipment. Had another diver been present the fatal incident may have been avoided.

**(5) Fatality,**

Work carried out for a Constabulary. One of a pair of divers, using an independent twin cylinder set with four possible air sources, experienced a free flow from his main regulator, was unable to locate any of his spare regulators, refused his buddy’s octopus, and surfaced quickly from 34m.

The main regulator tested in this report appeared to be in good condition and was found to comply with the relevant European Standard, EN250. It was not possible to induce a free flow in the laboratory by breathing from the regulator under a variety of work rate conditions in cold water. It would be possible for any regulator to go into free flow for a variety of reasons such as knocks or blows, use of the bypass flow control, or dynamic pressure conditions (water pressure depths described in this report are static pressures - localised pressure can be further increased dynamically by movement through the water).

The spare regulator (supplied from the other cylinder to the main regulator) on the deceased's scuba equipment would not have been capable of providing the diver with enough air at a depth of over 25 metres unless the diver was breathing calmly and normally. Reportedly, the deceased attempted to use this regulator at a depth of approximately 35 metres. If the diver was breathing moderately heavily, he would not receive enough air. This may have induced a recognised panic response of trying to attain the surface rather than accepting either his buddy's octopus regulator, or using his own. (The deceased's Octopus regulator, supplied from the same cylinder as the spare regulator, was reportedly not used in the incident but was tested. It would have been capable of supplying sufficient air at any depth down to 50m). The computer dive profile suggests that the deceased was both conscious and aware upon reaching the surface as he descended again to 6m (a decompression safety stop depth) for approximately one minute before surfacing again.

The air cylinders fitted to the apparatus both contained air with higher moisture content than that permitted by the standard EN12021. This would not however affect the function or operation of the apparatus in any way.

**(6) Nitrox cylinder ignition,**

Work carried out for a District Council Environmental Health Department. The whip connecting a Nitrox cylinder to a filling compressor burst as a result of an ignition, and the cylinder was projected around the filling room emitting blue flames / sparks. The valve had been dismantled prior to being received by HSL.

From the description of the incident it was apparent that an ignition had occurred somewhere in the internal parts of the valve. The combustion deposits inside the valve were analysed it can be concluded that some unidentified form of contaminant dirt, organic grease or debris had been present within the valve. The ignition then caused the phosphor bronze and brass components of the valve to burn; this would have been the source of the intense sparking seen by the witness.

Although it is probably common practice to fill air and nitrox cylinders from the same whip, the practice should be firmly discouraged, not least because the whip is not 'oxygen clean' after it has been attached to a standard air cylinder. Several nitrox cylinders had been filled from the whips before the air cylinders were refilled although it is not clear from the information available which or how many of the whips were used. The incident cylinder was then filled on its own when the ignition occurred. One possibility is that the whip used was still filled with oxygen from the previous nitrox fills. Another is that the nitrox cylinder in question contained high levels of oxygen. In either case the ignition could only occur if a contaminant was present in the pressurised oxygen atmosphere. The contaminant could have been something as small and seemingly innocuous as a breadcrumb or even a greasy fingerprint. It is not possible to say where the contaminant came from, but it is possible to say that the ignition would not have occurred without the presence of oxygen under pressure. It should be noted that once a nitrox cylinder has been filled with air from a non-clean source, it should have its nitrox and oxygen compatibility marking removed.

Risk assessments required under the Management of Health and Safety at Work Regulations 1992 should include guidelines for employees regarding working practices such as for instance, whether nitrox and air cylinders should be placed on the same whips (they should not), and defined procedures which should be followed. The operator in this case implied from the statement that he 'decided' to fill the incident cylinder on its own because it was marked as nitrox, presumably because there was a perceived risk associated with doing this. It is the employer's responsibility to ensure that the risk assessment considers all possible risks that may arise, however small, and then to implement working practices which eliminate risks where possible, and if not, reduce the risks to acceptable levels.

British Standard BS 4001-1:1998 "Care and maintenance of underwater breathing apparatus" contains, among other things, statements that:

- Compressed oxygen should never be put into air cylinders.
- Before charging it is the responsibility of the gas compressing firm or person to ensure that any cylinder to be filled complies with the relevant regulations.
- Before recharging the cylinder valve should be cracked open to blow clear any dust or moisture in the valve passages. This should always be done before connecting to a whip.

There is also an annex which contains procedures for filling cylinders from decant storage, including statements regarding connectors being 'clean and free from oil or grease'.

Although the reason for this particular ignition is not clear, the risk of an ignition like this is substantially reduced by keeping nitrox cylinders and other oxygen service equipment separate from all connections etc. which have been in contact with standard air cylinders and equipment. The Air and Nitrox charging connections should be mutually exclusive. Nitrox cylinders, once filled with ordinary air from an air charging facility should be taken out of oxygen service until they have been re-cleaned.

**(7) Fatality,**

Work carried out for a Constabulary. One of a pair of nitrox divers at ~40m signalled to abort the dive and they started to ascend. At 20m the deceased was seen to sink rapidly with considerable loss of air. His buddy followed and found him on the sea bed with his regulator out of his mouth and his mask displaced. Attempts to replace the regulator were unsuccessful. He was brought to the surface and later pronounced dead.

The scuba equipment tested was in good condition, well maintained and in full working order. It was unlikely to have caused or contributed to the incident by way of malfunction or inadequacy of operation.

The dive computer being used by the deceased was programmed with the wrong oxygen concentration, and would have given an underestimate of the divers exposure to oxygen partial pressure. This, and the witness statement account of the dive buddy, suggests CNS or Acute Oxygen Toxicity due to exposure to high oxygen partial pressures as the likely causal factor in this incident.

**(8) Rebreather fatality,**

Work carried out for the a Coroner. This fatality occurred prior to the start of the project, but the investigation was still underway. The deceased was using a rebreather at ~75m as part of a dive team, but became separated from other team members and failed to surface. He was recovered the following day.

The equipment he was using had been examined and tested prior to HSL becoming involved. It was received in a dismantled and incomplete state, after prolonged storage in less than ideal conditions, and was effectively not testable. HSL's investigation was limited to comments to the Coroner on the documentary evidence received.

The evidence was extremely complex, with many opinions and comments to be considered. On balance, it appears that there were a number of equipment maintenance faults, unauthorised modifications, and misuses involved in the incident. The diver was certified for rebreather use to a maximum depth of 39m with an air diluent. The incident took place at 73m with a trimix diluent – an application for which training was not available at the time.

**(9) Fatality,**

Work carried out for a Police force. Two divers died during a nitrox dive to 62m. One body was recovered immediately. The other diver has not been found.

HSL was initially asked to analyse the contents of a spare cylinder belonging to one of the deceased. Contents were clean breathable air in compliance with EN 12021, except for a slight excess of moisture, which would be unlikely to affect equipment performance.

See also (18) below.

**(10) Fatality,**

Work carried out for a Police force. One of a pair of nitrox divers lost control of his buoyancy and became inverted (the legs of his drysuit inflated) while at 40m. Despite attempts to correct this by his buddy, he made an uncontrolled ascent.

Only the relevant witness statements, drysuit and dive computers were received for examination. The drysuit inflation and dump valves tested in this report were found to be in good and well maintained condition and were in proper working order at the time of testing. The drysuit was also in good condition.

The buddy diver had qualifications up to IANTD Technical diver level. This allows dives to be made using nitrox mixtures to a maximum of 51m depth, the diver was therefore diving within the limits of his training. The level of qualification held by the deceased was not stated.

The deceased's dive profile shows that if the nitrox gas mix programmed into his computer was correct, then the divers ventured deeper than training agency advice would dictate at the start of the dive in terms of their oxygen toxicity exposure. A few minutes into the dive this situation was corrected and the divers stayed at a depth above which the oxygen toxicity limit is considered safe. It is possible that the deceased experienced some of the onset symptoms of oxygen toxicity.

The deceased's dive profile also shows that if the nitrox gas mix programmed into his computer was correct, then the divers ventured to the limit of training agency advice in regard to nitrogen narcosis exposure at the start of the dive. A few minutes into the dive this situation was corrected and the divers stayed at a depth above which the nitrogen narcosis exposure potential is considered low enough to be safe. However the divers would experience some degree of nitrogen narcosis at that depth, it is not possible to state the extent of the effects.

Diver training agencies do not advise on specific courses of action to be undertaken when a diver experiences inversion due to air in the legs of a drysuit. The fact that the deceased routinely did not use a weighted waistbelt, may have increased the possibility of becoming inverted due to air in the legs of the drysuit.

**(11) Fatality,**

Work carried out for HSE. During a trimix diving course, one of four pupils was observed in difficulty at 62m. He refused assistance from his buddy but was then lost in poor visibility due to stirred up silt. His body was recovered several hours later.

Various dive computers and timers from the party, and the equipment used by the deceased, were examined. The deceased may have been the victim of a number of circumstances that combined to cause his observed difficulties, namely:

The primary regulator being used reaches its limit of performance on air at approximately the very depth at which the deceased was observed having problems. If the deceased did experience difficulty with breathing from the primary regulator, the problems could have been alleviated by switching in this case to the secondary regulator, or by accepting a spare regulator from another diver provided that spare regulator was functioning correctly.

The manifold valve connecting the two cylinders on the diver's backplate reaches its open/closed cut off point at between 3/16 and 1/4 turn open. The valve was found to be approximately 1/4 turn open on receipt at HSL. Just 1/16 turn less than this would effectively shut off the valve, and movement as little as 1/32 turn may restrict the flow severely. It is not possible to say whether the valve has been moved slightly in transit or during handling upon recovery.

If either or both of the above occurred then the diver would have alleviated the problem had he switched to his secondary regulator as the performance of his secondary regulator was significantly better at 62m, also the cylinder to which the secondary regulator was connected would still have been almost full if the manifold valve was not open or severely restricted.

The regulator connected to the deceased's 40% stage bottle was unsuitable for the dive being undertaken in terms of its performance at low temperatures. It was marked as being for use in water temperatures greater than $10^{o}$C, and was found to free-flow at 20m when tested in water at $8.5^{o}$C. The water temperature on the dive varied between 7 and $11^{o}$C.

**(12) Dive computer,**

Work carried out for a Coastguard, to assist with an on-going investigation. A compressed air diver had descended to 70m and returned alive, without decompression stops. The information in his dive computer was required.

The profile shows the diver descending to almost 50m depth within 4 minutes of the start of the dive. The diver then slowly ascends for 3 minutes to 40m before then descending to 70m, 12 minutes after starting the dive. The diver then rapidly ascended to the surface in just over 1 minute. At the deepest part of the dive the computer was telling the diver that he had 16 minutes of decompression before being able to leave the water safely.

On surfacing the diver's computer was showing that the diver had missed 11 minutes of stops, which may explain why he immediately made a second dive where he descended to over 3m for 11.5 minutes.

**(13) Valve shearing,**

Work carried out for HSE. Cylinder valves on bail-out cylinders had reportedly sheared off on two occasions. Metallurgical examination was carried out at HSL.

The connectors were made from leaded copper – 40% zinc brass and had been nickel plated after machining. Both the valve connectors had been weakened by severe dezincification corrosion (probably from immersion in sea water) at the thread roots. The initiation of this dezincification was caused by damage to the nickel coating, which probably occurred when the connectors were tightened.

Valve connectors on other breathing apparatus will also be susceptible to weakening by dezincification if they have been manufactured from the same alloy as those examined. It is recommended that the use of a copper alloy with greater resistance to corrosion in sea water is considered for the valve connectors.

**(14) Air cylinder,**

Work carried out for HSE. The contents of an air cylinder required analysis, following a report of a “bad fill”.

The contents conformed to the requirements of EN 12021 for breathing air except that:

- Moisture content was somewhat higher than specified (200 $mg/m^3$ instead of 25 $mg/m^3$)
- The air had a musty smell.

This odour, while not strong, could cause nausea if breathed for a period of time.

**(15) Fatality,**

Work carried out for HSE. A surface-supplied diver, wearing a bandmask, was recovered from workings at 5.5m. His equipment and supply system was examined.

The complete system was tested under conditions of depth between the surface and 5.5 metres, and under all breathing loads up to and including 75 l/min. During the tests the apparatus functioned normally and correctly at all times.

The band mask worn by the deceased showed no signs of recent damage likely to have been caused by falling objects or debris. The band mask clamp band and hood worn by the deceased could not be dislodged by a short blow or knock. The band could be dislodged but only when subjected to a sustained force applied laterally to the plane of the band.

The air output provided by the compressor and by the high pressure storage cylinders was found to be clean and breathable in accordance with EN 12021.

**(16) Fatality,**

Initial enquiry received from a firm of lawyers regarding a death while using a rebreather at 54m, followed by a rapid uncontrolled ascent. No further communication received despite requests.

**(17) Fatality,**

Work carried out for a Police force. One of a pair of compressed air divers failed to surface at the end of their dive to 51m. The deceased's SCUBA equipment was not recovered from the wreck for a further 8 months.

The contents of three gas cylinders were tested and found to be clean breathable air with no contaminants and of sufficient dryness for the dive being undertaken. The contents of the buddy's dive computer memory agree with the witness statement given by him except for his estimate of the length of one time period.

The main diver training agencies do not advocate diving using air beyond a limit of 50m, and in many cases at least 10m less than that. Both divers would experience a degree of Nitrogen Narcosis on a dive to 51m using air as a breathing gas, but it is not possible to say whether this was as a causal factor in this incident.

Some 8 months after the incident, the SCUBA equipment was recovered from the wreck and sent to HSL for examination.

Due to the length of time the equipment had spent in seawater, it was not possible to conduct performance tests on any of the recovered equipment. Visual examination suggested that the equipment being used for the dive was both suitable and adequate for the planned dive being undertaken. Although the internal parts of the regulators examined were corroded, some areas remained uncorroded where seawater had not been in contact with the metal (due to trapped air). These few areas, mainly within the second stage regulator bodies, appeared clean and consistent with that expected within a well maintained regulator. Clean areas within the BCD hoses also indicate equipment that was cleaned and maintained.

**(18) Fatality,**

Work carried out for a Police force. Two divers died during a nitrox dive. One body was recovered immediately. The other diver has not been found. This incident was first notified at 9 above.

Subsequently, other items of the deceased's equipment were received for examination. Two further cylinders were analysed for contents – one contained a nitrox mix with 36% oxygen, the other contained breathable air. In both cases, the moisture content of the gas was marginally above the specified limit in EN 12021.

The inflation and dump valves on the deceased's drysuit were examined. The inflator functioned correctly, but the dump valve was missing a cover. The cover also allows adjustment of the dump pressure of the suit and manual control, and these functions would not be possible in its absence. Control of buoyancy would be restricted as a result. However, it is not known at what point in time the cover was lost – before, during or after the fatal dive.

Submerged weights of the cylinders in use at the time of the fatality were measured, to inform the Procurator Fiscal on whether the total weight carried by the diver was appropriate.

**(19) Air cylinder,**

Work carried out for HSE. Twelve minutes into a dive, a diver had to be assisted to the surface from 20m by his buddy after blacking out. Only the contents of two air cylinders were required to be tested.

Both were found to contain clean breathable air to the requirements of EN 12021, except for a slight excess of moisture. This would not have adversely affected the performance of diving equipment.

**(20) Fatality,**

Work carried out for HSE. A novice diver under instruction got into difficulties in less than 8m of water and drowned. The instructor's dive computer required downloading.

The downloaded information from the computer was provided to HSE, who in turn provided it to the Police force investigation. The logged data differed from that made in statements.

**(21) Fatality,**

Work carried out for HSE and a Constabulary. One of three students got into difficulties during a dive at ~7m. Their SCUBA equipment, and parts of their instructor's, were sent to HSL for examination and tests.

All of the equipment worn by the deceased during the incident was found to be in good condition, compliant with the relevant standards and fully functional in all respects. Analysis of the air in the deceased's cylinder showed it to be of clean breathable quality, if slightly higher in moisture content than specified in EN 12021.

The Scuba regulators worn by the instructor during the incident were found to be in good condition, compliant with the relevant standard and fully functional in all respects.

The BCD and regulators worn by one of the other students during the incident were found to be in poor condition having had makeshift repairs and performance which indicated a general lack of maintenance. However the primary regulator and BCD were found to be fully functional in terms of compliance with the relevant standards. The octopus regulator did not comply with the performance standard.

The BCD and regulators worn by the remaining student during the incident were found to be in good condition, compliant with the relevant standard and fully functional in all respects, with the exception of a broken computer unit incorporated into the console containing the pressure gauge.

**(22) Rebreather fatality,**

Work carried out for a Police force. A lone diver using a rebreather was recovered from the sea after police were alerted to his parked van. The equipment was sent to HSL for comment.

The equipment in question was a ex-military submarine escape model. Information on this unit was not easy to obtain. The unit was designed to be used with "superoxide", but it is reportedly possible to convert the unit to run on less dangerous chemicals with some modification. This unit appeared to be filled with the less dangerous chemical and so the question arose as to whether or not the unit has been modified correctly or indeed at all. From information found on the Internet the unit had not been modified and a build up of Carbon Dioxide is believed to have been the cause of the fatality.

The condition of the gas cylinders and some of the high pressure components attached to the unit was such that they could not be safely refilled in order to test the unit without risk of explosion or fire from high pressure oxygen reacting with contamination.

**(23) Fatality,**

Work carried out for HSE. A student got into difficulties at 14m, and was being brought to the surface by her buddy. Close to the surface they lost contact, and the deceased sank back down to 7m from where she was recovered some minutes later. Attempts at resuscitation were unsuccessful.

The main regulator and octopus tested in this report were both found to be in reasonably good condition, to function adequately and in compliance with the relevant EN 250, at depths down to 40m. On the incident dive the regulators would have been capable of providing sufficient air at breathable pressures to a diver who was breathing at high work rates or panic work rates (62 - 100 l/min).

No faults were found with the BCD or other ancillaries examined.

The scuba equipment was unlikely to have contributed adversely in any way to the incident.

**(24) Fatality,**

Work carried out for a Police force. Rebreather equipment from this incident had been previously examined and tested. Comments were sought on the associated documentation and reports obtained from this investigation. The equipment itself was not in a suitable condition to be tested.

The crucial pieces of evidence were that at least one of the oxygen cells on the rebreather was faulty, and that the witness to the incident observed convulsions. The likely cause was considered by the Coroner to be oxygen toxicity.

**(25) Diver Training course incident,**

Work carried out for HSE. During a diver training course, an incident was caught on video and the voice communications audio tape. The video did not have an audio track. HSL Video and Photographic Section tried unsuccessfully to synchronise the two.

**(26) Fatality,**

Work carried out for a Police force. During ascent from 23m, a compressed air diver signalled to his buddy that he was out of air. He was assisted to the surface, breathing from his buddy's octopus regulator. On surfacing, he complained of being unable to breathe, and collapsed.

The main regulator and octopus tested in this report were both found to be in very good condition, to function well and in compliance with the relevant European Standard, EN 250 at depths down to 50m. No faults were found with the BCD or other ancillaries examined.

The scuba equipment as tested was unlikely to have contributed adversely in any way to the incident.

Dive profiles were downloaded from computers worn by the deceased and his buddy. The two dives executed by the divers on the day of the incident were deeper than allowed by the scope of the deceased's training. Both divers missed decompression safety stops on both dives, and the second dive undertaken was longer than the recommended BSAC 88 no-decompression limits.

**(27) Fatality,**

Work carried out for a Police force. A pair of compressed air divers surfaced after a dive and clung to a rock to await pickup by the dive boat. One of the divers, who was in some distress, was washed away from the rock and shortly thereafter recovered unconscious. Attempts at resuscitation were unsuccessful.

The deceased's main regulator was found to be in good condition, but failed to comply with the relevant EN 250 at depths greater than 30m. However at 22.5m, the dive depth immediately prior to the incident, the regulator performance was well within the standard parameters. The regulator would breathe easily at 22.5m and would not have placed undue load on a diver even working at an average rate of 62.5 l/min as tested (Information derived from the dive computer shows that the deceased averaged 47 l/min on the dive). The regulator's general performance could be described as 'adequate' rather than 'good'.

No faults were found with the BCD or other ancillaries examined, other than the fact that the 7kg of weight within the BCD would not be quickly detachable in an emergency. The BCD is designed to be used with quick-release weights which are quickly detachable, however these were not present and the weights were simply bags of lead shot placed in the pockets, this is not considered good practice.

The divers air consumption on the fatal dive and on previous dives was high, indicating a high work rate and (from statements) possibly a high state of anxiety. The choice of dive site and the prevailing sea conditions may have been a factor.

It is possible that the diver finished the dive with insufficient air remaining to attain stable buoyancy at the surface, in which case a correct course of action would have been to remove some weight and ditch it or pass it to another diver with sufficient buoyancy. It would also have been possible to put more air into the BCD by mouth, although an out-of-breath diver may find this difficult.

The scuba equipment as tested at HSL was unlikely to have contributed adversely in any way to the incident, in terms of its performance and suitability at the depths being dived. Potential problems may have been avoided by closer air monitoring, and by the use of properly sited and detachable weights.

**(28) Fatality,**

Work carried out for a Constabulary. Two compressed air divers surfaced after a dive to 21m. One of the divers had insufficient air remaining to establish buoyancy, and despite efforts to assist by his buddy, sank to 11m.

The deceased's equipment, including a dive computer, was sent to HSL for examination. The main regulator and octopus regulator were both found to be in good condition, to function well and in compliance with the relevant EN 250, at depths down to 40m (octopus) and 50m (main regulator)

No faults were found with the BCD or other ancillaries examined, other than the fact that the emergency inflation bottle appeared to be in a state of disrepair or disuse.

The dive computer used by the deceased indicated that the diver exceeded the recommended safe ascend rate at some point during the ascent, this may have resulted in decompression illness injury, or lung over expansion injury. The computer contained details of 9 other dives, all but one of which indicated the recommended ascent speed had been exceeded.

Divers are trained to ditch weight if they cannot achieve buoyancy at the surface, by dropping weightbelts and any other significant weight they may be carrying. A diver who does not do this is not following his or her training; this may indicate that the diver was in a state of panic or near-panic at the time. In this instance, the deceased had been collecting scallops, which were attached to his equipment in a bag. This was cut away by his buddy during his rescue attempts at the surface.

Divers are also trained to leave sufficient air in their main cylinder as a reserve to cope with emergencies which may be encountered on ascent or at the surface. A properly planned and executed dive would result in a diver surfacing with between 30 and 50 bar minimum air left in the cylinder depending on the prevailing diving conditions. This should be understood by both divers in a buddy pair before the dive is made.

The scuba equipment as tested at HSL was unlikely to have contributed adversely in any way to the incident. The BCD emergency inflation bottle could have prevented the incident had it been available, if the diver had familiarised himself with its correct use prior to diving with it. Divers are not normally trained in the use of these emergency cylinders during standard training courses; it would be the responsibility of the individual concerned to familiarise themselves with its correct use.

**(29)** F**atality,**

Work carried out for a Police force. During a training dive, the pupil was unable to achieve buoyancy at the surface, began to panic, and sank to 7m. He was recovered within a few minutes, but could not be resuscitated.

The deceased's equipment was sent to HSL for examination. The problems experienced by the deceased on the fatal dive and recorded in witness statements were probably due to two major faults with the diver's equipment, assuming that the faults were present during the dive and did not occur later upon recovery of the diver and equipment.

Firstly, the BCD control console was found to be detached from the inflator hose, which would render the BCD unusable as no air could be retained within the BCD for buoyancy. A trained diver in this instance would add air to their drysuit for buoyancy and/or drop any lead weight carried if the drysuit alone could not provide sufficient buoyancy. The diver was at the time a novice under instruction and may not yet have been taught this. The observed detachment of the BCD control would require excessive pulling force assuming it was correctly fitted before the dive.

The regulator in use by the diver was faulty in that it allowed water to leak into the air breathed through a damaged diaphragm. This may have given the impression that it was not possible to breathe from the regulator and, coupled with the lack of buoyancy from the BCD, may have been contributing factors to why the deceased began to panic.

**(30) Fatality,**

Work carried out for a Police force. A pair of compressed air divers descended using a surface marker buoy to approximately 15m depth whereupon the deceased immediately gave the signal to resurface before becoming unconscious and rejecting his regulator. The second diver then escorted the deceased to the surface.

The equipment used by the deceased was fully functional and suitable for the dive being undertaken, was in good condition and contained clean breathable air. However, a number of minor faults and observations were identified:

1. The pony cylinder being used was out of test date, and was also found to be overfilled. However, this had no bearing on the incident.

2. The drysuit inflator control was found to allow a minor constant leak into the drysuit. This would necessitate the diver having to dump air from the suit occasionally to avoid becoming too buoyant. For a diver experienced in drysuit use this would not be a major problem, and was unlikely to have had a bearing on the incident.

3. Both breathing regulators tested in this report narrowly failed to comply with the EN 250 performance standard, however both regulators perform well within the standard limits at the incident depth of 15m and shallower.

The equipment being used by the deceased on the fatal dive did not have faults or other performance factors which may have caused or contributed to the incident.

**(31) Fatality,**

Work carried out for a Police force. One of a pair of compressed air divers entered a wreck at 33m and was shortly afterwards found by his buddy without his equipment. In addition to air, he had been carrying a pony bottle of enriched air nitrox (42.2% oxygen).

The main SCUBA equipment used by the deceased was fully functional, suitable for the depth of dive being undertaken, and was in good condition. The buoyancy control device was found to be fully functional and in good condition. It also met the relevant standard requirements.

The primary regulator being used easily met the performance requirements of the relevant standard. The pony regulator being used did not meet the relevant performance standard to 50m depth, but did perform within the standard parameters to a depth of 45m.

The main gas cylinder was found to be empty. The pony cylinder contained 100 bar pressure which equates to just under half full, indicating that it had been used. The pony cylinder gas was of 42.2% oxygen concentration which would be likely to cause CNS oxygen toxicity symptoms and possibly convulsions if breathed at depths greater than 23-27m.

The equipment being used by the deceased on the fatal dive did not have mechanical faults or other performance limiting factors which may have caused or contributed to the incident.

### (32) Fatality,

Work carried out for a Constabulary. Towards the end of a dive to 26m, one of a pair of compressed air divers experienced buoyancy problems and made a rapid ascent. The diver was using Scuba apparatus having twin independent back mounted cylinders, a standard Buoyancy jacket and drysuit. The deceased was apparently aware that he had a faulty regulator on one cylinder and elected to dive using the remaining cylinder and the spare regulator.

The scuba equipment examined was all of older design being roughly 5-10 years old, or possibly more in the case of the BCD.

The first factor in considering the fatal dive was the failure of the diver's left-hand regulator prior to entering the water. This was due to a major fault within the first stage regulator meaning that the cylinder to which it was connected was shut down and not used on the dive. This meant that several potentially unsafe factors were introduced:

1. The diver's BCD was connected to the closed off supply meaning there was no supply to the BCD if required. The BCD is normally only used on ascent after the dive, and to stabilise the diver at the surface.
2. The diver would be diving without a back-up regulator for either his own or his buddy's use in an emergency, should either of their air supplies fail. Given the internal condition of the regulator which was being used this was a very likely occurrence. The BSAC (British Sub-Aqua Club) diving manual contains the statement 'All divers should be equipped with an alternative air source'. In this instance after closing down the faulty regulator and cylinder, the diver did not have this facility. The dive was therefore undertaken under conditions contrary to BSAC advice.

Both of the deceased's regulator assemblies were examined, and exhibited faults and limits in performance capability. Both sets were in poor condition, likely to have been due to either ineffective or nonexistent maintenance.

No faults were found with the drysuit valves, the BCD or the DSMB and reel. Similarly, no faults were found with any of the parts of the equipment that normally control the diver's buoyancy, namely the drysuit valves and the BCD.

Weighing up the various factors surrounding the fact that the deceased was observed to be overly buoyant, it follows that excess air was introduced into his equipment at some point. This could only be from either his drysuit inflator, which was tested and found to be in working order, or from the emergency inflator bottle of the BCD.

### (33) Air tests,

Work carried out for a Police force. Contents of three air receivers (one single cylinder and two twins) required analysis following reports of a suspected "bad fill".

The gas in the three receivers was found to comply with the compressed air quality standard EN 12021 with the exception that the gas contains more water vapour than the allowed limit, and the gas also had a discernable odour. The excess water vapour in the gas presents no health risk whatsoever. However, the odour present may cause mild nausea or headaches when breathed despite posing very little or no other risk to health.

The configuration of the compressor used to fill these cylinders was unknown, but use of a charging air compressor without an air filter would very likely result in increased oil mist and possibly water vapour content of the gas produced. It is recommended that the moisture content of the compressor output be monitored regularly. The addition of a compressed air drier to the charging system should also be considered.

**(34) Fatality,**

Work carried out for a Police force. One of a party of three rebreather divers became separated from his buddies and failed to resurface after descending to a wreck at 130m. His body and equipment were recovered from this depth 4 weeks later.

The equipment included the basic closed circuit rebreather with on-board oxygen (almost empty) and air (60 bar) diluent cylinders, plus two additional “stage” cylinders, one containing air (30 bar) and the other trimix (7.5% oxygen, 76.5% helium, at 110 bar). When recovered, the diluent connection on the rebreather was attached to the stage cylinder containing air, but the connection was not fully engaged, being stiff and corroded. On recovery, the breathing loop of the equipment was flooded, and both handsets were dead (although in the “on” position); the batteries supplying them and the oxygen sensors were corroded, and not functional owing to flooding of the system. The performance of the rebreather could not be tested in the as-received condition. Also the diluent was being used to depth therefore the narcotic effect of the nitrogen in the diver’s gas would have been significant.

None of this equipment is certified for use at depths greater than 50m. Performance testing of the on-board regulators at the pressures encountered on this dive is not possible with currently available equipment. Experience has shown that it is not possible to extrapolate performance at one pressure to that at a higher one.

A selection of dive decompression tables were carried by the diver, these indicated that the diver was accepting excessive levels of oxygen exposure during the dive (up to 48% above the recommended limits). Though there is no evidence of the diver having suffered an Oxygen toxicity event as all three mouthpieces on the equipment are in good condition.

**(35) Fatality,**

Work carried out for a Police force. Part way through a compressed air dive to 15m, one of a group of divers lost control of buoyancy and rose slowly to the surface. He was unconscious when found a few minutes later, and did not respond to resuscitation. The equipment was sent to HSL for examination.

All equipment tested was found to comply with all relevant standard requirements and was in good condition. The apparatus was found to contain clean breathable air with no contaminants present. This equipment was unlikely to have contributed adversely in any way to the incident, in terms of its performance and suitability at the depths being dived.

**(36) Fatality,**

Work carried out for a Police force. One of a pair of nitrox rebreather divers got into difficulties during the ascent at the end of a dive to 38m, and sank out of reach of his buddy. His body and equipment have not been recovered. Only the buddy diver's equipment was available for examination.

The onboard rebreather cylinder was marked as nitrox with 41.6% oxygen, but was empty and could not be tested. A bailout nitrox cylinder attached to the main cylinder carried labels for both 49% and 50.9% oxygen. This too was empty and could not be tested. The gas in two offboard 3l cylinders with remaining gas in them were both found to contain clean air which complied with the compressed air quality standard EN 12021 with the exception that one gas contains marginally more water vapour than the allowed limit. This would however not cause problems for the user. One of these cylinders was marked as containing nitrox with 48% oxygen.

The computer profile memory of the dive corresponded with the dive plan written on the diver's wrist slate, except for a discrepancy in the percentage oxygen in use. There was evidence of a delay in the ascent of 2 minutes at approx 25m.

No fault was found with the DSMB bag and reel assembly which were both in good condition and operated as designed.

**(37) Fatality,**

Work carried out for a Constabulary. Shortly after surfacing from a shallow training dive (<3m) with cramp, the instructor suffered breathing difficulties and collapsed. He had a history of asthma.

Only the air cylinder contents required analysis. The gas in the cylinder was found to comply with the compressed air quality standard EN 12021 in all respects, including moisture content.

**(38) Fatality,**

Work carried out for HSE. During a first training night dive, one torch failed and a pair of divers became separated. The divers surfaced separately, and one was unable to maintain surface buoyancy, removed his regulator to call for help and sank in 7m of water.

The main regulator and octopus regulator were both found to be in good condition, to function well and in compliance with the relevant EN 250, at depths down to 50m. While no faults were found with the BCD or other ancillaries examined, the medium pressure inflator hose was not connected to the BCD on receipt, and would not supply air in this state.

The diver was carrying a lot of lead weight for a person of his size and build and using the particular size and buoyancy capabilities of his drysuit and BCD.

The scuba equipment as tested at HSL was unlikely to have contributed adversely in any way to the incident. The lack of BCD inflation capability was probably a crucial factor.

**(39) Fatality,**

Work carried out for a Police force.  One of a trio of divers became separated from the others at ~15m during ascent from a ~30m dive. His body and equipment have not been recovered. His spare air cylinder and the dive computers of his buddies required examination.

The spare air cylinder was found to contain clean air in accordance with EN 12021, except for a slight excess of moisture.

The two dive computers were of different types:

- One stored only time, temperature and maximum depth data. It had been set for "diving at altitude", which gives an extra margin of safety, but its internal clock was incorrect by more than 112 days.
- The other contained a full downloadable dive profile, which agreed with the statement of the witness except for a slight change in the order of events. Ascent rates were faster than considered safe.

Nothing here provided any information on the possible causes of problems to the deceased.

**(40) Fatality,**

One of a party of 3 open circuit compressed air divers became separated from his buddies during a dive to 65m, and failed to surface. He was recovered from 93m the following day.

The equipment in use consisted of manifolded twin 12.2 litre cylinders (two first stages, three second stages), attached to a backplate and wing style BCD. In addition, a 7 litre nitrox (73.2% oxygen) cylinder with first and second stages was carried. The main second stage regulator used on this dive allowed small quantities of water to leak into the inhaled air ("wet breathe"), but remains just within the performance requirements of EN 250 down to 60m. The octopus regulator on this first stage exhibited a small self-correcting free flow during test at 46m. The alternative second stage from the manifolded twin showed excessive interstage pressure drop, and exhibited much higher inhalation resistance than allowed when tested at 60m. The regulator attached to the small nitrox cylinder failed the requirements of EN 250 at only 26m.

Quite apart from these equipment performance faults, the use of air at a depth of 65m results in an oxygen partial pressure of ~1.6 bar, and nitrogen partial pressure of ~5.8 bar, well in excess of the recommended limits for avoiding both oxygen toxicity and nitrogen narcosis.

**(41) Fatality,**

Work carried out for a Police force. One of a party of compressed air divers experienced a problem with his equipment during ascent at the end of a 51m dive. He began to breathe from a buddy's pony cylinder as they ascended together, but subsequently lost consciousness. The buddy was unable to support his weight and continue to the surface, and the deceased sank to be recovered about 10 minutes later.

The Buoyancy control device was found to be in nearly new condition. However, the inflator system on the left hand side was found to have a connector that did not attach securely due to the locking ring remaining in the unlocked position.

The cylinders being used for the dive were within their test period for recharging at the time of the dive. The gas contents of twin cylinders were found to be clean air in accordance with the relevant standard, and therefore could cause or contribute to the incident by diving gas narcosis.

The narcotic effect of nitrogen is likely to have been affecting the diver, it is insidious and the diver may not have realised the effect it was having on his mental reasoning processes.

The main scuba equipment as tested at HSL was unlikely to have contributed adversely in any way to the incident. It is also unlikely that the pony system would have caused the incident at the relevant depth.

The amount of weight used by the diver was 16.1 kg, which in itself is not uncommon for some divers using a neoprene drysuit. However, a further 28.2 kg is to be taken into consideration by the weight of the divers twin set plus a further 3.72 kg of the pony cylinder carried as well. Therefore the diver carried a total of 48.02 kg of lead and cylinders during the dive. It is a known fact that a diver being over weighted will use his gas quicker than a diver correctly weighted. The higher amount of gas used due to the weight would add to the narcotic effect referred to above.

**(42) Fatality,**

Work carried out for HSE and a Police force. One of a pair of compressed air divers (initially thought to be under instruction) experienced a free-flow at ~40m and sank. A deeper diver noticed him as he was sinking, and a rescue attempt was made without success. He sank to ~74m from where he was later recovered. His equipment, including two dive computers, was sent to HSL for examination, together with the dive computer of his buddy.

Most items of equipment used by the deceased (BCD, drysuit), on the fatal dive were in good condition, complied with relevant standards and were in fully functional order when examined. However, one regulator also being used on the same air supply was found to have faults with regard to excessive interstage pressure and its susceptibility to free flow at breathing rates greater than 37.5 l/min when tested at the incident depth of 40m. If this regulator was being used at the time the reported free flow occurred then it is likely to have been the cause of the incident. There were indications that the deceased may have then switched to breathing from a nitrox (60% oxygen) pony bottle, and suffered oxygen toxicity problems.

**(43) Incident,**

Work carried out for HSE. One of a party of trainees complained of cold at 16m, and the party returned to the surface (with a safety stop for 3 minutes), where she was found to be unconscious. Only the quality of air in the cylinder in use at the time required analysis.

The cylinder was found to contain clean breathable air in accordance with EN 12021, except for a slight excess of moisture.

**(44) Fatality,**

Work carried out for a Police force. A lone diver, using an air / helium mix, was found floating face-down at the surface, after previously being seen at ~50m. His equipment and two dive computers were sent to HSL for examination.

Several faults were identified which may have contributed in whole or in part to the incident in question.

- The diver's buoyancy system consisted of a primary system and a redundant back-up system. One of these systems (which are ostensibly the same) was found to be inoperable, and the other system was found to operate correctly in all respects apart from the overpressure valve, which appeared to dump air before the bladder was full.

Dependant on the weight the diver was carrying at the time, he may not have had adequate buoyancy available to him at the time of the incident.

- The diver was using a Trimix or more likely Heliair breathing gas consisting of Oxygen, Nitrogen and Helium in the ratio 19:70:10 (remaining 1% Argon). This is not the best gas for use at 57m depth as the Nitrogen fraction is still high enough to potentially cause significant Narcosis problems.
- The dive computer memory lists the fatal dive as being the deepest made with the unit by over 20m, the computer also recorded that the diver missed 28 minutes of decompression on ascent.
- The diver's left hand regulator set narrowly fails to meet the standard test requirements, however it would be usable at 57m provided the user was not panicking or breathing at a rate greater than 50 litres per minute.
- The divers right hand regulator set was found to be incorrectly adjusted or out of tolerance such that tests could not be performed on it without excessive free flow. Internal examination showed the regulator to be clean and well maintained in appearance. Regulators do occasionally exhibit unusual or inexplicable faults despite being well maintained – the most likely explanation being a mismatch of tolerances within the components of the first stage. It should be noted that a diver would still be able to get air from the regulator even when free flowing.

**(45) Fatality,**

Work carried out for a Police force. A compressed air diver was ascending using a SMB (surface marker buoy) and reel from approximately 42m depth, and was seen to fall to the seabed for no obvious reason. The body and equipment remained underwater for several weeks at 44m before recovery. Equipment was sent to HSL for examination.

The Buoyancy control device was found to be in good condition, fully functional and in compliance with relevant standards. It is unlikely to have had any bearing on the incident by way of faulty performance or malfunction.

The cylinders being used for the dive were outside their retest period for recharging at the time of the dive. This would however have had no bearing on the incident.

The diver's isolation manifold valve was found to be in the fully closed position on recovery, with one empty cylinder and one full cylinder. The configuration the diver was using i.e. having a contents pressure gauge on one side only, indicates that the manifold valve should have been in the open position for the dive. The gas contents of the full cylinder were found to be clean air in accordance with the relevant standard, and would not cause or contribute to the incident in any way other than by diving gas narcosis. At 44m this would not be excessive but would be present nonetheless.

The computer memory contents show a gap of almost 6 months prior to the fatal dive. If this applied to the diver concerned then the diver may have been out of practice for attempting a dive to this depth without working up to it progressively.

The regulator set connected to the unused left hand cylinder was of a non-matching combination of first and second stage made by different manufacturers. The performance of such a combination is therefore an unknown quantity, and it is inadvisable to do this. The dry bleed system of the first stage in this combination was found to be non-functional, therefore the regulator was not performing as designed and may not have been capable of providing sufficient air at depths greater than 25m.

The regulator set connected to the empty right hand cylinder showed signs of wear and was due for a service. A small free flow was present, however this may be in part due to sea water ingress during the considerable time spent in the sea. The observed wear on the high pressure seat would not be caused by sea water and would have been present during the dive, but may not have affected the diver's breathing.

The diver's contents pressure gauge was connected to the isolated full cylinder and would have indicated full throughout the dive. With the diver breathing from the other cylinder having no pressure gauge attached, he would run out of air without warning if the cylinder was breathed empty. If this happened, the diver would attempt to switch to the other regulator, which would in theory give air (as the pillar valve was open). However tests performed showed this regulator combination to be difficult to breathe from at depths greater than 25m.

The likelihood then arises that the diver, having inadvertently failed to open the isolator valve, ran out of air or experienced a freeflow at some point during the dive. Once this occurred the necessity to switch to the other regulator arose, and the performance of the other regulator may have been such that the diver was unable to breathe from it.

**(46) Incident,**

Work carried out for HSE. A trainee commercial diver experienced loss of air supply at 8m, during his first use of this type of full face mask.

The full face mask apparatus used was found to be in good and well-maintained condition and was found to perform correctly in terms of resistance to breathing at depths less than 30m.

The apparatus as tested exhibited an unusual drop in interstage pressure under flow due to some unidentified characteristic of the first stages being used. This was most likely due to a mismatch of tolerances within the components of the first stages, particularly if the two first stages had been serviced together with replacement parts from the same batch. There was no evidence that the apparatus would fail to give air to a wearer on demand.

A possible contributing factor to this incident may have been poor fit of the mask to the wearer.

**(47) Fatality,**

Work carried out for a District Council. A student diver in an indoor pool at 3.8m lost her mouthpiece and was assisted to the surface, but lost consciousness and died. The equipment used was sent to HSL for examination.

The equipment used by the deceased was fully functional and suitable for the dive being undertaken, was in very good condition and contained clean breathable air. The equipment being used during the incident did not have faults or other performance factors which may have caused or contributed to the incident.

**(48) Fatality,**

Work carried out for HSE. During a dive to 13m, one member (breathing nitrox) of a group of three lost his air supply. In the ensuing confusion, during which octopus regulators were exchanged between the three, and regulators were dislodged from mouths, another member of the group (breathing air) appeared to mistake his snorkel mouthpiece for a regulator, and panicked. He was recovered unconscious shortly afterwards. Three sets of SCUBA equipment and three dive computers were sent to HSL for examination.

The set which reportedly stopped supplying air could not be made to reproduce this effect during tests. The primary and secondary regulators on this set both exhibited excessive breathing resistance at depths greater than 35m, but performed within specification at the incident depth of 13m. Further examination of the first stage regulator revealed inter-stage creep from 10 to 12.5 bar, missing anti-tamper paint on the cover, and wear and internal scoring of a component.

The other two sets were found to be in good condition and to perform within specification. There were some anomalies related to appropriate marking of one main and one pony cylinder (designated for nitrox, but filled with air and empty respectively), but these had no bearing on the incident.

None of these findings could explain the reported course of events.

### (49) Fatality,

Work carried out for HSE. A lone fish farm compressed air diver became entangled at 16m and drowned. His complete equipment and dive computer were sent to HSL for examination.

Of the items examined, the following were found to be in good condition, in full working order or in accordance with relevant standards and were unlikely to have contributed to the incident in an adverse way:

- Backplate and harness assembly
- Diver's drysuit and associated valves
- Breathing air quality
- Weightbelt and weights
- Diver's fins
- Wrist computer

A few items were in poor or damaged condition but were still unlikely to have contributed to the incident in an adverse way:

- Diver's Neoprene Hood
- Neoprene Gloves
- Gas cylinder may be out of test date

This leaves items which were in poor or badly maintained condition and may have contributed to the incident in an adverse manner.

- Diver's knife may have been inadequate
- First and second stage regulator assembly.

The regulator assembly was found to be in poor condition and showed evidence of poor or non-existent maintenance. The regulator was in such a condition that its performance could not be fully assessed owing to the high resistances caused by badly damaged internal parts. It is likely that the regulator resistance levels were such that breathing from it at depth would be difficult, and may have been inadequate to sustain a diver breathing at high demands (e.g. high work rate, anxious or panicked). The limited machine tests which were able to be performed indicated this for a few breaths before the regulator went into excessive free flow. During test, the mechanical strength of the breathing machine had sufficient power to drag the jammed internal components open; this would not have been possible for a diver.

**(50) Fatality,**

Work requested by a Police force. During a mask removal, refitting and clearing exercise, a compressed air diver at ~13m experienced difficulty in refitting his mask and began to panic. His ascent was controlled by his two buddies, but he was unconscious on arrival at the surface, and did not recover. His equipment was initially sent to HSL for examination, but subsequently recalled before full testing had been carried out.

Only a visual inspection was carried out on this equipment. No obvious serious faults were observed, but the equipment appeared to be of older design, with evidence of repairs to the BCD, wear on second stages, and modifications to the hose connections to the first stage regulator. Date and time information from the deceased's dive timer were unobtainable. Depth and duration data for the last 4 dives were available, but not very informative.

Witness statements on the incident point to inhalation of water through the nose during a mask clearing exercise at ~13m. With properly functioning equipment, the inhalation effort required for breathing is generally sufficiently low to avoid drawing water in through the nasal passages, so this may indicate that the performance of the regulators was less than ideal.

**(51) Fatality,**

At the start of a planned dive to 60m, one of a pair of rebreather divers was noticed moving lethargically, and then sinking rapidly without moving. His body and equipment were not recovered for a further three months.

His rebreather equipment had been adapted to accept two forms of diluent (air or 7.5% oxygen trimix), and three other off-board cylinders of gas were being carried for suit and BCD inflation, and decompression. Because of the time spent under water before recovery, no performance testing of this equipment was possible; the breathing loop was flooded, and the oxygen cells and handsets of the rebreather were inoperative; regulators and valves were siezed. Of the two dive computers being worn, only one could be interrogated to extract the dive profile. This showed an immediate and accelerating descent from the surface to 45m, followed by a slight slowing down until the bottom was reached at 58m. The whole decent took less than 3 minutes.

There were no obvious faults with the equipment in use, although some of the cylinders were out of test, and the condition of the sorbent in the scrubber at the time of the dive was unknown. The mix of gases being carried, and the configuration of the equipment were appropriate for the planned dive. Given the shallow depth and rapid onset of the problem, two possible causes could have been:

- Failure of the scrubber through becoming spent or wet, leading to a very rapid build-up of carbon dioxide, causing "shallow water blackout".
- Flushing the rebreather with hypoxic trimix instead of air when close to the surface, leading to immediate unconsciousness.

**(52) Fatality,**

Work carried out for a Police force. Two nitrox divers experienced difficulty in deploying a delayed surface marker buoy (SMB) at the end of their dive to 52m. One was running out of breathing gas when, on the third attempt to deploy the buoy, they both became entangled and were dragged rapidly to the surface, missing over 20 minutes of decompression. One died, but the other survived following recompression therapy.

The deceased's equipment as tested was found to be in very good condition and fully functional in accordance with relevant standards, with the following exceptions:

- The pony regulator set was of an unapproved combination, but would be usable at depths down to 40m.
- The SMB Reel line was found to be entangled.

The diver was using nitrox with 26% oxygen. Observations related to this are:

- The levels of nitrogen narcosis experienced by divers at 52m and breathing gas containing 74% nitrogen would slightly exceed training agency recommended limits.
- The oxygen toxicity risk to divers at 52m and breathing gas containing 26% oxygen would also slightly exceed training agency recommended limits.

It is believed that the dive was started with only 150bar of nitrox in his cylinder.In addition, evidence from the deceased's dive computer suggested that this was the first dive undertaken for over 5 months, and was the deepest dive made by more than 9m. The bulk of his previous dives had been in warm water, and he had not dived in water at the incident temperature for over 8 months.

**(53) Fatality,**

Work carried out for a Police force. Towards the end of a trimix dive to 67m, one of a pair of divers lost control of his buoyancy when the legs of his drysuit inflated and he inverted. Despite attempts to correct the problem by his buddy (who became entangled in marker lines) he made an uncontrolled ascent from 58m, and subsequently died. The bulk of his equipment was lost during his recovery from the water. The deceased's drysuit valves, dive timers, and wrist slates indicating the dive plan were sent to HSL for examination.

The drysuit valves were found to be in good condition, and worked as intended, shutting off cleanly. The adjustable automatic dump valve was set to retain the maximum amount of air in the suit. The two dive timers agreed closely, although they were of a type which recorded only minimal information. The stated gas mixes and dive plans were suitable for the intended dive.

**(54) Incident,**

Work carried out for a Police force. Two divers (one nitrox, one air) encountered difficulties at 20m, and one started to use the other's octopus regulator as they ascended. At ~10m depth, the distressed diver appeared to black out and sank, to be recovered a few minutes later (his own octopus regulator was found to be in place), and was revived. Two scuba sets and two dive computers were sent to HSL for examination.

The equipment was subjected to a visual examination only at the request of the customer. The pressure gauge on one set indicated 70 bar with no applied pressure. Two dive computers were downloaded, and agreed closely up to the point where the buddy diver made a rapid ascent to the surface. Markings on one cylinder indicated that it had been oxygen cleaned in October 2003, ten months <u>after</u> the date of the incident.

# ANNEX 2

Copy of the promotional material and request form for the testing of diving equipment, developed for this project.

## Health & Safety Laboratory

# Diving Equipment Testing and Examination Service

The Health and Safety Laboratory (HSL), in conjunction with the Offshore Division of the Health and Safety Executive, is currently providing a testing and examination service for Diving Equipment that has been involved in incidents or dangerous occurrences.

- Diagnostic examination of incident samples
- Performance testing of SCUBA regulators
- Performance testing of closed-circuit rebreathers
- Performance testing of diving helmets
- Testing of buoyancy compensators (BCDs) and drysuit inflation valves
- Cold water performance testing
- Testing to European Standard EN250
- Experienced and Trained Personnel
- State of the art ANSTI test equipment

Tests are performed on the diving equipment which may identify whether the diving equipment was faulty, whether it was being used beyond its capabilities, or if it was being used incorrectly. Problems caused by poor and incorrect maintenance can also be identified.

The basic service is currently being offered free of charge, this will include collection of the incident sample(s) by HSL staff within 3 working days, followed by testing of the apparatus and a standard report on the findings. Witness statements can also be provided on request, although this will incur a charge.

HEALTH & SAFETY LABORATORY

An Agency of the Health and Safety Executive

## Commissioning an examination of diving equipment

Upon identifying equipment for examination you should conduct the following procedures as soon as possible:

- Close any cylinder supply valve(s), note the number of full turns of the handwheel required to do so, and in which direction. Do not subsequently re-open the cylinder valve as this can dislodge any foreign bodies which may be present.

- If avoidable, do not disconnect any parts of the equipment from each other.

- If the apparatus is contaminated (e.g. with oil or silt), do not attempt to clean it as this may dislodge any foreign bodies which may be present.

- Impound the equipment by placing it in a suitable bag or container. Seal the bag or container in as tamper-proof a way as possible. Label with the time and date of sealing.

- Contact HSL by telephone on (0114) 2892000, and ask for the Personal Protective Equipment Section to notify of the incident occurrence, and to arrange subsequent collection of the equipment. Out of office hours please fax on (0114) 2892526.

- Complete the examination request opposite (photocopies are acceptable) and forward it to HSL with the equipment for test (work cannot be commenced until this is recieved by HSL)

Please note that it is important that HSL recieve the apparatus for examination in an unaltered state. Cursory examinations by manufacturers or third parties (eg other divers) should be discouraged until after the apparatus has been tested by HSL.

## Examination Request Form

Examination requested by:[1] ...........................................................................................................

Tel: .............................................................. Fax: ..............................................................................

Contact name: ..........................................................................................................................

Address: ...................................................................................................................................

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Short description of incident:[2] ...........................................................................................

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Location of Incident: ............................................ Time/date of incident ......................................

Are Dive Profiles available?[3] ...............................................................................................

Type of diving equipment involved.[4] .....................................................................................

Likely contaminants:[5] ...........................................................................................................

Is the equipment Impounded/secured? ....................................................................................

Are legal proceedings likely? ..................................................................................................

Is Scottish law involved? .........................................................................................................

On completion, please send with the equipment to: Personal Protective Equipment Section, Health and Safety Laboratory, Broad Lane, Sheffield, S3 7HQ. Fax number is **(0114) 2892526**. If you require further advice before submitting this request please contact HSL by telephone on **(0114) 2892000**, and ask for the Personal Protective Equipment Section.

**Notes:**

1. Name of applicant body or organisation
2. Include as much information about the circumstances of the incident as is known. If possible also include notes on where the equipment was found (e.g. if recovered from depth), what the diver was doing at the time (e.g. type of work) and anything else which you consider could be relevant. Descriptions of the incident given by accompanying divers can be of use to HSL in recreating the incident conditions.
3. Most divers use wristwatch-style Dive Computers which record factors such as depth, temperature etc during a dive (a dive 'profile'). If dive profiles are available - the 'incident' divers computer, or a dive computer profile from another diver in the same party - it may be possible to recreate the same profile at HSL. These should be provided along with the apparatus if available.
4. e.g. SCUBA, Rebreather, Diving Helmet etc. In the large majority of recreational diving incidents the apparatus will be SCUBA.
5. Indicate whether equipment is contaminated (e.g with oil, sand or silt etc) either internally or externally.

# Health and Safety Laboratory

The Health and Safety Laboratory (HSL) is Britain's leading health and safety facility and has an established international reputation. Operating as an Agency of the Health and Safety Executive (HSE) we play a pivotal role in support of HSE's mission to ensure that risks to people's health and safety from work activities are properly controlled. As well as delivering a comprehensive service to HSE, we are also able to offer our unique portfolio of skills and expertise to other public and private sector organisations, both in the UK and overseas.

**What services do we provide?**

- assessment of levels of risk and investigation of their control
- contract research and development
- forensic investigation into the causes of work-related accidents
- establishing realistic requirements for standards and processes for meeting those standards
- environmental and biological monitoring
- specialist advice
- validation and certification
- provision of expert witnesses
- training

Drawing upon our wide range of skills and expertise we can rapidly assemble multi-disciplinary teams to help solve your health and safety problems.

**For further information contact:**

**Business Development Unit**
**Health and Safety Laboratory**
**Broad Lane**
**Sheffield S3 7HQ**

**Telephone: 0114 289 2920**
**Fax: 0114 289 2850**
**email: hslinfo@hsl.gov.uk**
**Website: www.hsl.gov.uk**

May 2000

## ANNEX 3

Current Documentation used by HSL for information to potential customers, and guidance for equipment involved in a diving incident.

### Health & Safety Laboratory

# Diving Equipment Testing and Examination Service

The Health and Safety Laboratory (HSL) offers a comprehensive testing and examination service for diving equipment that has been involved in incidents or dangerous occurrences. Tests can help to identify whether the equipment was faulty or was being used incorrectly or beyond its capabilities. Problems caused by poor or incorrect maintenance can also be identified.

HSL's trained and experienced staff use state of the art ANSTI test equipment to provide a range of services:

- Diagnostic examination of incident samples
- Performance testing of SCUBA regulators
- Performance testing of closed-circuit rebreathers
- Performance testing of diving helmets
- Testing function of buoyancy compensators (BCDs) and drysuit inflation valves
- Cold water performance testing
- Testing to European Standard EN250
- Breathing Gas Analysis

In addition to a report on the findings, witness statements can be provided on request.

Whether you are looking for testing, forensic investigation into the causes of diving accidents or research and development work related to diving equipment, HSL can meet your needs.

HEALTH & SAFETY LABORATORY

An Agency of the Health and Safety Executive

# Diving Equipment Testing and Examination Service

## Commissioning an examination of diving equipment

Upon identifying equipment for examination you should conduct the following procedures as soon as possible:

- Close any cylinder supply valve(s), note the number of full turns of the handwheel required to do so, and in which direction. Do not subsequently re-open the cylinder valve as this can dislodge any foreign bodies which may be present.
- If avoidable, do not disconnect any parts of the equipment from each other.
- Send photographic records of equipment prior to the disassembly if the equipment has to be disassembled.
- If the apparatus is contaminated (e.g. with oil or silt), do not attempt to clean it as this may dislodge any foreign bodies which may be present.
- Impound the equipment by placing it in a suitable bag or container. Seal the bag or container in as tamperproof a way as possible. Label with the time and date of sealing.
- Contact HSL by telephone on (0114) 289 2000, and ask for the Personal Protective Equipment Section to notify of the incident occurrence, and to arrange subsequent collection of the equipment. Out of office hours please fax on (0114) 289 2526.
- Complete an examination request form and forward it to HSL with the equipment for test (work cannot be started until this is received by HSL). The form can be found on HSL's website at www.hsl.gov.uk/xxxxxx/ or sent to you by post or email on request.
- Quotes for the cost of work proposed are available from HSL.

Please note: It is important that HSL receives the apparatus for examination in an unaltered state. Cursory examinations by manufacturers or third parties (e.g. other divers) should be discouraged until after the apparatus has been tested by HSL.

For further information contact:

Business Development Unit
Health and Safety Laboratory
Broad Lane
Sheffield S3 7HQ

Telephone: 0114 289 2920
Fax: 0114 289 2830
email: hslinfo@hsl.gov.uk
Web site: www.hsl.gov.uk

July 2004

HSL offers a comprehensive testing and examination service for diving equipment that has been involved in incidents or dangerous occurrences. Tests can help to identify whether the equipment was faulty or was being used incorrectly or beyond its capabilities. Problems caused by poor or incorrect maintenance can also be identified.

HSL's trained and experienced staffs use state of the art ANSTI test equipment to provide a range of services:

- Diagnostic examination of incident samples;
- Performance testing of SCUBA regulators;
- Performance testing of closed-circuit rebreathers;
- Performance testing of diving helmets;
- Testing function of buoyancy compensators (BCDs) and drysuit inflation valves;
- Cold water performance testing;
- Testing to European Standard EN250;
- Breathing Gas Analysis.

In addition to a report on the findings, witness statements can be provided on request.

Whether you are looking for testing, forensic investigation into the causes of diving accidents or research and development work related to diving equipment, HSL can meet your needs.

## Commissioning work at HSL

Before sending any equipment to HSL for examination, it is important that you contact us for a quotation. Ring 01298 218000 and ask for the PPE Section, or fax details to 01298 218393. You should have available as much information on the equipment as possible as well as details of the incident, if appropriate.

NB: It is important that we receive equipment for examination in an unaltered state wherever possible, particularly when forensic investigation is required. Cursory examination by other divers, manufacturers, etc. must be discouraged.

QinetiQ

HEALTH & SAFETY LABORATORY

## Guidance in the event of Handling Diving Equipment Post Accident

### Personal Safety

If mishandled, diving equipment can be hazardous to health.

Do not place any person in a dangerous situation to recover any equipment.

Diving equipment may contain gas at high pressure.

Re-breathing equipment may contain hazardous chemicals.

Diving equipment may be heavy, ensure when lifting equipment that correct handling techniques are used.

### General Procedure

**DO NOT DISMANTLE THE EQUIPMENT**

Record the following dive information:

- Date, time and location of incident.
- Dive time and maximum depth of dive for the diver and any companions.
- Dive plan, decompression schedules used and if completed correctly.

Try to handle the equipment as little as possible.

Note and record on recovery of equipment:

- If buoyancy device or dry suit hoses are connected on recovery.
- If equipment was damaged, prior to or during recovery.
- Information displayed on a dive computer at time of recovery.
- All pressure displays/gauges and record pressures.
- Any details displayed on other electronic instruments.

Gather together and isolate all equipment involved in the accident, including:

- Dive Slate/Logs covering previous 48 hours.
- If available at least one other gas cylinder charged from the same source.

Attempt (do not force) to close all cylinder and isolator valves, note and record number of turns required for each valve (1 turn = 360°).

Tape valves on cylinders and manifolds in the closed position.

Tape any controls or valves on regulators, buoyancy devices and dry suits (including swivel inflation connections) in the position found to prevent any inadvertent movement.

## Specific for re-breathers

All re-breather mouthpieces to be closed.

The rebreather to be stored in an upright position.

Close any automatic overpressure exhaust valves (note number of clicks or turns needed to close valve).

Retain and keep with incident apparatus any samples of unused soda lime (from same batch) in the original container.

## For storage and transportation

Allow any computer(s) to go into standby mode preferably by air-drying or switch computer off.

## DO NOT

- Seal wet electronic equipment in plastic bag (a discharged battery can wipe any memory available).
- Leave valves open on cylinders.
- Vent the gas in a cylinder prior to transport.
- Move maximum depth recordings on analogue gauges.
- Change position on any regulator controls.

## Examination Request Form

Examination requested by:[1] ……………………………………………………………………………………………………

Tel: ……………………………………………………..………… Fax: ……………………………………………………….

E. Mail:.........................................................................

Contact name: ……………………………………………………………………………………………………………….

Address: …………………………………………………………………………………………………………………….

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Short description of incident:[2] ……………………………………………………………………………………………

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Location of Incident: ……………………………………………………………………………………………………….

Time/date of Incident: ……………………………………………………………………………………………………..

Are Dive Profiles available?[3] …………………………………………………………………………………………….

Type of diving equipment involved:[4] ……………………………………………………………………………………

Likely contaminants:[5] ……………………………………………………………………………………………………..

Is the equipment impounded/secured? ……………………………………………………………………………...

Are legal proceedings likely? …………………………………………………………………………………………

Is Scottish law involved? ……………………………………………………………………………………………….

Is collection of the incident sample required? ……………………………………………………………………….

On completion of this form please email to diving.services@hsl.gov.uk , or fax to 01298 218393. If you require further advice before submitting this request, please contact HSL by telephone on 01298 218000, and ask for the Personal Protective Equipment Section.

**Notes:**

1. Name of applicant body or organisation.
2. Include as much information about the circumstances of the incident as is known. If possible also include notes on where the equipment was found (e.g. if recovered from depth), what the diver was doing at the time (e.g. type of work) and anything else which you consider could be relevant. Descriptions of the incident given by accompanying divers can be of use to HSL in recreating the incident conditions.

3. Most divers use wristwatch-style Dive Computers which record factors such as depth, temperature etc during a dive (a dive ‘profile’). If dive profiles are available – the ‘incident’ divers computer, or a dive computer profile from another diver in the same party – it may be possible to recreate the same profile at HSL. These should be provided along with the apparatus if available.
4. e.g. SCUBA, Rebreather, Diving Helmet, type of breathing gas etc. In the large majority of recreational diving incidents the apparatus will be SCUBA.
5. Indicate whether equipment is contaminated (e.g. with oil, sand or silt, body fluids etc) either internally or externally.

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