	Title of report: Health surveillance programme for diving in the range 180-225 msw			
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Work carried out by: Jan Risberg Marit Skogstad Stein Modahl Olav Sande Eftedal Lars Ole Goffeng	NUI's contact: Jan Risberg		Checked by: NA	

Summary:

Legislative requirements and industrial standards call for extended health examinations for divers participating in dives deeper than 180 msw. A previous report (NUTEC Report 20-94) specified a health examination programme for divers diving deeper than 180 msw. The report is outdated and in need of a revision. A working group was tasked to elaborate a revised programme for health surveillance of divers participating in dives 180-225 msw. The working group was supervised by a reference group consisting of representatives from the scientific community, industry, and regulatory bodies. The working group reviewed the scientific literature to ensure that health examinations was based on current knowledge of health effects of diving in general and deeper diving in particular. The group recommends that the existing health surveillance programme for diving on the Norwegian Continental Shelf should be strengthened by examination for HPNS including neuropsychological tests. The extension of the health surveillance programme is motivated by the observation that HPNS might have caused CNS sequelae in some cases. To monitor changes, the examinations should take place before, during and 1-2 days after the dive. Any symptom or finding suggesting injury or illness should be investigated further. The report details the recognised limitations and improvement areas (in particular organisational matters) of the programme.

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Saturation Diving Health surveillance	Metningsdykk Helseoppfølging Dykking

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1 EXECUTIVE SUMMARY – HEALTH SURVEILLANCE PROGRAMME

RECOMMENDED HEALTH SURVEILLANCE PROGRAMME FOR COMMERCIAL DIVERS PARTICIPATING IN DIVING OPERATIONS IN THE DEPTH RANGE OF 180-225 METERS OF SEA WATER (MSW)

The health surveillance programme (short- and long-term) should be based on the existing programme established for health surveillance of divers participating in dives to shallower depths.

The health surveillance for divers participating in dives ranging 180-225 msw should be expanded with these examinations:

- HPNS tests
    - The HPNS tests should include a questionnaire for HPNS symptoms, tests for tremor, hand grip strength and a selection of neuropsychological test. The neuropsychological tests should as a minimum include testing of:
        - Executive function (e.g. Trail making B, WAIS Digit span backward, Stroop Colour Word Interference test)
        - Attention (e.g. Trail making A, Digit span Forward)
        - Memory (e.g. Benton Visual Retention Test, California Verbal Learning Test, Wechsler Memory Scale)
    - The HPNS tests should take place immediately before the dive, when compression is paused at pressure exceeding 150 msw, at bottom “depth” (isopressure) and 24-48h after finished dive

The occupational health service (OHS) should consult a specialist in clinical neuropsychology in the preparation of the HPNS and neuropsychological test battery. At least one recognised clinical neuropsychological test should be applied for assessment of each of the areas: executive function, attention and memory. The OHS should consider need for additional tests to assess any HPNS impairment. Tests results should be reviewed by the OHS and the neuropsychologist. Changes suggesting CNS affection should be followed up.

The programme for health examinations, including selection examinations and short- and long-term health surveillance, is detailed in Chapter 19.3.

2 CONTENTS

3 MEDICAL EXPRESSIONS/ABBREVIATIONS

Anisocoria	Different size of the eyes´ pupil
Antioxidants	Substances that prevent or reduce oxidation and, consequently, quality deterioration and reduced durability of natural and synthetic products
Aphasia	An inability to comprehend and formulate language because of damage to specific brain regions
Apoptosis	Death of cells
Ataxia	Cerebral symptoms; unsteady gait
Auditory evokes potentials	Testing used to determine if specific parts of the vestibular system are functioning properly
Barotrauma	Damage to the cavity in the body due to change in the volume of the gas in the cavity (Boyle Mariotte's law)
Bell run	The period the (saturation) diver stays within or locked out from the diving bell. This is the diver's work period in contrast to the rest period within the living chamber.
Bends	Bridge/dam workers who first experienced decompression sickness/illness from working in caissons (airtight chambers) coined the phrase because it made them bend over in pain
Bone scintigraphy	An examination in which a radioactive chemical is injected into the blood stream. The chemical attaches to areas where there is a high production of new bone, which usually indicates bone damage. A gamma camera is then used to detect the chemical in the bone tissue and a digital image is created
BMI	Body mass index, (kg/m^2)
Complement	A group of proteins present in the blood which play an important role in the defence of many viral and bacterial infections
Compression	Increase of ambient pressure during the first phase of the dive, increase in storage depth or during the descent of an excursion
Cohort	HERE: a group of individuals subjected to a follow-up study

CNS	Central nervous system. This is commonly subdivided into the spinal cord, brain stem, cerebellum, and cerebrum.
CRP	C-reactive protein
CT	Computer tomography
DCI	Decompression illness
DCS	Decompression sickness
Decompression	Reduction in ambient pressure during decrease in storage depth, the last phase of the dive or during the ascent of an excursion.
Diving contractor	The company responsible for the provision of diving services (manned underwater operations) to the operator company.
DL_{CO}	See TL_{CO}
DON	Dysbaric osteonecrosis
Doppler technique	A supplement to ultrasound examination that can be used to measure blood flow rate and blood pressure
Echocardiography	A medical examination of the heart using ultrasound waves and their reflections ("echo") from the heart's different parts
EEG	Method for registering the electrical activity in the brain
Endothelial dysfunction	An abnormal function of the endothelial layer inside the vessel
Erythrocyte	Red blood cell
Erythropoietin	A protein which stimulates the formation of red blood cells
Excursion	A short period of pressure increase or decrease from storage depth. Usually due to the need for the diver to descend or ascend from the diving bell to the worksite.
$FEF_{25\%}$ / $FEF_{75\%}$	Part of the pulmonary function test: Speed of exhalation *at* the time when 25% and 75% of the forced lung volume (FVC) has been exhaled.
$FEF_{25-75\%}$	The average exhaled flow rate in the mid-expiratory part of a maximum expiratory manoeuvre. A reduced $FEF_{25-75\%}$ is commonly interpreted as a dysfunction of small airways.

Femur	The thigh bone
Ferritin	Iron-containing protein found in the cells of the intestinal mucosa, in the liver and spleen. The protein acts as iron depot and emits iron to the blood when iron consumption exceeds the supply
FEV_1	Forced expiratory volume in 1 second. The air volume the subject can blow out in the first second of the manoeuvre
Foramen ovale	A passageway between the right and left chambers in the healthy foetal heart. Normally closes during the first two years of living.
Heliox	Gas mixture of helium and oxygen. This is the most common breathing gas in saturation diving.
Hematology	The diagnosis, treatment, and prevention of diseases of the blood and bone marrow as well as of the immunologic, haemostatic (blood clotting) and vascular systems
Hemolysis	Active destruction of red blood cells
Hemiplegia	Paralysis of one side of the body
Hgb/Hct	Haemoglobin found in the red blood cells / Haematocrit (Hct) is the percentage volume of red blood cells (erythrocytes) of a blood volume
HPNS	High pressure nerve syndrome
Hyperbaric exposure	Exposure to high level of pressure
Hyperbaric nurse	A nurse engaged in manned underwater operations and trained in hyperbaric medicine
Hyperoxia	Exposure to high levels of oxygen
Hypercapnia	Exposure to high levels of CO_2
Hypoxia	Exposure to low levels of oxygen
Humerus	The long bone of the upper arm
Inert	Without chemical activity
Infarct	Damage to the tissue in the body due to lack of blood supply (ischemia)
In vivo/in vitro	In vivo: in the living, tests/examinations made in living organisms (human or animal) / in vitro: studies in laboratory settings of tissue and cell cultures.

Ischemia	Insufficient blood flow to sustain the organ's demand.
Juxta-articular	Near or in the region of a joint
LOC	Loss of consciousness
Lock-out	When the saturation diver is in the water (lock-out from diving bell)
MRI / MR	Magnetic resonance imaging
msw	Meters of sea water. A pressure unit corresponding to the ambient pressure of 1 meter of sea water. Is commonly (though erroneously) even used as a description of diving depth.
NCS	Norwegian Continental Shelf
Neutrophil cells	One subgroup of leucocytes (white blood cells). Plays an important part in immune system in general and defence of bacterial infections in particular
NPV	Negative predictive value. A statistical index describing the proportion of the negative test results that will be "true negative". A low NPV of a diagnostic test will suggest that a large proportion of subjects with a negative (normal) test result will be ill.
Nystagmus	Involuntary rapid eye movements. A symptom of inner ear or CNS disease.
Operator company	Company with the right to explore for oil and gas in a block and to develop a possible commercial discovery. Usually acts on behalf of a licensee partnership.
OR	Odds Ratio. A statistical index used to compare the ratio of a certain outcome in an exposed group to the ratio in an unexposed group. Though not necessarily correct, a high OR will usually be interpreted that the exposed group has been in higher risk for the outcome than the unexposed group.
p	Prefix denoting a partial pressure. According to the law of Dalton the total pressure of a gas mixture is the sum of the partial pressures for each gas in the gas mixture.
Pneumothorax	Air in the pleural cavity on the outside of the lung. Causes parts of the lung to collapse.

Polyneuropathy	An inflammation (acute or chronic) of many peripheral nerves
PPV	Positive Predictive Value. A statistical index describing the proportion of subjects with a positive test result that will be “true positive”. A low PPV of a diagnostic test will suggest that a large proportion of subjects with a positive test result will actually be healthy.
Prevalence	The number of subjects with disease in a particular population at a given time
PSA	The Norwegian Petroleum Safety Authority
PTSD	Post-traumatic stress disorder
RCDD	Responsible competent diving doctor
Saturation	Colloquially used in this document for the hyperbaric exposure of a saturation diver.
Saturation diving	The diver is exposed to a continuously raised pressure for a long time (usually days) and is transferred from a pressure chamber to the work site by means of a diving bell. The diver is “saturated” with inert gas. In contrast the diver in surface-oriented diving will return to surface after minutes or a few hours of pressure exposure. Saturation diving is in practice the only manned subsea intervention used for depths exceeding 50 msw and is commonly used even for shallower diving in oil and gas exploration. While saturation diving may allow long dives, the decompression phase is slow – typically in the order of 10-30 msw/day.
Saturation period	The total time of a saturation dive. It will include the time for compression to storage depth, time at storage depth (isopressuer) and the decompression time.
SCUBA	Self-Contained Underwater Breathing Apparatus, Breathing gas is supplied by pressurised containers carried by the diver. Contrasts to surface supplied diving in which the diver breathes gas supplied from a gas storage on surface.
SPECT	Single-photon emission computed tomography (SPECT, or less commonly, SPET) is a nuclear medicine tomographic imaging technique using gamma rays
Storage (depth)	The stable pressure (isopressure) at which the diver rests between bell runs. This is usually the longest

	part of the saturation dive preceded by the compression and followed by the decompression phase.
Surface oriented diving	Conventional diving, usually breathing compressed air to depths 50 msw or shallower. In-water decompression time is typically 30 min or shorter. Dive time may be in the order of 4h for very shallow dives but is typically less than 1h for depths exceeding 18msw.
Tibia	Shinbone or shankbone
TLCO/DLCO	Diffusion capacity for CO (Carbon Monoxide) - a part of an advanced lung function examination. Used to measure the diffusion rate of CO from the lungs to the bloodstream
WMH	White matter hyperintensities. Changes in MR images presented as “bright spots” located in cerebral white matter.
WOB	Work of breathing. The work required to complete a respiratory cycle. As breathing gas get denser when diving depth increased, WOB will increase as well unless the gas mixture is changed.

4 INTRODUCTION

The oil and gas industry has identified a need for manned diving operations to depths down to 225 meters. This is based on an assessment that modifications, maintenance, and repair work to some of the subsea installations on the Norwegian continental shelf potentially cannot be completed by unmanned operations.

The term “deep diving”, defined as diving deeper than 180 meters, was introduced by the Norwegian Petroleum Directorate and the Directorate of Health in *Regulations concerning manned underwater operations in the petroleum activity* published in 1990 [1]. The background for the 180-meter divider was the challenge of hyperbaric evacuation if the saturation chamber complex consisted of groups of divers pressurised to different levels deeper and shallower than this threshold. The guidelines to §63 of these regulations stated that “current equipment and procedures for such operations indicate that special measures should be taken”. The regulation prescribed stricter limitations for exposure time and double time off between saturation periods for divers participating in deep diving. Although the mentioned regulation is no longer valid, the provisions for deep diving are still found in current regulations and standards for manned underwater operations in the Norwegian petroleum activities [2].

As a consequence of injury to divers participating in a simulated verification dive to 250 meters in 2002 (see chapter 11.2), the Norwegian operator companies introduced a temporary 180-meter depth limit for diving operations. The Norwegian Petroleum Safety Authority (PSA) agreed to this temporary limit and stated that the safety for the divers must be proven before the authorities can give consent for diving operations deeper than 180 meters. A suggestion for safety in this context is a risk level not exceeding the risk in conventional saturation diving shallower than 180 meters.

The strain on the diver is conventionally expected to increase with increasing depth. We will discuss this claim later in the report. To prevent increased risk, mitigating measures should be implemented when maximum diving depth is increased. Some measures are detailed in national Norwegian regulations and industry standards, e.g. provisions regarding maximum bottom time, maximum in-water time and minimum rest period between saturations. NORSOK U-100 [2] holds the majority of such detailed requirements. Additional mitigating measures may be specified by the diving contractor or the operator company.

We recognise that the extent of long-term health effects of diving remains debated and controversial. We have based our approach to this subject on the consensus statement in the proceedings from the conference “Long Term Health Effects of Diving” in Bergen 1993 [3]:

> *There is evidence that changes in bone, the CNS and the lung can be demonstrated in some divers who have not experienced a diving accident or other established environmental hazard.*
> *The changes are in most cases minor and do not influence the diver’s quality of life. However, the changes are of a nature that may influence the diver’s future health.*
> *The scientific evidence is limited, and future research is required to obtain adequate answers to the questions of long term health effects of diving.*

The status of knowledge, which forms the basis for our recommendations, are detailed in Chapters 10 an onwards.

This report will discuss and detail the requirements for a health surveillance programme. In NORSOK U-100 [2] it is stated that “When diving deeper than 180 msw, the divers shall be followed up in accordance with detailed examination as specified in Nutec-1994-20 (…) or equivalent.” We consider that the report NUI-1994-20, “*Helseovervåking av dypdykkere”,* [4] was a thorough work, co-authored by experienced specialists, and reflected the basis of knowledge and practice at the time. New studies of health effects of diving have been published since the report was issued. Equally important is the fact that there has been a general development of principles in the field of occupational medicine for health surveillance of workers. We have described the current level of knowledge in chapters 8-16. The influence of these principles on the interpretation of NUI-1994-20 is detailed in chapter 17.2.

5 SCOPE OF WORK

The original scope of work (APPENDIX 1) for the working group was linked to diving operations with Equinor as the operator company. Based on discussion in the reference and working groups, we have decided to make the procedure general, i.e. applicable for long-term health follow-up of all diving operations in the depth range 180-225 meters. An additional minor deviation from the scope, related to HPNS screening, has been necessary and the background for this is detailed in section 11.2.1. The scope of work for the reference group (see section 6.1) is attached as APPENDIX 2.

6 METHODS

6.1 Organisation: Working group and reference group

The report has been compiled by a working group comprising diving physicians, occupational physicians and a psychologist. The working group members and their affiliations are listed in Appendix 3.

In Norway, there is a strong tradition to ensure broad involvement in the development of occupational health and working environment regulations and standards. Such involvement includes employers, employees and the worker union(s) as well as the governmental agencies. This is done to ensure that different aspects of risk assessment and risk management related to the performance of the work are covered. To ensure such a broad involvement in the present work, a reference group was established with representatives from the parties and the government agencies supervising inshore and offshore diving operations. The members of the reference group and their affiliations are listed in APPENDIX 2.

6.2 Working process

The reference group as well as the working group started the working progress with separate meetings May 3rd 2018.

The working group initially evaluated whether the NUI-report NUI-1994-20 [4] could be revised. It was evident that parts of the examination programme as recommended in NUI-1994-20 was outdated since it could not be substantiated by current knowledge of health effects of diving (e.g. extent of blood tests and requirements for skeletal and lung x-ray examinations). This is discussed in further detail in chapter 17.2. Rather than revising NUI-1994-20 we decided to structure a new report based on current knowledge of health effects of diving and current principles of occupational health surveillance. In agreement with the scope of work, the current report was limited to health surveillance for divers participating in diving operations in the depth area 180-225 msw.

The working group initially discussed which organ systems were known to be affected by diving. Previous studies [3, 5-7] have identified potential long term health effects on lung function, the nervous system, hearing, balance and bone. Surveillance of these organ systems have therefore been discussed in detail in separate chapters. Additionally, we have reviewed health effects on other organ systems as discussed in Chapter 15.

These topics were addressed for each organ system:

- Recognised acute and long-term health effects
- Mechanisms expected to cause these health effects
- Methods to identify the health effects

- Sensitivity, specificity, and efficacy (NPV, PPV) of the various methods applied for the surveillance of divers participating in dives ranging 180-225 msw, if this information is available.

We refer to chapter 6.4 for details regarding editorial responsibility and institutional commitment.

The result of the work is presented in this report. We have assessed and discussed occupational exposure in saturation diving in general and the potential increase in health risk with increasing maximum diving depth from 180 to 225 msw. This is done for each organ system separately. In the very last phase of the work, we completed a literature search for diver health surveillance programs. The result of this is presented in chapter 17. The last chapter of the report details a health surveillance programme for divers participating in diving operations in the depth range from 180 to 225 msw. The programme is based on current practice and principles in occupational medicine with respect to risk-based health surveillance of employees.

6.3 External review of the report – comments from the reference group

There has been a constructive dialogue between the working group and the reference group in the preparation of the health surveillance programme. Input from the reference group has been of great value and improved the quality of the report. Still, the suggested health surveillance programme is not based on a consensus with all members of the reference group. The main discussions have been related to the extent of medical tests and the sensitivity and specificity of various tests. It has been stated by members of the reference group that the proposed health surveillance programme has low sensitivity, i.e. it will not be able to detect possible adverse health effects on a subclinical level. We do agree that the ability of the suggested programme to detect sub clinical health effects is limited. However, it is our strong opinion that medical tests performed on a presumed healthy population should correctly identify healthy individuals, i.e. the test specificity is crucial. We have discussed this in further detail in section 18.1.

6.4 Institutional commitment

The National Institute for Occupational Health in Norway (STAMI) initiated this work on request from Equinor. The scope of work, working group participants and reference group representatives were all mutually agreed Q2 2018. The working group jointly contributed to the report (see chapter 6.2) with Marit Skogstad as the principal co-ordinating editor. A draft version of the report was distributed to the reference group Sep 7th 2018 for comments. A final report was distributed to the reference group May 27th 2019. Comments were received from Haukeland University Hospital, Norwegian Petroleum Safety Authority, the Norwegian Labour Inspection Authority and one of the Norwegian trade unions organising divers. Haukeland University Hospital presented in detail a number of disagreements. In January 2020 the working group was informed that STAMI would not take responsibility for publishing the report. This decision was based on the fact that substantial disagreement existed between the conclusions of the working group and those vocalised by other organisations. STAMI accepted that two of their scientists (MS and LOG) could contribute to co-author the final report but pointed out that STAMI as an institution would not endorse the report contents.

The question of publishing was returned to the client (Equinor) who tasked NUI to complete the work. This work was started Q4 2020. The report was revised with Jan Risberg as the principal co-ordinating editor but with a shared responsibility and contribution from the other members of the working group. NUI publishes this report, but the content remains the intellectual responsibility of the authors. The content of this report is not claimed to be representative for the authors' employers or clients.

7 PRIMARY PREVENTION AND CONSEQUENCE REDUCTION IN COMMERCIAL DIVING

7.1 Introduction

Commercial diving implicates work in a hostile environment. Without taking precautions, such work may impose a high risk for illness, injury, or death for the diver. Proper risk management is therefore important to reduce the likelihood and consequence of hazardous incidents.

Risk management in the oil and gas industry is often illustrated by the bow-tie model (Figure 1). Barriers on the left side of the potential incident are preventive and contribute to reducing the probability of an incident. If an incident should occur, barriers on the right side are activated to reduce the consequences of the incident.

To remove or isolate a harmful exposure or burden is the preferred risk reducing measure. This barrier is located on the left side of the bow-tie model. Primary preventive barriers and interventions on the left side of the figure can be viewed as *hierarchically organised* [8]. Such hierarchical organisation means that the organisational barriers or prerequisites for safe behaviour should be optimised to increase the probability of interventions closer to the actual work-situation, i.e. the more individual or relational interventions, to be efficient.

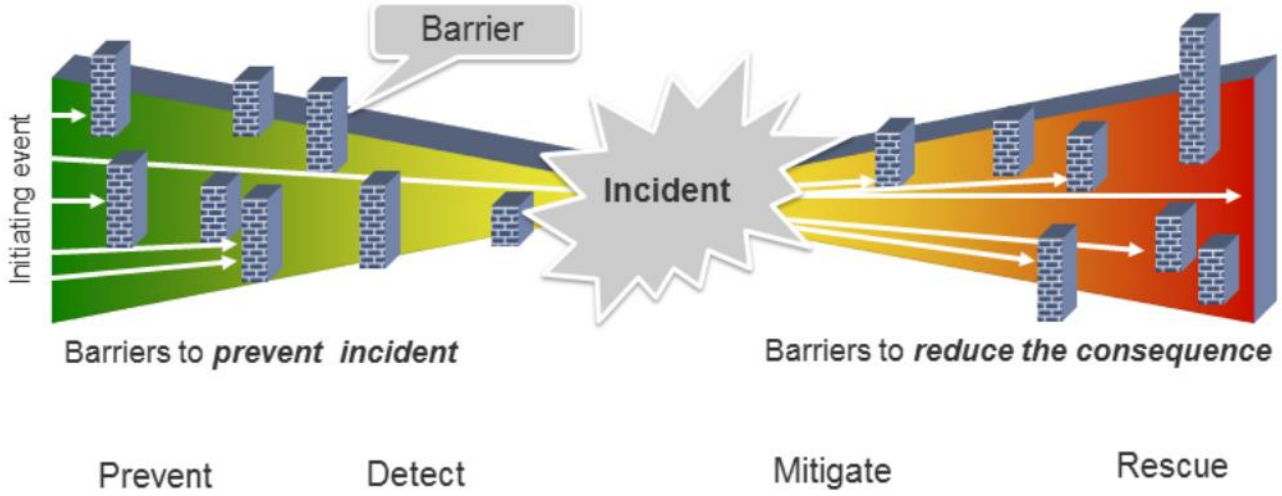

Figure 1 The bow-tie model for risk management

For all diving operations, independent of diving depth, focus is given to the preventive barriers. Important preventive barriers include organisation of working life, procedures, proper equipment, and competence [9].

How working life is organised can affect the likelihood of incidents [10, 11]. A recent systematic review found that holding multiple jobs instead of only one job increases the risk for occupational injuries. The same was found for being employed through a sub-contractor.

Although a literature review from STAMI [12] suggested an association between temporary contracts and increased risk of occupational disease or fatal accidents, Koryani [13] concluded that factors such as extent of temporary contracts, part time-work and level of unionisation, did not show any relation to occupational injury. In fact, union memberships supposedly including safety training and permanent employment, showed the opposite. One explanation of this seeming paradox may be that these factors, rather than contributing to a higher injury rate, contribute to increased knowledge of safety issues. Such an increased knowledge may in turn promote attention to, confidence in and willingness to report incidents. Different group of workers may have different motivation to report, or tend to remember differently (recall bias) [13]. Additionally, there may be a tendency for scientist to search for findings supporting their initial hypothesis (reporting bias) [14, 15].

The reporting of deviations from established procedures is an essential preventive barrier. A safe and sound organisational and psychosocial environment is a prerequisite for such reporting of hazardous exposures and incidents. It is important that the divers' employment situation allows for a certain latitude to express concerns and report adverse events and non-compliance with the specified requirements for the dive. The divers should be encouraged to report deviations from procedures (non-compliances), accidents and near-misses as well as symptoms and signs of adverse health effects. In a more general term of occupational medicine, a high demand on the divers should be followed by a high degree of control of the work situation.

Considering the conclusions of Koryani [13], the operator should consider inclusion of requirements for incident reporting at the early stage of invitation to tender for diving contractors. This will promote the divers' latitude to express concerns regarding their work situation. Such incident reporting has since long been established for offshore diving on the NCS.

7.1.1 Risk management

Risk management is the process of identifying, assessing, and controlling risks. The regulatory bodies may define acceptable risk levels for working life, usually in terms of occupational exposure limits. The employer must have a system to evaluate and reduce occupational risk to an acceptable level. The risk should ideally be determined on scientific knowledge, but the criteria for *acceptable risk* is (in Norway) agreed by the three-party cooperation and finally decided in a political context.

For diving, we do not have a fully developed scientific basis to define a no-risk or low-risk level for the complex exposure situations encountered, and the risk management is therefore based partly on traditional risk assessment and partly on the precautionary principle [16]. Extra precaution is advocated when managing risk under circumstances when there are threats of irreversible effects or where it is more important to avoid false negatives than false positives [16]. The precautionary principle is especially relevant in situations where the scientific knowledge includes uncertainties. Modern risk assessment also includes uncertainty assessment of unexpected outcomes [17].

There is a regulatory requirement in the "Arbeidsmiljøloven" (Working Environment Act) §3-1 [18] for the employer to establish a risk management system. To ensure that the safety and health of workers are respected, the employer must perform systematic health, environmental and safety work at the workplace. This shall be done in cooperation with the employees and their representatives. Systematic Health and Safety Work (HSW) is the

working method for continuous improvement, and this requirement is stipulated in the Working Environment Act [18].

Overall principles for good HSW leadership are systematic routines and good practices. Continuous and systematic improvement work means that the overall HSW work is to be reviewed and assessed regularly.

The legislative framework for the systematic work on health, environmental and safety conditions is elaborated in the "*Forskrift om systematisk helse-, miljø- og sikkerhetsarbeid i virksomheter*" (The Internal Control Regulations) [19] which broadly lists three steps:

1) The first part is mapping that can be done partly through interviews and questionnaires. The practical aspects should be taken care of by the employees when it comes to psychosocial, chemical-biological, ergonomic and organisational factors. However, other information sources must also be considered: In organisations with a poor safety focus and leadership involvement, or a strong culture for punishing deviations, fear of reporting unwanted incidents may overrule the importance of reporting of such incidents [14]. In addition, organisational aspects of risk factors are not always easily experienced and revealed through self-reporting methods. Together, this may limit the representativeness of self-reported information.

2) The second part consists of a risk assessment of the company's work environment challenges. Here a requirement is to try to uncover unsatisfactory work- environment conditions and take action to resolve these.

3) The last part is the action plan. The plan should be written including a schedule. After mapping the conditions, a plan must be implemented. It must be written with an overview of what to do and the responsible person involved.

7.1.2 Risk-based health examinations

Some exposure sources are not easily removed, isolated or even easy to measure. In such cases, absence of health effects can be taken as an indirect proof of acceptable exposure levels. This is particularly relevant for exposure factors that are vaguely defined and when there is a lack of scientific evidence supporting any dose-response and dose-effect relationships.

From a legislative perspective, The Working Environment Act states that the employer shall "ensure continuous control of the working environment and the employees' health when necessitated by risk factors in the undertaking". Requirements for medical examinations of employees in the offshore oil and gas industry is also described in the "Aktivitetsforskriften" (Activities Regulations) section 6 [20]. These regulations call for health examinations in workers exposed to raised ambient pressure.

Inshore diving is mainly performed under the jurisdiction of the Norwegian Labour Inspection Authority. The legal requirement for health examination of divers participating in inshore diving is regulated by "Forskrift om utførelse av arbeid" (Regulations concerning the Performance of Work) [21] §26. These regulations stipulate health *examinations* but not health *surveillance*.

Health surveillance of (saturation) divers should be defined within the frame of risk assessment and risk management. *Risk assessment* is a framework of identification of

hazards, their dose-response associations with negative health outcomes as proven by the published scientific literature, and the expected exposure levels. The risk is summarised in a risk characterisation [22].

Whether an employee has the obligation to undergo health examinations offered by the employer under the Working Environment Act [18], has been subject for debate. In an interpretation of the regulations, the Norwegian Petroleum Directorate (now Petroleum Safety Authority) [23] has previously commented that the employer cannot impose such health examinations on the employee. If the employee does not agree to such an examination, the employer shall file that the offer to participate has been given. It should be considered whether a reservation to take part in health surveillance for dives in the 180-225 msw range is compliant with the employers' responsibility to monitor the working environment. The preventive aim of the health surveillance of divers participating in such dives will be difficult to reach without a high degree of participation. One option would be to mandate participation for divers participating in dives ranging 180-225 msw without obligation to participation in dives shallower than this.

8 HEALTH EXAMINATIONS IN COMMERCIAL DIVING

8.1 Introduction

Offshore occupational divers are subjected to several health examinations with different purpose. Some are negative selection: They are aimed to identify illnesses and injuries that may jeopardise the safety or of the diver, the diving team and the diving vessel or impose a risk to the divers' health. Such health examinations are primarily established as a barrier for untoward effects (primary prophylaxis). Other health examinations are intended to identify short or long-term health effects of diving (secondary prophylaxis) to identify failures in barriers and allow individual advice to the affected diver. To complicate further, the legislative and practical framework varies for these examinations as some of them are completed by independent diving physicians onshore annually while others are administered by the hyperbaric nurse on the diving vessel immediately before and after diving.

8.2 Current system for health examinations in saturation diving (down to 180 msw)

For offshore saturation divers working on the NCS, the following regime is established for health examinations:

- Annual health certificate examination performed by an approved doctor and in accordance with national standards [24, 25]. This includes test of physical fitness by direct or indirect measurement of maximum oxygen uptake (VO_2max).
- Pre-saturation (pre-sat) examination before entering saturation chamber, performed by hyperbaric nurse on board the diving vessel
- Post-saturation (post-sat) examination after saturation, performed by a nurse ("hyperbaric nurse") on board the diving vessel
- Annual questionnaire mapping exposure, incidents and potential work-related symptoms (IMCA-programme, Appendix 4)
- 3-yearly examinations including (but not limited to) medical interview, spirometry and audiometry, assessed by the contractor's responsible competent diving doctor (RCDD)

The content of the pre-sat, post-sat and 3-yearly examinations is defined by the contractor's RCDD. For all examinations, interviews and questionnaires, indications of adverse health effects contracted during diving or health conditions with potential consequences for fitness to dive shall trigger the responsible doctor to assess the need for further medical investigation.

Abnormal exposures due to incidents or accidents may call for special measures and follow-up of involved personnel, depending on the nature of the incident and exposure, and is not within the scope of regular health examinations.

	Authority	Objective	Frequency	Managed by	Professional responsibility
Fitness to dive	Forskrift om helsekrav for personer til havs (§§1,4)	Safety	Annual	AME	AME
Long term initial examination	NORSOK U-100 5.1.4	Baseline for identifying changes in long term health	Start of employment	RCDD	OHS
Pre-dive	NORSOK U-100 5.1.4	Safety *and* basis for identifying changes in short term health	Immediately before each saturation dive	HN	OHS
HPNS	NORSOK U-100 8.2.4	Safety	Before compression and before first bell run on dives deeper than 180 msw	HN	OHS
Post-dive	NORSOK U-100 5.1.4	Short term health changes	Immediately after each saturation dive	HN	OHS
Long term follow-up	NORSOK U-100 5.1.4	Long term health changes	Annual during employment period and extended examination every 3rd year	RCDD	OHS

Table 1 Brief overview of routine health examinations of offshore divers. Abbreviations: AME: Approved medical examiners ("dykkerleger"), HN: Hyperbaric Nurse, OHS: Occupational Health Service, RCDD: Responsible Competent Diving Doctor ("Dykkermedisinsk faglig ansvarlig lege")

8.3 Selection of divers fit for diving

From a primary prevention perspective, an important barrier to safeguard the health of divers as well as the safety of operations, is to select the divers on a medical basis and to assess if they are physiologically fit for the challenges of the diving operation. Professional divers are required by legislation to be subjected to an annual health examination by approved medical examiners (diving physicians). This legislative requirement has been established to ensure that the divers do not represent a safety risk for themselves or others, thus this can be considered a barrier on the left side of the bow-tie model. The diver is required to present the result of the examination (the health certificate) to the employer, but the detailed medical file is subject to medical confidentiality.

8.4 Risk-based health surveillance of commercial divers

Risk-based health surveillance is a barrier included in the execution of safe and sustainable diving operations targeting the employed divers and performed by the employer's occupational health service. From an occupational medicine perspective, the objective of risk-based health surveillance is to verify that risks are adequately controlled, or if not adequately controlled, to identify areas that need improvement. Risk-based health surveillance can be considered a consequence reducing barrier (right side of the bow-tie model).

However, the results from the surveillance may highlight a need for stronger barriers on the left side of the bow-tie model. Risk-based health examinations may also identify personnel with vulnerability to specific exposures. In general, such vulnerability may be mitigated by reduced exposure or ultimately by redeploying the employee to alternative work.

Risk-based health surveillance can be performed if a suitable method for detecting health effects of exposure is available. A suitable method shall be based on scientific principles when it comes to the test's ability to exclude or diagnose work related illness (specificity and sensitivity of the screening test) and shall not pose unacceptable adverse effects to the person examined. If a suitable medical test is not available, it may still be appropriate to monitor subjective health complaints (symptoms). This should be done as a medical interview performed by health professionals from the occupational health service. The assessment will then relate occurrence of symptoms to exposure and adherence to barriers and recommended work procedures.

The resources required, and any inconvenience or harm to the diver, should be balanced against the expected benefit of the examination. The extent of health surveillance should ideally be agreed by all involved parties: the diver, the employer, occupational health service, experts, and legislative agencies. The result will eventually be a balance of benefit vs inconvenience.

For many medical tests there is a trade-off between sensitivity (the ability of the test to identify persons with the injury/disease caused by the exposure) and the specificity (the ability of the test to identify persons without injury/disease caused by the exposure). The importance of specificity is higher if the prevalence of injury is low. E.g. if prevalence is 1% and the specificity of the test is 90%, 9 out of 10 persons with a positive test will not have the injury/disease. A high frequency of false positive tests will give erroneous input to further risk management. It may have consequences for the capacity to follow up divers. For the individual it may have negative consequences [26], especially if the false positive test result will initiate follow-up investigations that may be either harmful to the diver or indicate non-fitness for diving.

With sufficient preventive barriers and adequate control of risks, the prevalence of health injury from occupational exposure will be low. Thus, medical tests in risk-based health surveillance should generally have a high specificity.

Individual results from the surveillance shall be treated as confidential medical information, and not reported to the employer. It is however important that any information indicating unacceptable exposure is reported back to the employer so that measures can be taken to reduce exposure levels. This should be done in such a way that confidentiality is ensured. The occupational health service should compile a sum-up of results on group-level along with a conclusion from the responsible competent diving doctor in a written report to the employer.

Each diver shall have access to his/her own test results and assessments of these made by health professionals. The divers should also have access to the written report with results and conclusion on an aggregated level.

8.5 Limitations of risk-based health surveillance as a tool for primary prevention

Contractual restraints and the diver's freedom to change employer pose challenges for the execution of long-term health surveillance. It is beyond the scope of this document to suggest changes in employment structures, but the structure of the long-term health surveillance programme should account for limitations enforced by the present short-term employment contracts.

A challenge for a health surveillance programme as a tool for risk assessment and primary prevention is that some outcome data (i.e. near misses or subjective complaints) depend on the divers' initiative. Self-reported information may be context-dependent; A short-term individual benefit of maintaining a health-certificate, and ultimately a job as a certified diver, may overrule a long-term benefit of maintaining health unaffected by the working conditions, increasing the risk of group-level underreporting.

Normally, it takes time to detect and establish the quantitative associations between exposure and health effects. The latency between relevant exposure and health effects may be measured by years or decades (e.g. development of cancer after asbestos exposure). It is difficult, and in some cases impossible, to design a health surveillance programme for health effects arising decades after exposure. In such cases it is even more important to establish effective barriers on the left side of the bow-tie model.

9 EXPOSURE PARAMETERS AND HEALTH EFFECTS

9.1 Introduction

The purpose of this chapter is to introduce the reader to the main mechanisms expected to affect physiological responses, illnesses and injuries related to diving. This chapter will probably be of minimal interest for those experienced in diving and diving medicine. It is written for those having limited knowledge of these topics. Later chapters present current knowledge of the effects of diving on various organs and organ functions. Presumed mechanisms, underlying these changes are described in the relevant chapters. The authors of this report decided to focus resources on the description of known health effects of diving (listed in the following chapters) rather than a comprehensive description of all possible mechanisms. The reader is encouraged to read textbooks [27, 28] or investigate scientific literature [29] to reach a more detailed understanding of the topics listed here.

9.2 Challenges in assessing exposure levels in saturation diving

There is insufficient knowledge of the health effects of each occupational exposure factor a saturation diver is subjected to. In fact, it is difficult to precisely identify each exposure factor. The diver is exposed to multiple concurrent environmental factors such as increased ambient pressure, immersion, increased breathing gas density, hyperoxia, breathing gas contaminants and formation of free gas in blood and tissue. This comes in addition to psychosocial factors such as shift work, near-misses, and long periods away from friends and family. To add to this problem, the saturation diver is exposed to many of these factors continuously for weeks. In contrast, a conventional worker is exposed on average for 8h per day for five days. Metabolic systems for detoxification (e.g. antioxidants and hepatic degradation systems) have no time for reconditioning during the prolonged hyperbaric exposure for a saturation diver. Though hyperbaric exposure limits have been implemented for some exposures such as hyperoxia and volatile organic compounds (VOCs), there is little knowledge of health effects caused by toxic substances when exposure time is counted in weeks rather than hours (which is the normal occupational scenario). Parallels may be drawn to spacecrafts and submarines, but these lack the concomitant effects of hyperbaria (raised ambient pressure) and hyperoxia. The absolute magnitude of (inert) gas supersaturation is many orders higher in diving than e.g. spacecraft missions.

9.3 Immersion

When the body is immersed, blood is centralised and as much as 700 ml is moved from the periphery to the chest. This effect is enhanced by cold and cause increased urine production (diuresis) while immersed. Redistribution of blood may be one of the mechanisms underlying changes in pulmonary diffusion capacity measured after dives. Swimmers and divers are at risk of swimming induced pulmonary oedema (immersion pulmonary oedema). The mechanisms causing immersion pulmonary oedema are poorly understood, but the oedema is considered an acute effect of immersion rather than a persistent long-term health effect.

9.4 Changes in ambient pressure

Changes in ambient pressure exert the prominent effects on air filled cavities of the body. Flexible cavities – such as the lung – is least affected unless the mouth or glottis is closed. A

breath hold diver will experience compression of the chest and lung during descent (as ambient water pressure increases about 1 Bar per 10 msw) and it will expand to initial volume on ascent. A diver supplied with breathing gas during diving will maintain lung volumes identical to surface. Divers are trained not to hold their breath during the ascent since intrapulmonary gas otherwise may expand and rupture pulmonary tissue due to overdistension (pulmonary barotrauma). In such situations the gas may be trapped in the chest (mediastinal emphysema), part of the lung may collapse (pneumothorax) and/or the intrathoracic air may gravitate to the top of the chest and neck, accumulating under the skin (subcutaneous emphysema). Though the pulmonary injury may be serious, the worst outcome usually occurs if pulmonary gas is displaced into the pulmonary vessels. Such intravascular gas may be trapped in the arterial circulation and cause cerebral arterial gas embolism (CAGE). CAGE and pulmonary barotrauma are usually considered complications and injuries of diving and such injuries should be considered if changes in CNS and pulmonary function are observed.

Non-flexible air-filled cavities such as sinuses and the middle ear require an open connection to the airways to allow inflow and outflow of gas during descent and ascent. If the opening to the nasal cavity is closed (e.g. due to a common cold) the gas pressure within the cavities will be different from the ambient during descent and ascent. Since the mucosa of these cavities hold a pressure equal to ambient pressure, the thin capillary vessels will be injured, and blood and tissue fluid will be expelled to the cavity until pressure is equalised (sinus and ear barotrauma). Middle ear and sinus barotraumas are not expected to cause long term health effects. However, the membranes between the inner ear and the middle ear (oval and round window) may burst if the diver does exaggerated equalisation manoeuvres (valsalva). Leakage of air lymph may cause permanent hearing and balance deficits.

During deep diving (exceeding 150-180 msw) the diver may suffer High Pressure Nervous Syndrome (HPNS), a complex neurological syndrome including cognitive, autonomous, and neuropsychological symptoms and signs. The underlying mechanism is discussed in the following section. HPNS has traditionally been considered a reversible neurological syndrome, but there are case descriptions of HPNS-like symptoms appearing during compression and persisting after the dive. HPNS is among the few health effects that may be expected to increase when diving is increased from 180 to 225 msw.

HPNS is expected to be induced by increased ambient pressure and rate of pressure change. High pressure decreases the transfer across the synapses [27]. In the brain, there is a general reduction in the release of presynaptic neurotransmitters, which, combined with a reduction of the postsynaptic glycine receptor protein, leads to a reduction in inhibitory control, which then again results in HPNS. It seems that high pressure can affect Ca^2 + ion channels by reducing Ca^2 + influx in the axon, which in turn is important in the release of neurotransmitters in the synaptic transmission [30].

A significant amount of work has been put down by Bliznyuk and co-workers to investigate the effects of high pressure on the N-methyl-D-aspartate receptor (NMDAR)- response in a frog egg model. Their latest reports [31, 32] summarise their earlier work and current status of knowledge. The GluN2A subunit seems to the only subunit responsible for CNS hyperexcitability induced by high pressure. A recent work [31] demonstrated that the NMDARs containing the GluN2A subunit showed similar response to 100% O_2 at 0.54 MPa as 5.4 MPa He. The effect seems to be mediated through removal of Zn2+ from its binding site on the GluN2A subunit. These finding suggests that the CNS hyperexcitability caused by hyperbaric oxygen may share the same mechanism as HPNS. The authors speculate that

administration of Mg^{2+} and Zn^{2+} in the future may be useful to prevent CNS oxygen toxicity and HPNS. Though these *in vitro* studies have expanded our knowledge on HPNS they don't answer the question of whether HPNS may cause long-term effects. However, there is reason for concern as NMDA excitotoxicity is involved in several other CNS injuries and illnesses [33].

9.5 Changes in breathing gas pressure

To allow unrestricted breathing while diving, the diver must be supported by breathing gas delivered at a pressure approximately equal to the ambient. The breathing gas density is linearly correlated to the gas pressure. Unless the breathing gas is changed, the diver will breathe a gas with higher density than at surface pressure. This will cause a secondary increase in breathing resistance and work of breathing**.** Maximum breathing capacity (MVV) is approximately halved when breathing compressed air at 30 msw compared to surface. Increased breathing gas density may explain some of the changes in divers' pulmonary function such as increased FVC. It is speculated whether increased FVC may be an adaptation to increased work of breathing. To which extent altered intrathoracic pressure variations may affect divers' cardiac function remains unknown. Work of breathing will increase when diving depth is extended from 180 msw to 225 msw due to slightly increased breathing gas density. However, the practical consequence would be minimal and could be compared to the increased work of diving if diving depth was increased from 29 to 35 msw breathing air.

9.6 Changes in partial pressures of the individual gases in a breathing gas mixture

The total gas pressure in a gas mixture is the sum of partial pressures of each gas in the mixture (Dalton's gas law). When breathing gas pressure is increased, the partial pressure increases proportionally. Changes in partial pressure of breathing gas O_2, CO_2 and N_2 are usually the ones causing the most prominent effects. However, low concentrations of contaminants - causing minimal or no health effects at surface may induce more serious health effects during diving due to the increased partial pressure(s) of the contaminant(s) once the contaminated gas is pressurised.

9.6.1 Changes in partial pressure of the metabolic gases

Physiological responses are adjusted to maintain a constant partial pressure of O_2 and CO_2 in arterial blood. Cardiac, vascular, and pulmonary function have been adapted to an environment with approximately 20 kPa Oxygen and 0,03 kPa Carbon Dioxide maintaining an arterial pO_2 and pCO_2 of 13.3 and 5.3 kPa respectively. When diving, this setpoint is challenged. If the diver breathes compressed air, the pO_2 increases linearly with depth and reaches 120 kPa at 50 msw. During saturation diving the breathing gas pO_2 is controlled within a much shallower range. Details are listed in section 13.3. The increase of diving depth from 180 msw to 225 msw is not expected to influence arterial pO_2 or pCO_2.

9.6.2 Hyperoxia

The best described health effects of raised pO_2 (hyperoxia) in diving are those on the lungs and CNS. Divers breathing gas with pO_2 exceeding 130-150 kPa may experience acute oxygen toxicity on the CNS presented as generalised tonic-clonic seizures. The seizures will not subside until the pO_2 of the breathing gas is decreased. These seizures are not expected to cause long term health effects but may cause drowning if they occur while the diver is immersed. The long-term health effect of hyperoxia on the lung has been studied in detail. pO_2 exceeding 40-50 kPa may cause irreversible changes in lung function. Reduction in FVC, FEV_1, mid-expiratory flow volumes and DL_{CO} may occur. However, for moderate hyperoxic exposure it may be challenging to single out the effects of hyperoxia *per sé* on lung function from those caused by breathing a dense breathing gas and effects of venous gas embolism.

Hyperoxia is expected to cause its effects through formation of reactive oxygen species (ROS) causing injuries of proteins, lipids, and nucleic acids. Hyperoxia affects formation of nitric oxide (NO), in particular NO produced by endothelial NO synthetase. Much attention has been given to how diving in general, and hyperoxia in particular, may cause endothelial dysfunction. There are some indications that exposure to increased partial pressure of inert gas, i.e. helium or nitrogen, will reduce latency for oxygen induced seizures in rats [34]. However, these inert gas interactions are difficult to separate from those caused by increased gas density.

Oxygen levels in saturation diving are independent of depth, so the total hyperoxic exposure depends on exposure time. For diving on the NCS, the exposure time is shortened for diving beyond 180 msw due to regulatory restrictions. More detail is provided in chapter 13.2.1.

9.6.3 Hypoxia

The diver should be supplied enough gas with pO_2 20 kPa or higher to avoid hypoxic injuries. Loss of breathing gas supply or incorrect make-up of the breathing gas mixture may cause death or serious long-term health effects particularly on the CNS. Injuries are similar to those caused by suffocation (asphyxia) such as drowning or avalanche burial. Sundal *et al.* [35] reported that loss of consciousness had been experienced by 58 out of 219 former Norwegian offshore divers. 46 of these (79%) had either experienced this due to gas cut or incorrect gas mixture. While the external validity as well as the relevance for present North Sea offshore diving can be debated, the data strongly suggest that asphyctic and/or toxic breathing gas may have been a contributing factor for long term health effects (as reported by questionnaires) in this group. Extending diving depth from 180 to 225 msw is not expected to increase the likelihood for accidental hypoxia.

9.6.4 Hypercapnia

Raised inspiratory pCO_2 will initially stimulate breathing, increasing alveolar ventilation to maintain normal arterial pCO_2. Raised and prolonged exposure to high pCO_2 will cause raised arterial pCO_2 (hypercapnia) and additional symptoms such as palpitations and headache and will eventually cause respiratory arrest unless corrected. Long-term moderate hypercapnia (0.8-1.2 kPa) is considered the mechanism behind increased incidence of urinary tract calculi in submarine sailors in the past [36], but is not expected to be a cause of long-term health effects in divers. Though gas density will be approximately 20% higher at

225 msw compared to 180 msw, the associated increased work of breathing would not be expected to cause a clinically relevant increase in arterial pCO_2.

9.6.5 Changes in partial pressure of inert gases

Inert gas pressure of the breathing gas increases as the diver descends. In surface-oriented diving the diver usually breathes air and the concomitant increase in nitrogen pressure may lead to a narcotic effect on the diver – much like alcohol. The narcotic effect of nitrogen is expected to be reversible and not cause any long-term effects but may lead to erroneous decisions by the affected diver that in turn may cause incidents or accidents. In principle, O_2 and CO_2 exert narcotic effects similar to N_2. However, these metabolic gases cause severe symptoms (see section 9.6.2 and 9.6.4) at a partial pressure much lower than that required to induce narcotic effects. Helium is the most common inert gas used for saturation divers' breathing gas. Helium has a narcotic potency in the order of five to six times less than nitrogen. Though commonly considered "inert", Helium has been shown to be neuro- and cardioprotective [37, 38] and animal experiments have shown that the sensitivity to CNS oxygen toxicity is different in rats exposed to a N_2-O_2 compared to a He-O_2 atmosphere [34]. Whether helium *per sé* or rather increased ambient pressure cause the HPNS remains unanswered. Beyond the increased risk for HPNS (mentioned earlier) there is no reason to believe that the increased partial pressure of helium should have any relevant health effect when diving depth is increased from 180 to 225 msw.

9.7 Breathing gas contamination

The diver may be subjected to breathing gas contamination. The sources for these are multiple, and for saturation diving include welding gases, seabed contaminants, off-gassing of paint from the chamber interior and lining of the gas supply hoses (umbilicals). An extensive review has been published by Flook [39]. Human metabolism produce carbon monoxide (CO) and volatile organic compounds (VOC) that contribute to gas contamination in the recirculated saturation chamber atmosphere. Seabed contamination of the diving bell may cause toxic concentrations of hydrocarbons and sulphur compounds (H_2S) of the diving bell atmosphere. This contamination may propagate when the diving bell is connected to the chamber complex on the diving vessel. The chamber interiors need to be repainted from time to time and paint solvents may off-gas for a period. There are many historical examples of divers subjected to contaminated atmosphere in the living quarter. When the divers exit the diving bell, their gas is supplied through flexible rubber hoses ("umbilical"). The fabrics of these gas hoses are sealed by compounds that may off-gas for a long time. Within the welding habitat the divers are exposed to welding fumes, ozone, microparticles and potentially off-gassing from seabed contamination

There is limited knowledge of health impact of long-term (weeks) exposure to individual atmospheric contaminants. Even health effects of short-term exposure remain unresolved for many contaminants measured in the saturation diving atmosphere. Little data is available for the combined, long-term exposure to mixtures of contaminants during hyperbaria and hyperoxia.

A few potential contaminants of the divers' breathing gas have hyperbaric exposure limits (HEL) specified in Norsok U-100. One example is benzene, where the HEL is set to 0.001 Pa after an assessment of inherent properties and interaction with other gases in the hyperbaric environment [40]. For most potential contaminants the HEL is set to 20% of the normobaric

permitted occupational exposure limit. The HELs of these breathing gas contaminants are based on a presumption that the effects of each contaminant are additive (rather than synergistic, antagonistic or potentiation). There is not sufficient scientific support for such a “20%” and “additive” rule, but it has been put in place to allow for standardisation. Hopefully, the work performed on benzene can be used as a model for assessing other potential contaminants so that the list of specific HELs can be increased.

The attention to the risk of gas contamination has stimulated many mitigating actions to avoid harmful exposure. Seabed (soil) samples are routinely analysed pre dive to assess the need for additional protective measures such as covering the seabed or use of coveralls during diving. Gas samples from umbilicals, bells and living chambers are regularly analysed for gaseous contaminants and results have demonstrated that excessive contamination rarely takes place. There are also on-line sniffers for early detection of contaminants, e.g. VOC, in the diving bell, the divers will use respiratory protective equipment (BIBS) if a certain level is exceeded.

There is a lack of scientific data supporting any additional health effect of the interaction between hyperbaria and breathing gas contamination with the extension of diving depth from 180 to 225 msw.

9.8 Formation of free gas

During diving, the breathing gas must hold a pressure equal to the ambient. When diving to 190 msw the ambient and breathing gas pressure is twenty times the surface pressure. Blood passing through the lungs will absorb more gas and distribute these gases to the tissues. The tissues will be gradually saturated by gas until a new state of equilibrium has been established. During ascent/decompression the process is reversed. When ambient pressure is reduced, the tissues and venous blood hold a higher gas pressure than the surroundings – there is a state of supersaturation. Gas in supersaturation may be dissolved or change phase to a free gas phase (gas bubbles). Decompression sickness is believed to be triggered by the formation of free gas in blood and tissue, and diving procedures are designed to minimise the amount of free gas formation. It is difficult to observe extravascular gas, but intravascular venous and cardiac gas may be relatively easily monitored by ultrasound [41] . There is an association between observed venous gas emboli (VGE) and decompression sickness, and VGE is conventionally applied as a surrogate measure for decompression procedure safety. Absence of VGE will strongly suggest that the decompression procedure is safe from a decompression sickness point of view. The reverse is however not automatically true: Even in the presence of high bubble grades, the incidence of decompression sickness is relatively low. Observed VGE is thus considered associated to, rather than the causal mechanism of, decompression sickness.

Intravascular and possibly autochthonous (“in tissue”) free gas is thought to initiate decompression sickness, most likely mediated through the endothelium. Nitric oxide (NO) is expected to play a key role in the pathogenesis, initiating a cascade reaction of humoral and cellular responses. Much scientific effort has been put down to identify the effects of intravascular gas on the endothelium. Though details of the mechanisms are gradually revealed, the relationship between VGE and clinical long term health effects of diving is essentially unknown. In the absence of such data, it is recommended to design decompression procedures associated with a minimum of VGE. Two Norwegian studies [42, 43] have reported VGE during decompression from operational saturation dives ranging 95-

133 msw. VGE were monitored acoustically and reported on a 0 to IV grade categorical scale. The study by Hjelle *et al.* [43] reported Grade II VGE in nine out of 15 divers after a saturation dive in 1991. After this, the decompression procedures on the Norwegian Continental Shelf were standardised and to some extent made more conservative. However, Risberg *et al.* [42] observed VGE in all of the 19 divers in the 1994 study and eleven of these had Grade III bubbles. There has been no similar study after this, and it must be assumed that there is still room for improvement for further reduction of VGE in operational saturation diving. However, there is no data to support any relationship between saturation diving depth and VGE extent.

9.9 Decompression sickness

9.9.1 Introduction

Decompression sickness (DCS) is recognised to cause long-term health effects in divers. In the context of health surveillance of deep divers, it is important to understand whether health effects are caused by DCS or some other mechanism related to diving depth. The reader is advised to consult textbooks in diving medicine (e.g. [27]) and appropriate review articles (e.g. [44]) for a better understanding of DCS. This text is written as a background for chapter 10. Readers unfamiliar with DCS would benefit from reading this chapter to better understand the pathogenesis and presentation of the disease.

DCS incidence is highly dependent on the type of diving (recreational, military, or occupational) and diving method. In surface-oriented diving the incidence will typically range 1-10 /10 000 dives. The terminology of decompression related disease remains debated. Traditionally DCS was used to describe illness occurring as a consequence of supersaturated gas (see section 9.8) in blood and tissue. DCS was classified as either Type 1 (“not serious” – skin, musculoskeletal and lymphatic) or Type 2 (“serious” – neurological, inner ear and cardiopulmonary). Arterial gas embolism would contrary occur as a consequence of a pulmonary barotrauma, causing gas to leak from the pulmonary alveoli into the pulmonary capillaries as the walls of the alveoli were over-stretched during sudden reduction in ambient pressure. These intravascular bubbles would then be transported to the left side of the heart and distributed by arterial blood. Typically, these bubbles would obstruct cerebral vessels and case a cerebral arterial gas embolism (CAGE). A study demonstrated that even experienced diving physicians disagreed on the diagnosis (DCS Type 1, DCS Type 2 or CAGE) when case studies were presented [45]. The term “Decompression Illness” (DCI) was established, including DCS as well as CAGE. The intention of replacing the traditional terms with DCI was to avoid a fictious level of diagnostic precision. However, the nomenclature still remains a controversy [46] and the term DCS remains commonly used. When citing publications, we will use the term (DCS or DCI) used by the author. We will use the term DCI when we discuss injuries that may be caused by DCS as well as CAGE. CAGE is uncommon in saturation diving, and we will use the term DCS for illnesses expected to be initiated by supersaturated gas in blood and tissues during saturation diving.

Decompression sickness (DCS) is an illness caused by a reduction in ambient pressure. Divers and compressed air workers are those typically affected, but even astronauts, pilots, and attendants in hypo- and hyperbaric chambers can be affected. The disease is expected to start with formation of a free gas phase (gas bubbles, see section 9.8) though the precise location of the gas causing disease remains unresolved. The formation of free gas is

followed by a cascade reaction involving humoral (inflammatory) and cellular responses. The endothelium is expected to play a key role and NO production is affected by intravascular gas. The interaction between intravascular gas, the endothelium and NO has been reviewed by Møllerløkken et al. [47]. Molecular techniques are now available to disclose how diving, and decompression sickness, may affect gene expression (e.g. protein synthesis in the cells). A reader unfamiliar with the scientific literature related to the pathogenesis of DCS should probably reduce the disease process to be the one of free gas formation in tissues and blood followed by a cascade of inflammatory responses expected to last well beyond the presence of gas bubbles.

Pain is the most common symptom of decompression sickness and may remain the only one ("pain only DCS"). However, it is commonly co-existing with neurological symptoms and findings. About 60% of recreational divers suffering DCS will be affected by the neurological type. Neurological DCS, typically separated into spinal and cerebral, is considered to be the most serious type and may leave permanent sequelae. Other common presentations of DCS would be itching, rashes and articular pain. The inner ear (vertigo, hearing loss) and lymphatic vessels (oedema) are less commonly affected. DCS is usually not lethal, but severe violation of decompression procedures may develop into cardiovascular decompensation due to massive venous embolisation.

DCS is treated prehospitally with normobaric oxygen supply and rehydration. The patient is transported to a recompression chamber and conventionally treated with a "USN Table 6" recompression table breathing oxygen at 18 and 9 msw. Additional, but usually shorter, trailing treatments may be required in the following days until all symptoms have subsided or stabilised. Details regarding treatment of DCS during saturation diving is described in the next chapter.

The prognosis is mostly dependent on the severity of the initial presentation of the disease. In the order of 70-80% of the patients will experience complete recovery, or only minimal residua, within a month [44] following the accident. It should nevertheless be recognised that DCS is an independent risk factor for later neurological and neuropsychological dysfunction. This will be discussed in further detail in Chapter 10.

9.9.2 DCS in saturation diving

DCS is a rare event in saturation diving – since 1980 it has been lower than 5/100 000 manhours in saturation [48] and the past 20 years it has been in the order of 1/1 000 000 manhours in saturation (chapter 9.9.3). DCS occurring in saturation diving is recognised to mostly affect the musculoskeletal system, in particular the lower limbs with residual pain diminishing during recompression treatment [49-51]. The symptoms will usually resolve quickly during treatment with a therapeutic (hyperoxic) gas mixture and a minimum of recompression [51, 52]. This contrasts to DCS in surface oriented diving which has an order higher incidence [44, 53], characterised by neurological manifestations, multiple treatment sessions and a risk for long-term residua (see chapter 9.9.1).

9.9.3 DCS in offshore diving on the NCS

Diving exposure and diving related illnesses have been closely monitored by PSA since the 1990's [54]. A report published in 2005 [48] has applied conventional quantitative risk

analysis on morbidity (DCS) and mortality data related to diving activity on the NCS. Regrettably there is no similar data source for diving in UK waters.

Year	Manh Sat	Manh SO	DCS sat	DCS SO
1991-2000	930230	9436	2	2
2001-2010	558856	2404	1	0
2011-2020	589668	2779	0	0

Table 2 DCS incidence in saturation diving (Sat) and surface oriented diving (SO) on the NCS the past 30 years. Legend: Manh: Man hours in saturation (Sat) or in water (SO). DCS column summarise number of accidents. Sources: [48, 54] and personal communication, Jon Arne Ask, PSA Feb 2021.

As can be seen in Table 2, DCS is now extremely uncommon in saturation diving on the NCS. The incidence is in the order of 1/1 000 000 manhours in saturation the past twenty years. The incidence of DCS in surface-oriented diving is 1.4 /10 000 manhours in water. The number of dives for surface oriented diving is not known, but if average water time would range 1-3 hours, the incidence of DCS in surface oriented diving is within the 1-10 /10 000 dives reported for inshore diving [44, 53]

10 SELF-REPORTED HEALTH

Questionnaires have been used in most of the cross-sectional and longitudinal studies of divers' health. Irgens et al. [55] reported the results of a study on 230 Norwegian divers with diving experience from the North Sea prior to 1990. They responded to the 36 item Short-Form Health Survey (SF-36). The score in divers were lower for all subsets of the questionnaire. Previous DCS was a risk factor for low SF-36 in all subsets. The subgroup of divers having suffered DCS reported a decreasing trend in scores related to number of days in saturation and maximum diving.

McQueen et al. [56] compared responses to the 36 item General Health Questionnaire (GHQ36) from 36 recreational divers having suffered DCS to those of a control group of 50 recreational divers without such injuries. Divers with DCS reported more symptoms suggesting neurological damage and psychiatric morbidity than the control group.

Ross et al. [57] reported findings from a postal questionnaire to 1530 divers comparing them to a control group of 1035 non-diving offshore workers. Health related quality of life, as assessed by the 12 item Short-Form Health Survey (SF-12) was not different between divers and controls. However, significantly more divers complained of forgetfulness or loss of concentration, musculoskeletal symptoms, and hearing impairment than the control group.

A questionnaire holding eleven questions has been used by Doolette and co-workers in a series of studies [58-60]. The responses to ten of these questions were aggregated in a total "Diver Health Score" (DHS) ranging 0-30. The authors have validated the questionnaire for DCI incidence, but it has not been investigated for use in relation to long term health effects.

Most studies of long-term health effects of diving have included responses to questionnaires or clinical interviews in addition to the objectively measured outcome variable. This is discussed in the later chapters in context with the observed, objective outcome measure. IMCA has issued questionnaires for long-term follow-up of divers. These are attached as Appendix 4. No report has been published in the open domain regarding findings of the IMCA questionnaires.

11 EFFECTS OF DIVING ON THE NERVOUS SYSTEM

11.1 Decompression illness

Decompression illness (DCI) can damage the central nervous system with symptoms such as paraesthesia, dizziness, and coordination problems. In 1959, Rozsahegyi [61] was the first to describe psychological as well as neurological disorders due to DCI in the central nervous system. Neurological manifestations appear to be common, around 60%, for SCUBA divers seeking treatment for DCI [44]. Depending on the localisation of the lesion, such patients may present a wide variety of clinical signs and symptoms such as hemiplegia, loss of vision, convulsions, aphasia, headache, and confusion. Even after treatment, neuropsychological tests might deviate from normal values [7]. Two recent studies confirmed that divers having suffered DCS had increased prevalence of psychiatric disorders compared to the matched control group [62, 63] and the hazard ratio for sleep disturbances was 5.7 compared to the control group.

Divers with a cardiac right to left shunt, e.g. in the form of a patent *foramen ovale (PFO)*, are at a greater risk of neurological DCS with Odds Ratio (OR) ranging 2,5-6.5 in the various studies [64, 65]. Large PFOs are associated with higher OR.

Cerebral Arterial gas Embolism (CAGE) may occur due to barotrauma of the lungs [66] or paradoxical right to left shunting of venous gas emboli [67]. Barotrauma of the lungs can happen due to rapid, accidental decompression (uncontrolled ascent or sudden pressure loss in pressure chamber). As explained in chapter 9.9.1 it can be difficult to discriminate whether a decompression-related neurological insult was caused by DCS or AGE. This may in turn be a challenge when comparing results from scientific studies using DCI as the outcome variable.

Brubakk *et al.* [68] observed arterial gas emboli in the carotid artery of divers during ascending excursions from 300 to 250 msw. The divers had no symptoms of DCI and the potential significance of this finding on long-term health is not known. Both storage depth and excursion distances in this study are beyond what we consider relevant exposures for the current work.

11.2 High Pressure Nervous Syndrome (HPNS)

11.2.1 Deviation from original scope

Procedures for HPNS testing was not part of the original scope for the workgroup (Appendix 1). As will be explained below, HPNS has commonly been observed *during* deep dives. Previous studies have reported persistent neurological and neuropsychological impairment *after* deep dives. There is accordingly an association, though not necessarily a causal relationship, between HPNS and persistent CNS impairment. To allow a better understanding of this relationship we will initially present a background of HPNS symptoms and findings. Further we will explain why it is necessary to complete HPNS tests during and after the dive as part of the health surveillance. In the past HPNS testing has conventionally been applied to ensure that the diver is fit to dive (bellrun, lockouts). We will not discuss in any detail or conclude on the selection of HPNS tests for such purpose.

11.2.2 General description of HPNS

HPNS is a neurological, excitatory condition observed in human and animals exposed to raised ambient pressure. The reader is advised to read recognised textbooks or literature reviews (e.g. [69, 70]) for a comprehensive description with appropriate references. We have briefly discussed some of the mechanisms in chapter 9.4. This introductory chapter is intended to serve for background information only.

The presence of HPNS symptoms depends on compression rate, ambient pressure, breathing gas composition and inter- and intraindividual factors. The most characteristic symptoms are tremor as well as subjective impairment of intellectual and motor performance. Dizziness, nausea, vomiting, epigastric sensations, loss of appetite, diarrhea, sleep disturbances, jerks, euphoria, and hallucinations are other symptoms reported in previous studies. The most typical findings are EEG changes with increased slow waves in the Theta band (4-6Hz) and attenuation of Alpha activity (8-13 Hz). Sleep cycles are changed with an increase of awake periods, stage 1 and 2 and a decrease of stage 3 and 4 and REM periods. Most studies confirm increased tremor measured either by accelerometers or static steadiness. Psychometric measurements have shown great variation. In severe HPNS reaction time is prolonged while dexterity and arithmetic ability are impaired. Visual and auditory hallucinations, delusions and even a state of frank psychosis has been observed on rare occasions.

There is a significant difference in interindividual susceptibility to HPNS, though the intraindividual variation is reported to be small. The presenting symptoms seems to be characteristic for each subject.

Symptoms are clearly dependent on compression rate, ambient pressure, gas composition and gas switching. The minimum pressure required to elicit HPNS has not been confirmed, but 130-150 msw is sufficient to elicit tremor. Marked HPNS symptoms have been reported at 183 msw with a compression rate of 5 msw/min. Adding Nitrogen to the breathing gas has been shown to reduce HPNS symptoms and findings, while withdrawal of Nitrogen has the opposite effect.

Symptoms and findings subside at stable pressure. However, objective findings (e.g. EEG, measurement of tremor or psychometric measurements) may disclose changes and deterioration compared to pre-dive level in spite of subjective assessment of restoration. Whether symptoms or findings may exist after finished decompression will be discussed in a later section.

HPNS has been studied in animals, but the main studies of human HPNS have been completed during experimental deep dives in the USA, UK, France, Germany, and Norway. Peter Bennett (USA) and Jean Claude Rostain (France) are the two scientists having published most extensively on the subject. Regrettably most reports have been published as abstracts, proceedings, or reports outside the public domain. This is challenging with respect to assessment of level of evidence.

11.2.3 Tests for HPNS

There is no standardised test to monitor development and extent of HPNS. Many tests have been used in the different studies, but in general they have assessed these functions:

- EEG
- Tremor (intentional, position)
- Subjective complaints (interview or questionnaires)
- Psychometric assessment (a wide span of tests for intellectual, logical, arithmetic, attention, memory, reaction time a.o.)

11.2.4 Persistence of HPNS symptoms and neurological impairment after deep dives

The general concept and expectation of HPNS is that this is a temporary and fully reversible health effect related to deep diving and that no sequelae will remain after finished decompression [69]. This will be challenged below.

Most human HPNS studies have focused on the diver's ability to perform work during the bottom phase. Assessed by the diver's subjective description of personal symptoms, HPNS will usually subside within hours or a few days at stable pressure [69]. However, the presumption that HPNS subsides will he highly dependent on the symptom or finding studied. Bennett and Rostain [69] cites a work of Brauer et al. [71] in which EEG changes persisted for 10-12h during decompression following a dive deeper than 323 msw (details not provided). In another study Rostain et al. [72] demonstrated that sleep disturbances, as measured by polysomnography, occurring during dives ranging 500 to 610 msw did not subside until 40 h into the decompression when pressure was approximately 300msw. Bennett and Rostain [69] refer to a USN experimental dive to 549 msw. The divers experienced severe HPNS symptoms "….and the divers deteriorated rather than improved with time at depth." These findings could be interpreted as somewhat sustained presence of HPNS, and that pressure had to be reduced below a certain level to let all symptoms subside. Værnes et al. [73] reported persistent EEG changes and impaired arithmetic performance during a 8-12d bottom phase in two groups of divers exposed to 51 ATA.

While there is an abundance of data [69] describing HPNS symptoms and findings during compression, there is a paucity of studies systematically monitoring development of these symptoms and findings during decompression. One example would be the works by Værnes et al. [74-76] which details the results of extensive neuropsychological assessment of divers during the compression phase of deep dives, but do not disclose how symptoms and findings subside during bottom phase and decompression.

Bennett reported in a presentation [77] of HPNS during deep dives that neurological pre- and post-examinations were completed 3 months, 1 year and 2 years after the dive "…and we didn't see any change". However, when challenged in the succeeding discussion on the details of the German (GUSI) examinations and their exact results it became evident that the examinations had been done by German scientists and data had not been provided to Bennett – the quality of evidence is accordingly very low. In a personal communication (Peter Bennett, Personal communication, 19.5.21) he confirmed this statement regarding the GUSI dives. With respect to the Duke (Atlantis) dive he said that the divers had been examined extensively before and after the dive without any negative health effects. However, he could not substantiate this with any written sources. He was convinced that neither the Duke dives nor the GUSI dives had caused any permanent neurological effects and that the divers had been extensively examined to ensure this fact.

However, there are a few exceptions to this general description. Curley [78] reported the findings of 25 USN divers that had participated in five saturation dives ranging 198-335 msw. The general finding, on a group level, was that the divers performed equally good or better in

the extensive neuropsychological assessments after the dives compared to the pre-dive examination. It should be noted however, that there was some disparity with respect to subjective symptoms. Curley wrote: *"Interviews with all saturation divers approximately 3-7d after surfacing often revealed lethargy and a mild depression. Occasional transient visual focusing problems were reported and resolved within 10 d after the dives. Follow-up contact with the dive-team members months and years after their dive has failed to document any substantial changes."* The other studies suggesting short- and long-term neurological and neuropsychological sequelae after deep dives have been completed by Norwegian scientists. Værnes et al. [79] reported neurological and neuropsychological findings after two deep dives: The first one a simulated dive to 350 msw, the second taking place three months later as an operational dive to 300 msw. Testing took place before the 350 msw dive, during compression and during decompression (latest measurement at 100 msw). Neurological and neuropsychological testing was done before and one week after the 300 msw dive, but no measurement was done during this dive. HPNS symptoms (lethargy, exhaustion, depression, irritation) were mild to moderate during the compression and bottom phase of the 350 msw dive and EEG changes, tremor and neuropsychological test results confirmed a mild HPNS. Symptoms and findings subsided during the bottom phase and during decompression. The reported/subjective extent of HPNS was present in the same order in the 300 msw dive compared to the 350 msw. However, *after* the 300 msw operational dives postural tremor, hand grip strength and even several other neuropsychological tests (autonomic reactivity, concentration, auditory discrimination, and spatial memory) were impaired compared to predive status. EEG was normal. All divers complained of fatigue after both dives, and more so after the 300 msw dive. Three divers reported memory problems and one diver suffered ten days with dizziness, headache, and nausea after the 300 msw dive. A disturbing fact is that these symptoms and findings were present one month after the 300 msw dive. No DCS occurred during these dives.

Todnem et al. [80] reported neurological changes in a group of eighteen divers participating in simulated dives to 360 msw. They were extensively examined neurologically before and shortly after (within 48h) the dives. After the dives two divers had abnormal EEG, one diver had abnormal vibration sense and another ataxic gait. A third diver, with cerebral atrophy and polyneuropathia present before the dive demonstrated ataxia and abnormal EEG after the dive. No DCS was experienced during these dives.

Grønning et al. [81] reported neurological symptoms and findings in 101 divers having participated in sixteen simulated and operational saturation dives ranging 111-504 msw. New neurological findings (clinical or EEG) occurred in fifty of the 97 man-dives. The number of symptoms during compression and during the bottom phase were significantly associated (OR 1.94 and 1.55 respectively) with new neurological findings or EEG changes after the dive. This report will be discussed in further detail later. The finding suggests that HPNS symptoms were associated with post-dive neurological changes in these divers.

Todnem et al. [82] reported neurological symptoms and findings in a group of forty divers being examined after deep dives. They were compared to a group of 100 non-diving controls. The "deep divers" had significantly more subjective neurological symptoms and objective findings (clinical neurology and EEG) than controls. However, this study can't isolate the effects of deep diving to those of saturation diving in general. Værnes et al. [83] compared neuropsychological status before and after dives ranging 300-500 msw (Deep sea divers - DSD, N=64) to another group of saturation divers (SD, N=32). SDs were examined with approximately 3,5 years interval. Measures of tremor, spatial memory, vigilance, and

autonomic reactivity were impaired in the DSD group after the deep dives. Except for vigilance, these findings were not normalised one year later. In the SD group, mild to moderate impairment (>10%) was observed in spatial memory, autonomic reactivity and finger tapping. The author claims that the neuropsychological effects of one deep dive can be compared to that of 3,5 years of diving. An important fact is the observation that the divers in general performed better than the control population (non-divers) at the first examination. Cross-sectional studies of divers comparing findings to a control group may thus fail to identify health impairment amongst the divers.

A diver participating in a simulated dive to 250 msw at NUI in 2005 experienced long term neurological sequelae after the dive. He was significantly affected by HPNS during the bottom phase but did otherwise not experience any injury or illness (such as DCS) during the dive. No comprehensive description of this incident has been published, but parts of it has been discussed in a conference proceeding [6] and is briefly mentioned in the report by Grønning et al. [81].

A “Medical expert report” [84] has summarised the long-term neurological sequelae suffered by eight divers after an operational dive to 235-273 msw. Fifteen divers participated in the dive that took place 2017 outside Australia. The divers were compressed in two groups of nine and six divers. Compression rate was particularly rapid in the second group of six divers. Seven of the divers “…continue to suffer significant health impacts more than 2 years after the dive”. No definite cause for these long-term sequelae has been confirmed, but HPNS symptoms were commonly experienced in the second group of divers. HPNS symptoms seems to be common amongst the divers, but the report does not provide details.

A NUI report has been published in Norwegian (The “Predictor Study”) [81]. It reported findings from 101 divers having participated in 119 man-dives. Fourteen saturation dives took place 1981-1989 and two dives 2000-2002. The report included the dives referred to by Vaernes et al. [79]. The saturation exposures included simulated, experimental as well as operational dives. Outcome variables included symptoms during compression, bottom phase, decompression and after the dives. In addition, the presence of new neurological findings or EEG changes after the dive was reported (data available for 74 man-dives). The report does not disclose interval(s) between finished dive and neurological examinations except for EEG findings. The outcome variables were examined for association with potential risk factors (predictors) such as diving depth, oxygen partial pressure, age, BMI, smoking, physical fitness, and lung function. Previous head trauma, episodes of hypoxia, CNS DCS, CO_2 intoxication or alcohol abuse was categorised as “Neurological vulnerability”. Such neurological vulnerability appeared to increase the risk for new neurological symptoms or findings after the dive. In addition, poor fitness/endurance tend to increase the risk of new outcomes. After the dive, tiredness, and mental symptoms such as anxiety, light depression or hypomania, irritability and restlessness were prominent. Abnormal fatigue lasted for 2-4 weeks. More than 50% of the divers presented new neurological findings or changes in EEG (four of whom had residual symptoms one year after the event) after the dive. The results showed a statistically significant trend of increased incidence of new neurological findings and EEG changes as a function of diving depth. Univariate logistic regression showed an increased risk for neurological changes or EEG changes after dives exceeding 250 msw (see Table 3).

Depth msw	Number (%)	Odds ratio	95% CI	Test for linear trend (p-value)
111	1 (12.5)	1		<0,001
218-220	9 (20.0)	1.75	0.19-16.06	
250-300	16 (57.1)	9.32	1.01-86.16	
350-360	18 (60.0)	10.49	1.14-96.35	
450-504	6 (75.0)	20.97	1.50-292.6	

Table 3 Incidence of new neurological findings or EEG changes in 101 divers participating in 119 individual dives grouped according to maximum diving depth. The table is presented as shown in the NUI report [81]

The interpretation of this report is a matter of controversy and the limitations of the report should be recognised. The publication has not been peer-reviewed, but the methods and the statistical analysis are appropriate. *The main finding seems valid*: New neurological symptoms or EEG changes appeared in 50% of the subjects after the deep dives. The occurrence of new neurological findings or EEG changes increased as a function of diving depth. However, it should be recognised that the report details neurological outcome from dives adhering to operational procedures well before NCS saturation diving procedures were standardised in 1991 [85]. The external validity – applicability for diving operations adhering to current procedures – is thus unknown. Secondly the interpretation of "new neurological findings" is difficult since these are not detailed in the report. The focus of the present report is health surveillance of divers participating in dives from 180-225 msw. It can be seen from Table 3 that new neurological findings or EEG were not statistically different in divers participating in dives ranging 218-220 msw compared to 111 msw. This interpretation is strengthened by the fact that the neurologist examining the divers participating in the 218-220 msw dives (The "Gullfaks" operational dives) stated (Our translation of the original Norwegian text): *We have now examined the divers after dive 1 and 2, there are no effects from the dives in our examinations now at this depth, and for the last dive it is in my opinion only necessary with neurological examination and EEG in divers who; have had significant HPNS, have had DCS, have had other symptoms after the dive.*

11.2.5 Limitations of the cited studies

There are several flaws and biases in the published studies that significantly limit the interpretation:

- Many of the studies have been published in abstracts, proceedings, and technical reports with limited accessibility
- Studies are generally 25 years or older. Diving procedures – both for deep and shallower diving – have been modified since that.
- Most studies have reported results from diving depths 300msw and deeper. With one exception [86], none of the other studies identified by us, have investigated dives to 180-225 msw.
- There are no agreed diagnostic criteria for HPNS.
- Only a few studies, and with one exception only studies from Norway, have examined HPNS related symptoms and findings *after* finished decompression
- The divers in the Norwegian studies had a high prevalence of experienced loss of consciousness and DCS. It is not known whether divers with less CNS trauma would be less affected by deep diving.
- Most studies report changes in group performance (mean, spread) rather than individual responses. This may obscure identification of "vulnerable" individuals that experience impairment of clinical significance.

- The studies reporting neuropsychological findings generally don't account for test-retest improvement expected for such tests. Observing unchanged performance after repetitive testing may actually suggest impaired function.

11.2.6 Conclusion – persisting neurological and neuropsychological impairment after deep dives

It is our opinion that the studies of Værnes et al. [79] and Todnem et al. [80] have confirmed that neurological and neuropsychological impairment may develop and sustain after dives to 300 msw and deeper. These changes have occurred in dives that have caused HPNS but without other recognised injuries or illnesses such as DCS. There is one US study suggesting that neuropsychological status did not deteriorate after deep dives [78]. There is however a difference in reporting of the results. Værnes et al [79] reported the numbers of divers with "marked decrement" (>10% or >1 SD), Curley et al [78] reported changes in group mean performance. While the study of Curley et al. [78] suggests that no major change in group performance occurred after the deep dives, it cannot be used to exclude neuropsychological effects of deep diving on individual divers. While Peter Bennett claimed that no neurological injury was observed after the Duke and GUSI dives (Peter Bennett, personal communication 19.5.21 and [77]), the level of evidence for this conclusion is low in the absence of independent peer reviewed studies.

It is our interpretation of the reports that HPNS has repeatedly been observed in dives exceeding 300 msw. Though most data suggest that HPNS symptoms will disappear, and neuropsychological function normalise during decompression and surfacing, there is sufficient evidence to conclude that some divers have suffered long lasting and potentially lifelong neurological sequelae after deep dives.

11.2.7 The need for HPNS screening in dives ranging 180-225 msw

The objective of testing is to:

1. Ensure that the diver is fit for diving
2. Ensure that the diver has no neuropsychological impairment after finished dive (individual monitoring)
3. Provide guidance to the employer on the safety and health effects of the diving procedure (group monitoring)

11.2.8 HPNS screening to confirm that the diver is fit to dive (lock-out)

The need for HPNS screening as a safety measure in dives deeper than 180 msw is probably not controversial. It is beyond the scope of this report to conclude on appropriate tests to ensure that the diver is fit for diving. However, for sake of completeness, we refer the "HPNS mini-battery" recommended by Værnes [87] to be used for such purpose. The battery consists of these tests:

- Tremor (static steadiness, positional tremor. 30 sec test)
- Hand grip strength (each hand tested separately)
- Vigilance (comparing numbers with 5-10 digits and decide whether they are equal.1 min test)
- Reasoning (several mathematical expressions (additions) are presented, and the diver should state whether the suggested sum is correct or not. 1 min test.)
- Balance tests (four tests, each lasting 3 sec. One leg balance with eyes open and eyes closed. Each leg tested separately.)
- Co-ordination (Finger-nose test, each hand tested separately and finger-finger tests. Tests repeated with open and closed eyes.)
- Questionnaire (34 questions related to HPNS to be scored categorically from 1 (none) to 5 (severe))

It should be recognised that with exception for hand grip strength and static steadiness, none of these tests can be considered standardised clinical neuropsychological tests.

11.2.9 Neuropsychological tests to confirm reversal of HPNS after finished dive

As discussed in detail earlier (section 11.2.4 and 11.2.6) we consider that HPNS-related symptoms may have persisted after finished decompression in some divers after deep dives (250 msw and deeper). We agree that there is insufficient evidence to conclude that this impairment was caused by HPNS, but the findings suggest an association between HPNS and neurological impairment after deep dives. To confirm absence of persisting HPNS-related symptoms after dives ranging 180-225 msw, the HPNS tests should be completed after finished decompression. Recognising that divers have complained of problems with concentration and memory as potential long-term effects of diving (see section 11.3) we suggest that the HPNS battery should include tests for attention and memory. We advise that the HPNS battery should include tests of these functions as a minimum:

- Tremor (static steadiness or accelerometer)
- Hand grip strength (each arm tested separately)
- Executive function (e.g. Trail making B, WAIS Digit span backward, Stroop Colour Word Interference test)
- Attention (e.g. Trail making A, Digit span Forward,)
- Memory (e.g. Benton Visual Retention Test, California Verbal Learning Test, Wechsler Memory Scale)
- Questionnaire of HPNS related symptoms (e.g. as advised by Værnes [87])

The decision on the specific tests should be made by the occupational health service in close co-operation with a specialist in clinical neuropsychology. The tests for HPNS suggested by Værnes [87] would probably serve well to identify divers' fitness from a safety point of view. However, as discussed above, they are not recognised as clinical neuropsychological tests and care should be taken when interpreting consecutive test results (adaptation, training, test-retest, clinical interpretation). We advise that each function should be tested by a recognised neuropsychological instrument, examples have been provided in brackets. Interpretation of the test results will be dependent on neuropsychological competence, and we advise that the final decision on test instruments should be taken by a clinical neuropsychologist based on his/her personal experience and expertise. The number of

computer-based neuropsychological assessment batteries are continuously expanding, and a list of normative tests could quickly be outdated.

We advise that a baseline test should be completed shortly before diving (preferably 1-3 days before). These tests should be repeated 3-5 times to familiarise the diver with the tests and establish the intraindividual variation. The test should then be repeated at any interim compression stops deeper than 150 msw and finally at storage pressure. The tests should be repeated daily at storage pressure if performance is impaired by >1 SD (or suggesting a clinically relevant impairment as suggested by the neuropsychologist if SD has not been established). Criteria to start bell-run is beyond the scope of this document. Værnes [87] suggested that the bell-run should be suspended if the average impairment exceeded 20% from baseline measurement. The test should be repeated after finished decompression (1-3 days). A clinical neuropsychologist should review the test results and decide whether changes in test results suggest a clinically relevant impairment. In the event of a clinically relevant impairment, the OHS should organise further examinations to assess the cause and extent of the changes.

11.3 Chronic effects on the nervous system

11.3.1 Neurological symptoms and findings

Diving may cause long term health effects on CNS even in the absence of recognised accidents or illnesses [3]. Todnem et al published in 1990 a study of neurological symptoms and findings in a group of 156, predominantly saturation, divers [88] and compared them to a control group. Forty of the divers had participated in dives deeper than 180 msw, 51 had experienced DCS and 22 had experienced loss of consciousness (LOC) during diving. Symptoms from CNS, the peripheral nerve system and the autonomous nervous system were significantly more common in divers than the control group. Divers had significantly more abnormal findings from the nervous system (cranial nerves, motor, sensory, reflexes) than the control group. Stepwise logistic regression demonstrated that diving exposure (days of diving) and decompression sickness were independent risk factors for neurological symptoms and findings [88]. The study clearly shows a high prevalence of neurological symptoms and findings in this cohort of divers. It should be recognised that this group had a mean diving experience of ten years adhering to dive procedures that later has been changed.

Thorsen et al. [89] reported findings from an extensive examination of 96 Norwegian offshore divers with offshore diving experience prior to 1990. They had been referred by general practitioners' or social security offices to the Department of Occupational Medicine at Haukeland University Hospital on the suspicion of diving-related health complaints. The examination was extensive and included neurological, neuropsychological, pulmonary, and audio vestibular function. The findings were compared to controls from the general population. Forgetfulness was reported in the clinical interview by 83% of the divers. Articular pain, fatigue, sleeping problems and concentration problems were all reported by more than 50% of the examined divers. The fraction of divers reporting these symptoms on the questionnaire was even higher and additional symptoms such as irritability, sensory deficits, back pain, depression, and tinnitus were experienced by more than 50% of the divers based on the questionnaire response. Odds Ratio for these symptoms were

significantly higher amongst divers than the control group. Significant more divers than controls had findings from the cranial nerves, motor function, co-ordination, sensibility, and reflex asymmetry attributable to deficits in higher function. A significant proportion of the divers had other co-existent diseases, not related to diving, that could contribute to such findings. Even when the analysis was adjusted for this fact, a statistically significant difference (OR) persisted between the two groups except for cranial nerve differences. Trend analysis disclosed that the number of air dives, but not days in saturation or maximum diving depth, were significantly correlated to neurological findings. The authors don't claim that the results are representative for the estimated total number of 375 offshore divers active before 1990, but even if the findings are adjusted for the selection bias, the fraction of neurological symptoms and findings was disturbingly high. If this study is compared to those of Todnem [88] it is likely to conclude that the neurological symptoms and findings have progressed in the 14 years between these publication, possibly an "unmasking" of disease.

The findings of Todnem et al. [88] and Thorsen et al. [89] give strong evidence to the conclusion that Norwegian divers *having dived offshore before 1990*, have experienced neurological symptoms and findings exceeding that expected for a reference population and that these changes progressed as the divers got older. It is of course important to find explanations for these disturbing findings. Several explanations are likely. North Sea and experimental saturation diving procedures have changed much since 1990. Suffocation (loss of breathing gas, hypoxia), gross contamination of the breathing gas by e.g. volatile organic compounds from chamber paint or sea bottom sediments were common risk factors for divers in the 1970's-1980's. These risk factors are for all practical circumstances eliminated in present commercial diving (chapter 9.9.3). Older studies [61, 90] have clearly demonstrated that DCS may leave long-term neurological sequelae. The two studies on Norwegian offshore divers [88, 89] confirm this association and strongly suggest a causality with significant effect size. The effect size of LOC during diving on later neurological health seems significant based on these two studies. The contrast to divers practicing according to current recommended diving procedure is striking. Macdiarmid et al. [91] reported a study of UK registered divers (N=1540) and compared them to a group of offshore workers (N=1035) – the ELTHI study. The mean duration of diving activity in the group of divers was 14.9 years – i.e. they started their diving career approximately at the date of publishing of the Todnem et al report [88]. There is a large difference in reported DCS and LOC between the two. While Todnem et al [88] reported that 33% had experienced neurological DCS and 14% LOC, the figures in the UK ELTHI study were 11% and 7% respectively. In conclusion, the data suggest that LOC and DCS was an important contributing factor to the neurological impairment observed in older study while these risk factors are eliminated in saturation diving on the NCS today. A further interesting fact is that the amount of saturation diving were not independently correlated to neurological symptoms neither in the Todnem et al. study [88] in 1990 nor the Haukeland study in 2004 [89]. However, both studies confirmed a correlation between air diving and neurological symptoms. Accordingly, air diving, and possibly unsafe air diving procedures, seems to be an important predictor for neurological injury in divers.

Cordes et al. [92] did not find differences in cerebral MRI, neurological or neuropsychological function in military divers compared to a control group. Tetzlaff et al. [93] on the other hand observed more MRI changes and impaired neuropsychological function in a group of old (50±8 years) divers compared to a control group. Neuropsychological impairment was present for a few tests in the diving group and correlated with number of deep (40-60m) air dives.

It is unclear whether uneventful diving, in the absence of DCS, AGE and LOC, can cause central nervous health effects. This question has been raised in several meetings [3, 6, 94]. Some of the contributors at a consensus conference in 1993, the "Godøysund Conference", claimed there were reasons for believing that even uneventful diving could damage the CNS. Other participants argued that diving without hazardous events had not been shown to cause central nervous system effects [3]. The following statement was agreed upon: *There is evidence that changes in bone, the CNS, and the lung can be demonstrated in some divers who have not experienced a diving accident or other established environmental hazard. The changes in most cases are minor and do not influence the diver's quality of health.*

More recent reviews don't support the presumption that uneventful diving should be a significant risk factor for long term neurological health effects [95, 96] or CNS injury. A review article by Grønning & Aarli [97] concluded that results from long term neurological effects of deep diving are conflicting and inconclusive.

11.3.2 Neuropsychological studies

Some of the text in this section is overlapping with that presented in section 11.2.4 due to the fact that neuropsychological tests have been extensively applied in HPNS-related research. This section will not discuss HPNS-related neuropsychological impairment *during* the dives.

The first comprehensive study on neuropsychological function in divers was published by Curley in 1988 [78]. He reported findings from 18 divers participating in five saturation dives in the US Navy ranging 198-335 msw. He observed no significant change in neuropsychological functions after these dives. Later studies from Norway have challenged this position [83]. Neuropsychological tests have been included in studies of recreational, military, and occupational divers investigating the effect of deep diving, effects of DCS and long-term health effects of diving. A recent publication [98] holds extensive references to these previous studies and the reader is encouraged to review them for a better understanding. Neuropsychological changes have been reported in acute DCS – even in the absence of neurological findings [99]. Værnes et al reported that neuropsychological impairment correlated with years of saturation diving in a report published 1989 [83].

Thorsen et al. [89] reported findings from the extensive examination of 96 divers referred to the hospital due to suspected health effects of offshore diving prior to 1990. A matched control group was examined for comparison. The examinations included an extensive neuropsychological "package" of tests. Ninety-four divers completed most of the neuropsychological tests though a few tests were completed by less subjects. The reader is encouraged to read the original report to learn the details of the tests. In summary it can be concluded that a subgroup of the divers showed significant tremor. The diving group at large showed impairment in memory function, attention, flexibility, tactility a.o. The changes would suggest an unmasking or worsening of the neurological status of this group of divers compared to the previous examination published 14 years earlier [88]. The findings suggest development of a diffuse encephalopathy.

A study by Taylor et al. [100] reported neuropsychological findings in a group of 94 UK divers complaining of forgetfulness (FD). Even these divers gained their diving certificate before 1991, but the group included offshore as well as in-shore divers. The authors compared findings in this group to those of two age matched control groups of non-forgetful divers

(NFD) and non-forgetful nondivers (NFN). There were significant differences between FD and NFD, mainly related to impaired memory and attention. However, only one test (Rapid Visual Process) had a prevalence of abnormality exceeding that expected from a reference population level. The cognitive complaint of forgetfulness was, according to these authors, supported by objective tests, but the changes were of a mild degree. Further, the authors reported memory function impairment to be correlated with previous diving with surface decompression and mixed gas bounce diving, but not with other metrics for diving exposure or DCS. No correlation was observed with amount of saturation diving.

A Norwegian study, which included a group of inshore construction divers and compared them to control groups, was published 1999 [101]. The average diving experience was 18 years and most of the divers (70%) had experienced DCI. The authors reported no deterioration in neuropsychological tests with one exception; the divers had slower reaction time, measured with two tests than the case was for a group of age matched construction workers and diving students.

The only prospective study investigating neuropsychological function in divers was published by Bast-Pettersen et al. in 2015 [98]. The divers were followed with neuropsychological tests from start of diving training and 6 and 12 years later. The results reflect effects of *current* diving procedures on neuropsychological function. The results did not disclose any correlation between diving exposure (40-5604 dives) and test outcomes at the 12-year follow-up. The 11 divers who reported DCI had more neuropsychiatric symptoms and scored slightly worse on Benton Visual Retention Test (a visual memory test which does not include verbal memory) than divers without previous DCI.

Several cross-sectional studies reporting neuropsychological function of military divers, recreational divers and recreational diving instructors have been published the past ten years [102-107]. These studies have varying quality and most of them subject to bias. However, they all suggest that mild neuropsychological impairment may develop in divers compared to control groups. This may develop in the absence of recognised DCI.

If all these studies are considered in context, it seems well justified to conclude that a significant proportion of Norwegian offshore divers, starting their career prior to 1990, have developed neuropsychological impairment that later has worsened. There is some evidence to support that deep diving during this period may have been a risk factor. There is less evidence to support a clinically relevant impairment of neuropsychological function in occupational divers starting their career after 1990, but this question has not been sufficiently investigated for saturation divers.

We recognise that previous studies, examining divers taking part in deep dives prior to 1990, have observed neuropsychological changes after surfacing in some divers. The clinical consequences of these findings have not been studied in sufficient details. We have discussed the relationship between HPNS and persisting neurological impairment in section 11.2.

Neuropsychological Assessment Batteries (NAB) are useful research tools investigating potential organic brain injuries. NABs will *complement* clinical examinations when disease is expected. To the best of our knowledge, there are not established NABs designed for occupational health *surveillance*, e.g. of workers exposed to solvents or other neurotoxic compounds. Except for HPNS surveillance, we dissuade against implementing NABs as screening tools of divers until their validity for use as instruments in occupational health surveillance has been established. Threshold values for individual and group level advice

needs to be established before NABs are implemented in routine occupational health surveillance. Such threshold values can only be established by carefully designed scientific studies with sufficient power. We would support further studies in this area.

11.3.3 Diagnostic tools

Various diagnostic tools have been used for examination of the divers CNS.

Questionnaires (see chapter 10) have been used in several studies to present self-perceived health. Some of the questionnaires such as GHQ36 and SF36 have been validated for clinical use and contains subsets of questions identifying neurological and psychiatric impairment. There is however a concern that subjective assessment of cognitive functions may not detect neuropsychological impairment with a sensitivity comparable to standardised, neuropsychometric measurements. Bast-Pettersen [108] examined 48 patients referred for possible chronic solvent encephalopathy (CSE). She concluded that the patients reported many symptoms, but the neuropsychological tests showed only slight to moderate impairment of function. She concluded that objective testing with neuropsychological tests is necessary for diagnosis of CSE. Smargiassi et al. [109] concluded that the widely used Q16 questionnaire had a very low (<30%) diagnostic validity in the detection of neurotoxic impairment in styrene-exposed workers. A standardised questionnaire has been developed for long term health surveillance of divers (Appendix 4), but the sensitivity of this questionnaire for detecting neurological impairment remains to be established. However, a study by Taylor et al. [100] reported lower score for verbal memory, current intelligence and sustained attention amongst UK divers complaining of “forgetfulness or loss of concentration” compared to non-forgetful divers. The study does not add knowledge to the sensitivity of questionnaires since these divers had been diving for at least ten years at the time of the examination.

The validity of self-reported symptoms of forgetfulness and concentration problems in divers is controversial. Ross et al. [57] suggested that the high prevalence of cognitive, musculoskeletal, and hearing complaints amongst divers partly could be contributed to a somatisation disorder. The high level of disability of Norwegian offshore divers compared to UK offshore divers working prior to 1990/1991 could in part be explained by psychosocial factors. However, a later study by Taylor et al. [100] confirmed that occupational divers complaining of “forgetfulness or loss of concentration” indeed showed impairment on a number of neuropsychological tests related to memory and attention. Studies on other groups exposed to neurotoxic agents [108, 110] as well as healthy workers [111] strongly suggest that questionnaires have limited validity for assessment of cognitive function, and neuropsychological assessment is required to identify cognitive deficits.

The studies of Todnem et al. [88, 112] don’t discuss the sensitivity of clinical interviews by a neurologist to detect long term neurological health effects. The Haukeland [89] reported findings from divers referred to the hospital for suspected long term health effects of diving. The results will from this study can not be used to explain correlation between symptoms and findings in divers unaware of any long term effect. However the 2015 Bast-Pettersen study [98] on 37 inshore divers followed for twelve years after training shed important light on the potential subtle long-term neuropsychological effects of surface-oriented diving. Neither self-reported symptoms nor neuropsychological impairment correlated with the amount of diving exposure. However, divers with previous DCI reported more symptoms on the Q16 and

scored lower on the Benton Visual Retention Test (a memory test) than divers without previous DCI. The findings suggest that a questionnaire like Q16 may identify divers with neurological health effects of diving, likely attributable to DCI, in surface-oriented divers.

Regarding short-term effects of deep diving, Grønning et al. [81] reported the findings of 97 man-dives ranging 111-504 msw. Symptoms during compression, bottom phase, and decompression each predicted development of new neurological findings after the dive (Odds ratios ranging 1.55-1.94, $p<0.05$). Registration of subjective symptoms during the dive thus seems to be a valid tool to identify neurological impairment after the dive.

In conclusion there is regrettably no data to suggest the sensitivity or specificity of questionnaires to identify long-term neurological effects on saturation divers. In the absence of such data, we have considered the questionnaires and clinical interviews that have been used in previous studies and published long-term health surveillance programs. The IMCA questionnaire (Appendix 4) covers occupational exposure factors such as diving, vibrating tools, noise, welding, and solvents. Mishaps and symptoms of respiratory, musculoskeletal, and skin disease are asked for. However, persisting symptoms related to neurotoxic agents and exposure factors such as solvents, HPNS or DCI are not asked for. We don't consider the present questionnaire to appropriately search for neurological symptoms. We have searched for other questionnaires validated for detection of long-term neurological effects of diving, but as described above we conclude that no such inventory has been published. In such absence we have considered Q16 [113], 59-item Euroquest (EQ) [114], the 14-item abbreviated EQ [115] (which holds questions similar to Q16) and the 10-item abbreviated EQ [115] holding questions from the "memory and concentration" dimension of the full EQ. The need for a questionnaire identifying long-term neurological health effects of diving must be balanced against health surveillance of other occupational diseases experienced by divers. The current IMCA questionnaire (Appendix 4) holds twenty pages of questions for the entry questionnaire and eighteen pages for the follow-up questionnaire. Adding 59 additional questions as per the full EQ would probably exhaust the diver and significantly reduce the response rate and quality of the responses. We suggest that the health surveillance questionnaire should include the ten questions detailing "memory and concentration" (i.e. questions 38-47) from the 59-item EQ. The divers should complete the questionnaire annually. We recommend that the contents of the IMCA questionnaire (Appendix 4) should be reviewed, and consideration given to the volume of questions.

The Norwegian studies [88, 89] have reported findings from clinical neurological examinations completed by specialists in neurology. The sensitivity and specificity of clinical neurological examination as a tool for monitoring the development of neurological injuries at a pre-symptomatic stage remain unclear. Norwegian guidelines for health surveillance of workers exposed to volatile organic compounds or vibrating tools (exposure factors recognised for causing encephalopathy and hand-arm vibration syndrome) don't include neurological examination, but advise for questionnaires and clinical interviews [116, 117]. Despite the causal relationship between these exposure parameters and neurological injuries, the neurological examination has not been considered useful for health surveillance of these diseases. We dissuade against the introduction of *routine* clinical neurological examination of divers in the absence of symptoms suggesting neurological injury. The reason for this is – as described above – that no study has demonstrated these examinations useful for identifying diving-related injuries at a pre-symptomatic stage.

Abnormal EEG has been reported in divers suffering DCS [118, 119]. In a study published in 1991, abnormal EEG was found in 18% of a sample of 156 Norwegian construction and

saturation divers [120]. This prevalence was significantly higher than the 5% observed in the control group. In the Haukeland study [89] divers referred for investigation of health complaints related to offshore diving before 1990 had statistically increased prevalence of pathological EEG (OR 7.81) compared to the control group, but this was mainly caused by "drowsiness changes" in EEG amongst the divers (only one diver presented clearly defined pathological EEG). Another study did not disclose any difference in EEG amongst divers previously treated for DCS compared to non-diving controls [121]. Divers suffering LOC during diving complained of lower quality of health, but did not present EEG different from controls [35]. Grønning et al. [81] reported EEG changes in 74 divers participating in dives ranging 111-504 msw. Six divers presented pathological EEG after the dive and four of these had persistent EEG changes one year later. While the authors concluded that diving depth was correlated to new neurological findings *or* EEG changes after the dive, diving depth was not a risk factor for EEG changes after the dive. It is our opinion that EEG has not been validated as a useful tool for identifying diving-related injury at a pre-symptomatic change nor has it been demonstrated to correlate clearly with development of symptoms or findings of neurological injury in divers.

Magnetic resonance imaging (MR/MRI) is currently the best neuroimaging modality for DCS, but the sensitivity is low [122]. The most common finding is white matter hyperintensities (WMH). The studies of MRI changes in divers have given conflicting results. Some studies find no correlation between diving exposure and MR abnormalities, even amongst divers treated for DCS [92, 119, 120, 123]. Others, mostly cross-sectional studies including divers with a large patent *foramen ovale*, and a high degree of reported DCS and AGE, find cerebral changes [93, 124-128]. The studies on the relationship between cerebral MRI changes and PFO give conflicting results [106, 128]. The ELTHI study reported significantly more periventricular hyperintensities in "forgetful divers" than offshore workers, while WMH in general showed borderline (p=0.05) statistical significant predominance (OR=1.92) in the diver population in general compared to offshore workers [91]. Moen et al. [129] examined ninety-one former offshore divers having dived in the North Sea prior to 1990. They were examined with detailed parametric cerebral MRI combined with measurements of cerebral blood flow, cerebral blood volume and mean transit time. They observed regional functional abnormalities by diffusion- and perfusion-weighted imaging compared to a control group of 45 subjects. The authors conclude that the degradation of brain microstructure and brain vasculature was consistent with the long-term clinical symptoms reported among professional divers. A meta-analysis by Connolly and Lee [130] reviewed 11 studies on divers without recognised DCI reporting MRI changes as the outcome variable. They reported increased prevalence (OR 2.65) of WMH in the divers compared to controls. The authors recognise the methodological concerns in many studies (e.g. strength of magnetic field, use of FLAIR, selection bias and confounders), but they reported a low heterogeneity and minimal inconsistency amongst the studies. The authors conclude that repetitive diving may be an independent risk factor for development of white matter injury in otherwise healthy individuals. A later MRI study [107] reported more WMH in professional divers without previous DCS compared to non-diving controls. They observed more forgetfulness amongst the divers than the non-divers. In summary there is good evidence to suggest that cerebral MRI changes may develop during a diving career in absence of recognised injuries. However, the relationship between development of MRI changes on one side and the presentation and progression of symptoms and recognised illness on the other hand remains to be established. In the absence of such knowledge, routine MRI cannot be recommended as a tool for health surveillance of divers.

Some SPECT-studies have revealed cerebral perfusion disorders in divers with neurological DCI, others not [131, 132]. Differences may be explained by methodological differences. More recent studies suggest that cerebral blood flow, examined with SPECT, is reduced in some subgroups of occupational and recreational divers [133, 134]. However, there is insufficient data to suggest use of this method to monitor divers' neurological health.

11.4 Conclusion and recommendations for health surveillance of the nervous system

11.4.1 Selection of divers

Increasing the diving depth from 180 to 225 msw will probably increase the risk for HPNS. Data suggest that neurological vulnerability may dispose for HPNS and call for stricter selection criteria of divers [112]. However, selection criteria for divers are beyond the scope of this report and will not be discussed in further detail.

11.4.2 Pre-dive examination

The hyperbaric nurse on board the diving vessel (DSV) should perform a standardised pre-dive examination of all divers. Careful review of any neurological symptoms or complaints should be included in the pre-dive examination. The contractor's Responsible Competent Diving Doctor (RCDD) shall approve the results of this examination before the divers enter the chamber.

11.4.3 HPNS screening

Verified tests should be used to assess any signs of HPNS. Tests should be done immediately prior to the saturation to define a baseline. A minimum of three tests are recommended to establish intraindividual variation and to ensure that the diver is familiar with the tests. A questionnaire for HPNS should be complemented by measurement of static steadiness or tremor, hand grip strength and neuropsychological tests for executive functions, attention, and memory. These tests should be repeated at "holds" during compression deeper than 150 msw and at storage depth before bellruns. The RCDD shall assess any signs of HPNS, and new tests shall be performed after a defined hold period. If signs of HPNS persist, initiation of decompression shall be considered. The tests should be repeated 24-48h after surfacing.

11.4.4 Post-dive examination

A standardised medical examination after the saturation period shall be performed. The diver is also asked to fill in a questionnaire with questions about exposure, incidents and planned conditions during the dive that may affect health. This will include diving exposure in terms of the actual saturation dive (depth, bottom time, compression decompression time) but also questions about exposures in the periods between dive assignments.

Since it is difficult to self-evaluate one's cognitive function and because reporting of changes could have serious consequences for the employment relationship, we doubt the value of self-reporting (by questionnaire) changes in cognitive function. We expect divers to be

motivated to continue their diving career, and this may affect their motivation to report something that could put them at risk of having diving terminated. A personal clinical verbal interview is expected to reduce though not eliminate this concern. To compensate for this fact, the neuropsychological tests should be completed 24-48h after the dive as detailed in chapter 11.3.3

11.4.5 Health surveillance

We conclude that the available literature does not support an increased risk for neurological long-term health effects in divers participating in saturation dives ranging 180-225 msw compared to those diving shallower. We have systematically reviewed alternative methods for examination of the nervous system of divers. Our scope has been to consider examinations that can be applied to identify injuries and illnesses at a presymptomatic stage. We have concluded that HPNS testing – including selected neuropsychological tests – should be applied after finished dive as detailed in section 11.4.3. Beyond this it is our opinion that no specific examination can be recommended for routine use *in the absence of symptoms suggesting neurological injury or illness*. Recommending a mandatory neurological test as part of the health examination of divers participating in dives ranging 180-225 msw is not justified, based on the sensitivity and specificity of these tests. However, the knowledge in this field is limited, and appropriate actions should be taken for divers who show signs or symptoms of HPNS that do not subside during a relevant hold time. Such actions should include renunciation from diving and if needed initiation of decompression. Divers with persistent HPNS symptoms should be carefully examined by neurological and neuropsychological examinations after finished decompression.

It is our opinion that a standardised medical interview after the saturation period shall be performed. Here, various relevant questions about the diver's self-reported symptoms, exposures, and employment history will be answered by the diver. Also questions about exposures in the periods between dive assignments should be included.

12 DYSBARIC OSTEONECROSIS

Osteonecrosis or, bone infarction, may be caused by several non-traumatic factors and traumatic injuries in addition to decompression from increased ambient pressure. It is probably the best documented long-term health effect of diving. Other occupational groups than divers are also at risk of developing dysbaric osteonecrosis (DON) based on their exposure to increased ambient pressure and the following decompression. The condition was initially described among compressed air workers as early as 1911 [135, 136] and for divers in 1941 [137]. It is recognised as a long term health effect of diving [3]. Uguen *et al.* [138] recently published a review of DON among professional divers which summarises the prevalence of the condition, its pathophysiology and etiological factors emphasising that DON is presently a condition affecting divers in developing countries and not among e.g. military divers who strictly stick to the diving manuals and undergo medical examinations on a regular basis.

The scientific literature describes significant associations between decompression illness (DCI) and DON. Various scientific publications have shown a high prevalence of DON in populations of divers applying more or less self-developed diving routines, such as Hawaiian coral divers [139], Korean shellfish divers [140], Honduran lobster divers [141] Chinese divers [142] and most recently Mexican divers with a prevalence of 77% [143].

However, for commercial divers operating in the western world using established and proven dive profiles, the prevalence has been shown to be much lower [144].

The British Medical Research Council Decompression Sickness Registry and the British Central Registry filed x-rays from divers. In 1981 a report was issued showing that 204 out of 4980 North Sea commercial divers had radiographic findings of DON. Of these 204 divers only 62 had juxta-articular lesions (with the possibility for symptoms and subsequent degenerative arthritis). A later publication based on the material of the British Central Registry, having reviewed the x-rays from some 7000 professional divers found that only 0.17% had sub-chondral collapse and 4.3% if including all cases of identified DON [144]. For divers breathing heliox the prevalence was found to be 2,7% (all locations). For divers having dived beyond 150 msw, the prevalence of DON, at all locations, was 7.6%, but with a prevalence of sub-chondral collapse as that of the general diving population [145]. It is important, however, to notice that possible lesions only rarely develop to fulminant DON [146].

There are several diagnostic classification systems for DON. One of the most commonly used is the UK Medical research council radiological classification of dysbaric osteonecrosis [138] (Figure 2).

Symptoms do not arise until the collapse of parts of the articular surface, stage A4. Symptoms may include joint pains, stiffness, and weakness. A final diagnosis of DON will require a thorough history of the hyperbaric exposure and the absence of other risk factors.

Figure 2: Radiological classification of DON:

A – Juxta-articular lesions

A1-Dense areas with intact articular cortex

A2-Spherical opacities

A3-Linear opacities

A4-Structural failures

A5-Secondary degenerative osteoarthritis

B-Lesions in head, neck and shaft

B1-Dense areas

B2-Irregulare calcified areas

B3-Translucent or cystic areas

B4-Cortical thickening

The most common sites for developing DON are the long bones that contain the highest amount of fatty marrow and avascular articular cartilage, i.e. the humerus and the femur [147], and to a lesser extent the tibia [138]. Medullary lesions (metaphysis or diaphysis) are most commonly found [138] and these rarely give symptoms. Juxta-articular lesions (close to joint cartilage) constitute about 20% of all lesions in divers and are those that may cause symptoms.

12.1 Dysbaric osteonecrosis in saturation divers

Hunter *et al.* [148] reported radiological findings on 934 selected US Navy divers In their study, 21 lesions were classified in 16 radiologically positive cases (1.7% prevalence), and another 17 lesions were classified in 16 radiologically doubtful cases (1.2% prevalence of doubtful cases). Interestingly, the prevalence of radiologically positive findings was not different between saturation, mixed gas, and air only divers. Dysbaric osteonecrosis was found to be related to age, months in diving and number of treatments for DCI. The study suggests that saturation diving does not add to the risk of acquiring DON.

Davidson's work [144] seems to indicate that there may be an increased risk to saturation divers, but his work was based on x-ray reviews and did not reflect detailed exposure or diving history. However, a cross sectional study based on questionnaires, but with a high response rate and a vast number of participants, revealed more frequent symptom reporting of musculoskeletal disorders than what was the case among the other divers and a non-diving offshore population. If the musculoskeletal symptoms were caused by occupational factors like DCI or DON is not known [57].

12.1.1 Diving depth as a risk factor for dysbaric osteonecrosis

Hunter *et al.* [148] did not disclose any association between maximum diving depth during the diving career and DON in US Navy divers when compared to a matched control group. Davidson [144] found increased prevalence for the group that had dived beyond 150 msw, but with the same possible limitations to the material. The cohort referred to in Davidson's work was exposed to diving methods and tables that are no longer considered acceptable on the Norwegian Continental Shelf (i.e. bounce dives, rapid decompression). The NORSOK-based decompression tables have been empirically proven over time. The last 15 years no incidents of DCI have been reported from saturation diving on the NCS [54]. Note, however that the total diving activity on the NCS has decreased significantly over the last 20 years.

12.2 Mechanisms

There is an association between DCI and DON. More than 60% of divers with DON have experienced one or more episodes of limb bends [27].

The prevailing theory in literature states that bubbles form in fatty bone marrow during decompression and cause an increase in intramedullary pressure leading to a compression of the osteo-vasculature and ischemia [147]. Increased body mass has also been associated with DON [146].

Even though multiple mechanisms have been suggested for the development of DON, the formation of free gas seems to be pivotal in the pathogenesis [147]. However, Uguen *et al.*

[138] conclude that the pathophysiology of the disease is incompletely understood and other etiological factors are perhaps being overlooked.

12.3 Available methods for detection of dysbaric osteonecrosis

Traditionally, DON has been detected by means of conventional X-ray. Neither conventional radiography nor computer tomography are suited for early diagnosis, as death of bone tissue and marrow without a started repair process produces no radiographic abnormality [27].

MRI is superior with respect to sensitivity and will detect lesions earlier than conventional X-ray [149]. Scintigraphy may show increased isotope uptake at an early stage, but possible finding will not be specific and not be of predictive value. There are no pathognomonic MRI findings specific to DON compared to osteonecrosis by other mechanisms. Gempp *et al.* [150] reported positive MRI findings in six out of 21 divers treated for musculoskeletal DCS. Interestingly, two of the divers demonstrating bone marrow oedema immediately after the accident had normal findings when re-examined 3-4 months later. Accordingly, such oedema identified by MRI should not be considered equivalent to definitive DON.

12.4 Conclusion and recommendations for health surveillance of dysbaric osteonecrosis

The realisation that divers were at risk to develop osteonecrosis led to legislative measures in several western countries. «Long bone» x-ray examinations were introduced at intervals with the aim of early discovery of non-symptomatic (stage 2) DON in divers. However, no treatment could be offered to the affected divers in the very few cases where radiographic changes were found, and no symptoms were present. Neither did x-ray findings lead to restrictions on the divers' career other than that they were informed of the findings and possible future development.

As a consequence of these findings, the practice with routine long bone X-rays has been abandoned by all regulators in the western world except for Poland [151]. The last revision of the Health and Safety Executive's «The Medical Examination and Assessment of Commercial Divers MA1» 01.10.15, item 96 says:

«Routine long bone x-rays are not required for surveillance of divers. Long bone radiography/and or MRI is indicated in cases of suspected dysbaric osteonecrosis».

This is the present practice of other European and relevant American countries.

The decision to abort the routine with long bone examination of divers was reached through a risk analysis weighing exposure against possible benefits.

From the figures we assume that the prevalence of DON in the diving population is low. It is somewhat higher for divers breathing heliox, but as shown above, the benefits of an early detection in a symptom free diver are next to nil. Further, it is only juxta-articular DON that in any way may impair the diver's quality of life.

The prevalence of DON is correlated with the frequency of DCI. This recommendation addresses the Norwegian Continental Shelf, and since the introduction of NORSOK-based tables, there has been few cases of DCI reported on the NCS (see chapter 9.9.3). As discussed above, there is presently no identified non-invasive method that can identify DON at an early stage with high specificity. What is of importance in long term surveillance is a

good medical history focusing on joint symptoms and previous episodes of DCI and an adequate follow-up of divers with reported symptoms.

13 EFFECTS OF DIVING ON THE LUNG

Diving may cause acute pulmonary conditions such as pulmonary oedema and barotrauma. These injuries have been described in chapter 9.3 and 9.4 and will not be discussed further. Long-term effects of diving on the lung may occur in the absence of recognised injuries or diseases. The most important exposure factor for pulmonary long-term effects is hyperoxia, but decompression induced venous gas emboli (VGE), the thermal properties of the breathing gas, increased density of the breathing gas and immersion may also affect lung function. The interaction and relative contribution of each of these factors remain unresolved.

In the consensus conference "Long Term Health Effects of Diving" in Bergen, 1993, it was stated that "*There is evidence that changes in bone, the CNS and the lung can be demonstrated in some divers who have not experienced a diving accident or other established environmental hazard…..The scientific evidence is limited, and future research is required to obtain adequate answers to the questions of long term health effects of diving [3].*

Still, there are few prospective studies published on long-term health effects of diving on lung function. Pougnet et al. [152] reviewed fifteen publications on longitudinal change in commercial divers' lung function. Reduced pulmonary diffusion capacity and reduced mid expiratory flow rates were reported in three and five studies respectively. In their conclusion, the authors raise the question whether the observed changes were due to age or diving. Most of the publications included in this review studied surface-oriented divers. Two studies published after this review have confirmed statistically significant, but small, reduction in diffusion capacity, FEV_1 and mid-expiratory flow rates in occupational divers [153, 154]

Regarding diffusion capacity, results must take subacute effects due to immersion into account [155]. In a 6-year follow up of mostly construction divers, the authors found a larger reduction in gas diffusion among divers than among controls, but the observed reduction was not correlated to diving exposure. In a follow-up after 12 years, the authors found no significant changes in gas diffusion [156]. Pougnet et al. [153] reported a small reduction in TL_{CO} in 26 divers examined after 15 years of diving. However, the reduction was not statistically more than that expected for the reference population.

Commercial divers have been found to have a larger lung volume than the reference population [7]. The main reason for this is probably a selection bias in the population of divers with persons recruited to the diving industry having high vital capacity [157, 158].

In a survey of 1540 commercial divers in the UK, Ross *et al.* found no difference in diagnoses or symptoms related to the respiratory system compared to a control group of offshore oil industry workers [57].

13.1 Saturation diving and the lung

There are not many studies on pulmonary effects of saturation diving specifically, and available studies generally include few subjects. We have found no studies on lung function in NORSOK U-100 compliant saturation diving in the depth range 0-225 msw.

In a study of 152 professional saturation divers, Thorsen *et al.* found reduced dynamic lung volumes and flows and reduced diffusion capacity compared to a group of non-diving controls [159].

In another study, Thorsen *et al.* found a reduction in pulmonary carbon monoxide transfer factor (TL_{CO}) and reduction in forced mid-expiratory flow rate after saturation dives [160]. Changes were correlated with cumulative hyperoxic exposure. The authors also found a negative correlation between a metric for venous gas emboli (termed “accumulated bubble score”) and TL_{CO}. This should be interpreted with caution due to the non-linearity of bubble-scores. An observed increase in total lung capacity was correlated with hyperbaric exposure.

In a follow up of lung function one and four years after saturation dives to 300-450 msw, Thorsen *et al.* found a larger than expected reduction in FEV_1 one year after exposure [161] in 24 divers. The reduction was 210 ml (SD 84 ml), and this was significantly larger than what was found in a control group comprising divers performing “ordinary saturation diving”, i.e. diving to 70-150 msw. The control group had an annual reduction in FEV_1 of 35 ml, not different from the predicted value. From one to four years after exposure the observed changes in the group of deep divers were similar to changes in the control group. Changes in gas diffusion were not significantly different between the groups, and not significantly different from predicted annual loss.

Cotes *et al.* studied lung function in seven “diver/welders” after a test saturation dive to 300 msw [162]. They found a transient increase in FVC and PEF, but no change in flow rate at small lung volumes. The authors also found a 9.6% reduction in TL_{CO} with partial recovery one year after the dive. The divers were exposed to a pO_2 of 50-60 kPa throughout the bottom phase of 12 days, which gives a significantly higher oxygen exposure than current operational saturation diving. One of the divers had signs and symptoms suggestive of pulmonary oxygen toxicity.

In an experimental dive to 250 msw, Thorsen *et al.* found no changes in lung function of 8 divers [163]. In this dive, pO_2 in decompression was alternated between 50 kPa at daytime and 30 kPa during night stops (6 hours).

13.2 Exposure factors with potential effect on pulmonary function in saturation diving

13.2.1 Hyperoxia

Diving is done with hyperoxic breathing gas, i.e. increased partial pressure of oxygen compared to normal surface conditions. Van Ooij has reviewed pulmonary oxygen toxicity in divers [164]. Oxygen levels above 40-50 kPa can cause pathological changes in the respiratory system, i.e. pulmonary oxygen toxicity, by induction of inflammatory processes. Initial changes of interstitial and alveolar oedema are reversible. However, with persisting exposure, irreversible changes with interstitial fibrosis or emphysematous alveoli may develop.

The pathological effects of hyperoxia are believed to be mediated through increased formation of free oxygen radicals and other reactive species. These species may in turn interact with cell membrane lipids, membrane proteins and other parts of the cell and cause damage and cell death. Mechanisms of oxidative damage are described by Clark and Thom [27]. The lungs are particularly vulnerable to oxidative damage, as they are exposed to higher pO_2 than other organs.

The prolonged exposure to hyperoxia in saturation diving is a distinct difference to the short-lasting hyperoxia in surface-oriented diving. For saturation diving, pO_2 does not depend on diving depth. PO_2 in the inspired breathing gas will vary depending on whether the diver is in the chamber (storage mix), in the bell (bell mix), in the water (lock-out mix) or in decompression. Limits for pO_2 are company-specific, typical values for operational diving are 36-40 kPa for storage mix, 35-70 kPa for bell mix and 35-80 kPa for lock-out mix. During decompression pO_2 is kept at 46 - 50 kPa (NORSOK U-100 requirement is 40-50 kPa).

Thorsen and Kambestad studied lung function in 8 divers after a shallow simulated saturation dive to 15 msw with a hyperoxic exposure similar to a saturation dive to 360 msw [165]. One and three years after exposure, a significant reduction in mid-expiratory flow rates persisted, whereas FEV_1 and FVC were not significantly reduced. A reduction in TL_{CO} found immediately after the dive had recovered completely in the follow-up. The changes in pulmonary function after this dive can reasonably be ascribed to hyperoxia due to the absence of any immersion effect and minimal change in breathing gas density.

13.2.2 Venous gas emboli (VGE)

Venous gas bubbles may occur due to inert gas supersaturation following a reduction in ambient pressure, i.e. during upward excursions, after downward excursions and during the saturation decompression. VGE may also occur as a result of changing breathing gas, with one gas being absorbed faster than another gas is washed out, so-called isobaric counter diffusion [27]. Several studies have described VGE detectable by ultrasound in saturation diving.

Risberg *et al.* found VGE in all 19 divers during decompression from operational saturation dives with storage depths of 95-133 msw [166]. Decompression was done with NORSOK U-100 compliant procedures.

As previously mentioned, Thorsen *et al.* found a reduction in transfer factor of the lungs for carbon monoxide (TL_{CO}) correlated to accumulated load of VGE after saturation diving, calculated as sum of bubble scores [160]. It should be noted that the sum of bubble scores is not a valid measure of gas bubble load, as bubble scores are highly non-linear. An effect of VGE on pulmonary gas transfer function has also been found after air dives [167, 168].

The endothelium of the lung vasculature is the most exposed to VGE. It has been shown that high grade VGE correlates with various indices of dysfunction in the lung endothelium in animal experiments, including morphological changes like leukocyte infiltration, oedema, capillary expansion and congestion haemorrhage [169]. Such morphological changes are likely to have effect on pulmonary gas transfer function.

Whether increasing maximum diving depth from 180 msw to 225 msw also increases occurrence of VGE is not known.

13.2.3 Gas density

Gas density increases linearly with increasing pressure; however, the density also depends on the composition of the breathing gas. For heliox breathing gas at 180 msw, density is approximately 3 times that of air at surface conditions. Increased density yields increased breathing resistance and work of breathing (WOB). The WOB for a diver in the water can be considerable. For deep operational saturation diving, this is a limiting factor for physical work.

The high WOB is partly caused by immersion, but mainly by increased breathing resistance in the underwater breathing apparatus. For the resting, non-immersed diver breathing ambient gas in the chamber or diving bell, the WOB is not a problem.

13.2.4 Hyperbaric welding

Hyperbaric welding operations can potentially expose the welding divers to fumes, dust and ozone that may affect lung function [170]. Tungsten inert gas (TIG) welding is most common. This method produces less dust and fumes than other methods, but ozone production is increased. Furthermore, the hyperoxic atmosphere of the diving habitat enhances ozone production. Most hyperbaric welding on the Norwegian Continental Shelf (NCS) is performed with automated equipment, with the diver in a separate “safe zone” during the actual welding process. Also, respiratory protective equipment with over-pressure shall be used in the welding habitat and the quality of the habitat atmosphere shall be assessed before the respiratory protective equipment is taken off, in compliance with requirements (NORSOK U-100).

13.3 Effects attributable to diving depth 180-225 msw

As previously mentioned, pO_2 in saturation diving is independent of depth, but is increased during bell runs, lock-out and decompression compared to storage mix. The hyperoxic exposure depends on the duration of the bottom phase, time “at work” (in bell and water) and decompression time. For diving deeper than 180 msw, decompression time is increased, but bottom phase and time “at work” is reduced due to regulatory restrictions (Table 3). This will limit the total hyperoxic exposure.

	<180 msw	>180 msw
Maximum bottom time	14 d	10 d
Maximum bell run time	8 h	6 h
Maximum in-water time	5 h 30 minutes	3 h
Minimum rest period between saturations	Equal to last sat period	Twice last sat period

Table 4 Time limit provisions for diving shallower and deeper than 180 msw as stipulated by the Activities Regulations and NORSOK U-100 [2, 20]

We have used the method suggested by Thorsen et al. [160] to calculate the cumulative hyperoxic exposure on saturation dives to storage depths of 167 and 212 msw (with these storage depths, excursions can be performed down to 180 and 225 msw, respectively):

$$\int [pO_2(t) - 21]dt$$

We have used the following constants (see section 3 for terminology):

- pO_2 in storage breathing gas: 35 kPa
- pO_2 in bell breathing gas: 50 kPa
- pO_2 in diver’s lockout breathing gas: 50 kPa

- pO_2 in breathing gas during decompression 50 kPa
- Time limitations and decompression according to NORSOK U-100
- One daily bell run in bottom phase

With these parameters we find that the total cumulative hyperoxic exposure for a dive to 167 msw is 11401 kP*h, whereas the corresponding number for a dive to 212 msw is 10524 kP*h, i.e. 7% lower for the deeper dive. The reason for this is the stricter provisions of time as presented in Table 4. The exposure-reducing effect of double time off between saturations for deeper dives is not included in the calculation of cumulative hyperoxic exposure.

While maximum ambient pressure (diving depth) may affect static lung volumes, neither TL_{CO}, FEV_1 or $FEF_{25-75\%}$ were correlated to diving depth as reported by Thorsen et al. [160].

Respiratory resistance increases, and maximal flow decreases due to increased breathing gas density with deeper diving. Increase in lock-out breathing gas density (pO_2=50 kPa) is approximately 20% when going from 180 to 225 msw. Respiratory resistance is increased both in the breathing apparatus and in the airways of the diver, and the increased work of breathing (WOB) is a limiting factor on intensity and duration of the physical performance of the diver in the water [171]. The main measures to mitigate the increased WOB in diving beyond 180 msw are:

- Time limitations for lock-out when diving deeper than 180 msw, as shown in Table 4
- Careful planning of the work and use of remotely operated vehicles (ROVs) in strenuous tasks to avoid breathlessness for the diver in the water
- Careful adjustment of the underwater breathing apparatus before the dive to minimise work of breathing

Helium has a high thermal conductivity, and the specific heat capacity of the breathing gas increases with increasing depth. Breathing cold gas, particularly at high levels of ventilation, may induce bronchoconstriction and airway inflammation [172]. For diving deeper than 150 msw there is a requirement in NORSOK U-100 for active heating of breathing. Exposure to cold breathing gas should therefore not be adversely affected by increasing the diving depth to 225 msw.

13.4 Methods for detection of diving related pulmonary health effects

Dynamic spirometry (usually just termed “spirometry”) is a physiological test measuring expired and/or inspired volume of gas as a function of time. The examination is relatively simple to do, does not require expensive equipment and has no relevant side effects. There are recognised standards for the procedure, national reference values are published and threshold values for divers are established.

Lung diffusion testing, e.g. diffusing capacity for carbon monoxide (TL_{CO}), is sensitive to changes in lung function caused by oxygen toxicity [173] and changes in TL_{CO} has been suggested as a marker for recovery after exposure to hyperoxia [174]. However, it is not related to diving depth [160]. As we have shown, the total oxygen exposure is reduced for diving in the depth range 180-225 msw compared to shallower saturation diving. Increasing maximum diving depth from 180 msw to 225 msw does therefore not warrant introduction of lung diffusion testing as a new test in the procedure for long-term health follow up of divers.

Imaging techniques like chest x-ray and CT have low sensitivity and specificity for potential changes in lung function caused by diving. They are not considered useful in long-term follow-up of divers' lung function, unless indicated by specific symptoms or signs of pathology.

13.5 Conclusion and recommendations for health surveillance of lung function

We conclude that there is some evidence that saturation diving can affect lung function, with a reduction in mid-expiratory flow rates and diffusion capacity. These changes are generally reversible, although some studies indicate residual effects with repeated exposure. There is no support in the available literature that saturation diving, as it is practised today, causes clinically significant long-term effects on lung function in the absence of acute injuries or illnesses like pulmonary barotrauma or immersion pulmonary oedema. Still, the latest Norwegian review on this subject recommends regular examinations of divers' lung function [7].

The current procedure for commercial divers is an annual certification examination and a 3-yearly examination with the employer's occupational health service, both with spirometry. FEV_1 and FVC should be the main parameters in the assessment of potential long-term health effects. Examinations should be performed in accordance with recognised procedures and with calibrated equipment to minimise variability.

The annual questionnaire has questions about occupational exposure, smoking habits, and airway symptoms.

Divers should be encouraged not to smoke.

We have shown (Chapter 13.3) that the total hyperoxic exposure in saturation dives ranging 180-225 msw is less than shallower diving. On this basis we recommend following the same pulmonary health surveillance (dynamic spirometry) for diving in the depth range 180 to 225 msw as is used for diving down to 180 msw.

14 EFFECTS OF DIVING ON HEARING AND BALANCE

14.1 Does diving affect hearing acuity?

Hearing acuity is most commonly studied by audiometry with air conduction. The assessment of long-term shifts in hearing thresholds is complicated by the pronounced effect of ageing on hearing threshold and by the lack of control for non-diving related exposure that may affect hearing.

The sensitivity of the human ear to sound is dependent on ambient medium (gas, fluid) and pressure [175, 176]. The human ear has less sensitivity to sound while immersed/underwater than in the dry environment, typically an attenuation in the order of 40 dB. The immersed ear has best sensitivity for frequencies less than 1 kHz in contrast to surface air with a peak sensitivity at approx. 4 kHz. In the compressed air environment, hearing acuity is in general decreased as ambient pressure is increased – typically in the range of 30-40 dB [177]. In the heliox environment, hearing thresholds are increased for most frequencies, but the hearing sensitivity seems to increase for 6 and 8 kHz [176].

Two studies comparing hearing acuity before and after deep heliox dives (176 and 296 msw) failed to demonstrate any change in hearing threshold [178, 179].

Studies of long-term effects of diving on hearing acuity show conflicting results [180-185]. Two of the most recent reviews on this topic have been published by UK Health and Safety Executive (HSE) and the Norwegian National Institute of Occupational Health (STAMI) [5, 176]. The conflicting findings are most evident in the cross-sectional studies, but twelve of the 15 studies reviewed by HSE concluded that diving affected hearing threshold. The most common finding is that hearing deteriorates faster with age in divers than in non-divers. However, hearing acuity is in general better for occupational divers than in a reference group of the same age cohort.

Prospective studies have reported hearing deterioration for low, mid and high frequencies [180, 185, 186], while Goplen *et al.* only observed a threshold shift at 4 kHz in their 6-year prospective study [187].

On a group level, most of the studies [180, 185-187] report small to modest threshold shifts (typically <5 dB compared to the age-adjusted hearing deterioration). Wingelaar et al. [188] recently published a retrospective cohort study of 1117 divers from the Dutch navy followed by audiometry for a 25-year period. They observed less decrement in hearing threshold than expected from a normal age-related deterioration.

A causality between diving and impaired hearing would be expected to show a dose-response pattern. Molvaer and Albrektsen [185] and Goplen *et al.* [187] did not observe any relationship between diving exposure (years of diving) and hearing threshold. Neither did Skogstad *et al.* after six years of follow-up of an occupational diver cohort [189] but they reported a positive relationship between number of dives and hearing threshold for 4 and 8 kHz [180] after twelve years of observation.

14.2 Mechanisms

14.2.1 Noise

There are probably multiple mechanisms by which diving affects hearing [176, 180]. Noise-induced hearing loss has been suggested as a major contributor. Divers are exposed to ambient noise as well as self-induced noise from the breathing circuit [176, 190]. Curley and Knafelc [191] reported noise levels ranging 90.5 – 97.3 dB (A) in the MK 12 diving helmets during dives from 1.8 to 30.5 msw. After these dives, the divers experienced a temporary auditory threshold shift (TTL). Median TTL peaked at 40 dB at 2 kHz after 180 min exposure to 9.1 msw. The frequency range 2-4 kHz was most affected. Nedwell *et al.* reported noise measurements inside and outside the Kirby Morgen SuperLite 17 helmet during operational Heliox saturation dives to 30 and 120 msw [190]. Noise levels ranged L_{eq} 85.3-101.4 dB (A) after correction for the altered sensitivity of the human ear at increased ambient pressure and in the absence of specific noise-producing tools. The study strongly confirms that the North Sea saturation diver is exposed to a noise level exceeding the legislative border of 86 dB (A) for six hours exposure. Most of this noise is “self-induced”, i.e. caused by gas flow and communication within the helmet [190].

14.2.2 Other mechanisms

Traumas like decompression illness and inner ear barotrauma are known to affect hearing. Solvents commonly used in painting affect hearing as well as balance. Furthermore, such solvents may have a synergistic effect with noise on hearing threshold [192]. Repeated compressions and decompressions have been shown to damage hair cells in minipig cochleae [193] suggesting that repeated dives, without signs of clinical decompression sickness, may affect hearing. Whether hyperoxia may affect inner ear function is unanswered.

14.3 Is hearing deterioration dependent on diving method or diving depth?

This question has not been studied to an extent allowing firm conclusions. Three of the four published longitudinal studies that we have identified [180, 186, 187] reported hearing threshold of divers mainly using surface-supplied compressed air. Molvaer and Albrektsen [185] did not report the diving method in their study. Based on these longitudinal studies it is not possible to assess the relationship between hearing deterioration and diving method or diving depth.

In the absence of adequately performed longitudinal studies, two cross sectional questionnaire studies are reported below. Caution should be taken interpreting these due to the methodological challenges of questionnaire studies in general [194] and the poor (0.26) positive predictive value of a self-reported hearing impairment compared to audiometric results [195]. Ross *et al.* reported results from a questionnaire-based study including 2958 UK professional divers and 2708 non-diving offshore workers [57]. They achieved a response rate of 56 and 51% in the two groups, respectively. Divers reported impaired hearing more frequently than non-divers. However, this difference was attributable to the group of offshore divers only, since non-offshore divers did not report hearing impairment more than the reference group. The authors state a caveat that complaints of hearing impairment were related to multiple symptom reporting and they recommended objective

examination before any conclusion is drawn. In a later work [196] the authors reported audiometry results of 151 divers compared to a group of 120 offshore workers. Thirteen per cent of the divers had a threshold in the five-percentile range (suggesting a reason for referral according to UK standard) vs 4% in the group of offshore divers (OR 3,16, P<0.05). After adjustment for hearing risk factors, there was no difference between the groups. However, for any level of hearing threshold shift, the divers reported more hearing impairment than offshore workers, possibly over reporting such symptoms. Chung *et al.* [197] studied a group of 5422 US Navy divers serving between 1960 and 1990 by means of a questionnaire, reporting a response rate of 33%. Impaired hearing was reported by 39% of these, but in the subgroup of saturation divers having taken part in experimental dives, impaired hearing was reported by 72%. However, amongst saturation divers (not taken part in experimental dives) the observed 43% incidence of impaired hearing was comparable to fleet divers in general (38%).

14.4 Will diving affect vestibular function?

We have only identified two studies reporting long-term follow up of vestibular function in divers [198, 199]. Sharoni *et al.* [198] compared 13 occupational divers with matched controls using electro nystagmography and smooth harmonic acceleration rotary chair test. They concluded that there was no evidence of vestibular disease in any of the professional divers. Goplen *et al.* [199] completed a longitudinal study on 67 subjects examining these at the start of occupational diving training and then 3 and 6 years later. The subjects responded to a questionnaire and were completed a comprehensive oto-neurological examination. They found no vestibular disorders and there was no correlation between postural sway and diving exposure. In summary there is little evidence to suggest long term health effects on the vestibular system in the absence of identified injuries and illnesses such as inner ear decompression illness or inner ear barotrauma.

14.5 Methods for detection of long-term effects on hearing and balance

Epidemiological studies on divers' auditory function have traditionally reported audiometry results of pure tone thresholds. This examination has well documented reference values (ISO and national epidemiological surveys), is of a comparatively low cost, requires limited training and is usually widely available for occupational health services. The relationship between noise exposure and threshold changes is relatively well established and there are occupational health standards suggesting thresholds for classification of noise injuries as well as referral thresholds (to ENT specialists).

A wide range of alternative tests are available such as hearing threshold for bone conduction and speech audiometry, but these are not widely available, usually require additional equipment and training and adds little to the information gained from audiometry by air conduction.

Electrophysiological and imaging tests such as auditory evoked potentials, CT and MRI imaging have no place in screening and health surveillance as they are not suited to identify hearing impairment, but rather to investigate the underlying cause of them.

14.6 Conclusion and recommendations for health surveillance of hearing acuity

Divers experience hearing impairment that exceeds what is expected due to normal ageing. The size of the auditory threshold shift is small on a group level. Noise is probably the most important mechanism for the hearing deterioration, but other mechanisms including injuries and chemical exposure may add to this. There is little evidence to suggest that hearing is significantly affected by diving depth or diving method *per sé*.

Reducing ambient noise originating from tools, chamber noise, and breathing circuits is probably the most effective preventive measure. To monitor the effects of such primary intervention, it is recommended to include audiometry as a part of the routine health surveillance of *all* divers. This is in agreement with Norwegian and EU recommendations [200]. There is no evidence to support that saturation diving in general or deep saturation diving in particular increase the risk for hearing deterioration in divers and we don't recommend additional auditory or vestibular examinations of divers participating in dives ranging 180-225 msw.

15 EFFECTS OF DIVING ON OTHER ORGANS

15.1 The cardiovascular system

A Norwegian registry study reported a higher degree of cardiovascular disease (CVD) among divers with a higher intensity of exposure to diving, compared to lower exposure to diving [201]. A study of 20 saturation divers [202] found normal size and function of the heart by Doppler echocardiography when the divers were compared with 20 policemen. A questionnaire study encompassing 2958 divers, compared with offshore workers, has been published by Ross *et al.* [57]. The divers did not report more cardiovascular disease than referents; in fact, they were less likely to report hypertension.

It has been demonstrated that diving may affect the endothelium of blood vessel walls, as shown by repeated dives using trimix to depths of 55-80 meters [203]. The mechanism of such endothelial dysfunction is unknown, but it may possibly be related to the formation of reactive oxygen species (ROS) caused by hyperoxia, reduction of NO in the vessel wall, plate aggregation and a direct mechanical effect of the endothelium itself [204]. Thus, the hyperbaric environment might increase the risk of CVD.

It has also been suggested another cause of an atherosclerotic process among divers. Saturation divers infected by *P. aeruginosa* could be exposed to autoantibodies cross-reacting and binding to human heat shock proteins (HSP). A HSP variant, HSP60, is present in endothelial cells and binding of anti-HSP60 antibodies to this protein could cause atherosclerosis. An animal model supports the possibility of skin infections caused by *P. aeruginosa* in the diving environment giving rise to production of autoantibodies against HSP60 [205].

A high level of physical fitness has been considered an important factor to counteract adverse effects on the endothelial function after diving.

"Working hours and health, a systematic literature study;" a report from NIOH in Oslo was published in 2008 and updated in 2014 [206, 207]. The conclusions of the reports are mostly the same. Shift/night work and long working hours are associated with sleep disturbances, increased risk of malpractice, increased risk of injury/accidents, increased risk for female breast cancer and increased risk of CVD and diabetes.

A recent published systematic review and meta-analysis has shown an increased risk for CVD and mortality among shift workers, particularly increasing after five years as a shift worker [208].

As for divers, a small experiment among four divers in chambers pressurised to depths between 180-230 msw did not disclose serious sleep disorders [209].

Even though saturation diving is shift work, epidemiological data do not suggest increased occurrence of CVD in professional divers [57]. This may be due to limited exposure with the current regulations and/or a "healthy worker effect" with the health certification requirements. There are also no known factors that will increase the risk of CVD with deeper diving. Regulations regarding increased time between saturation will reduce exposure to shift work with diving deeper than 180 msw. There is therefore no indication to introduce screening for CVD in the long-term health follow-up for divers.

15.2 The teeth

Barotrauma and other damage to the teeth are now rare among divers [210, 211]. Subsea welding / cutting (electrolysis / electromagnetic fields) can cause metal taste in the mouth and affect amalgam fillings [212]. Dental examination should be part of the selection procedures.

15.3 Fertility

In an animal study, mice were pressurised over several weeks, and a study of a few divers exposed to saturation dives in the chamber to 450 meters have found reduced male fertility including negative effects on sperm production [213, 214]. No teratogenic or histological changes in the testicles were found in the mice [213]. In another mouse model, the animals were followed after being pressurised, and fertility increased gradually after decompression. This may indicate that the reduced male fertility after exposure to increased pressure is reversible [215]. A human study found no increased risk of unfortunate pregnancy outcomes observed among partners of male divers [216].

15.4 Cancer

No evidence has been found for an increased risk of cancer among divers [5], but oxygen toxicity can possibly lead to increasing DNA damage [29]. However no DNA-damage in mononuclear cells was found in eight subjects participating in a 250 msw simulated dive [217]. A German group [218] has found that oxygen toxicity can cause DNA damage in a cell test, but *in vivo* exposure caused less damage compared to *in vitro* experiments, which may indicate the living organisms' ability to adapt and compensate for oxidative stress.

Furthermore the hyperoxia may increase ROS which in turn can adversely affect proteins, fat tissue and nucleic acids in the genome and may thus increase the risk of cancer.

Telomeres are specialised nucleoprotein complexes that maintain the integrity and stability of eukaryotic chromosomes. Telomeres are shortened during the ageing of mammals. Measuring telomere length in leukocytes (white blood cells) in the blood is used to monitor haematological stem cells in different situations. The telomeres are shortened at each round of cell division in the absence of the enzyme telomerase. The robustness of this enzyme and telomeres thus becomes a prognostic marker for aging and disease. The telomere length of highly educated marine divers exposed to a high partial pressure of oxygen during diving lasting a year was studied. An unexpected prolongation of the telomeres in the white blood cells was observed, possibly due to a renewal of cells from the stem cell group with longer telomeres or a favourable activation of telomerase [219].

15.5 Eyes/Vision capability

Capillary anomalies, a reduction of capillary density and increased retinal pigment epithelial defects have been described among divers [220]. These findings could not be confirmed in a study of 56 divers (among them 20 saturation divers) and 24 controls [221]. Here, none of the divers had microvascular defects and other abnormalities were similar among divers and controls. Murrison *et al.* [221] could therefore not support the idea of diving being associated with retinal abnormalities. Transient myopia has been described among recreational divers exposed to oxygen levels exceeding the present recommendations [222] and hyperbaric

oxygen treatment can result in new/progression of cataracts [29]. This phenomenon has not been studied among saturation divers.

A Chinese group of scientists has found that damage of the retina is commonly found among divers, and they have closely followed groups of divers and treated them, e.g. with laser [223].

15.6 Skin

Divers' hands is well known among saturation divers [224]. The phenomenon is characterised by transitory peeling and scaling of the skin on the palms and sometimes even affecting the soles of the feet. The aetiology is unknown. Skin infections such as external otitis, caused by *Pseudomonas aeruginosa,* are described among saturation divers, and the microbe has been detected in the chamber systems [225]. The condition is treated with local antibiotics and it is not known to cause complications or long-term effects.

15.7 Changes in blood chemistry

Exposure to hyperoxia can change vitamin status such as reducing vitamin B12, increase iron levels through a reduction in erythropoietin, haemoglobin (Hgb)-but increased ferritin [226]- and haematocrit (Hct) and trigger haemolysis of de novo formed erythrocytes, but also adversely affect various lines of white blood cells and platelets.

15.8 Musculoskeletal disorders

We have previously (section 12) discussed dysbaric osteonecrosis as a recognized, but infrequent long-term health effect of diving. Hand-arm vibration syndrome will be discussed in section 15.9. Flatmo et al. [227] submitted a questionnaire to 6138 Norwegian divers and reached 49% response rate. Divers working in the quay/construction industry reported significantly more musculoskeletal complaints, strain injuries and joint pain compared to other divers. Musculoskeletal complaints were more common among divers having suffered DCS. The Haukeland University Hospital study on previous North Sea divers [89] included an extensive questionnaire submitted to referred divers (N=96), non-referred divers ("Diver controls", N=134) and a reference population (N=151). The Odds Ratio for hand, leg and joint pain was significantly higher amongst referred and non-referred divers compared to the reference population. Back pain was more common in referred divers but not among non-referred divers compared to the reference population. The finding would suggest musculoskeletal symptoms to be common in Norwegian divers. A similar finding was reported by Ross et al. [57] in their postal survey to UK divers (N=1540) and non-diving offshore workers (N=1035). Odds Ratio for musculoskeletal symptoms was significantly higher amongst divers than non-divers.

The incidence of musculoskeletal symptoms was further examined in a study by Ross et al. [228]. They examined 151 divers and compared them to 120 non-diving offshore workers. The examination included physical examination, neuropsychological tests, and a series of health questionnaires (SF-36, Hospital Anxiety and Depression Scale, Cognitive Failures Questionnaire, Prospective and Retrospective Memory Questionnaire, Dysexecutive Syndrome Questionnaire, Musculoskeletal Symptoms and general unrelated symptom reporting. A weak association between musculoskeletal symptoms and physical signs were confirmed. However, divers with musculoskeletal symptoms tended to report symptoms

generally suggesting somatisation. The authors conclusion regarding musculoskeletal symptoms amongst divers was that "…caution should be exercised regarding their interpretation as an indication of physical disease or their use for health screening".

15.9 Hand-arm vibration syndrome

Hand-arm vibration syndrome (HAVS), first described among Italian miners in 1911 [229], is occasionally seen in occupational settings with manifestations in the peripheral neurological, vascular and musculoskeletal systems. Among manual workers in the Western world, metal sheet workers are the most heavily exposed to hand transmitted vibration.

The sensorineural component of HAVS includes subjective numbness, tingling and pain, and signs of sensory deficits, poorer manual dexterity, and muscle weakness. As to divers, we have not detected any publications, but divers using vibrating tools should be informed about the hazards of such tools and take precautionary measures.

15.10 Immunological responses to diving

Leukocytes were analysed during a saturation dive to 440 msw [230]. Polymorphonuclear leucocytes (PMN) increased during compression and bottom phase and gradually decreased during decompression. Lymphocyte concentration showed opposite changes. The dive caused different response on various lymphocyte subgroups. Regarding complement levels, it appears that increased levels of oxygen by diving do not cause changes among experienced divers, but the complement system may possibly be activated during DCI. The oxidative stress that divers are subjected to [231] leads to activation of neutrophils, monocytes, and macrophages and suppresses lymphocytes. This leads to a subsequent change in apoptosis, inflammation, and immune response in the divers [232]. However, ROS that are generated under circumstances of increased partial pressures of oxygen during saturation diving, may possibly protect against such responses through a beneficial effect on the immune system and an antibacterial effect.

A cytokine response similar to that induced by exercise has been seen after SCUBA-dives at great depth [233] but Thorsen *et al.* [226] found no increase of CRP (as evidence of increased inflammation) after a 28-day saturation dive to 250 meters.

Still, divers may be exposed to certain viral and bacterial infections, such as upper respiratory tract infections, skin, and external ear infections. A few hours of immune suppression, as observed during bounce diving, should not have any clinically significant effects. Suppression of immunocompetent T-cells over a period reaching 30 days or more may be unfortunate, though, leading to an increased risk of infections and neoplastic cells that are not contained by the immune system, but also in this respect, there are data to support that saturation divers develop compensatory mechanisms [234].

15.11 Conclusion and recommendations for health surveillance of other organs

We have found no evidence for health effects on the organ systems discussed in this chapter entailing a need to extend the standard programme for health surveillance of divers. In general, health surveillance of other organs should be done on indication, i.e. if exposure history or medical interview indicate that examinations should be done.

16 PSYCHOSOCIAL/ORGANISATIONAL FACTORS AND PTSD

16.1 Psychosocial/organisational factors

A working environment with predictable salary and employment conditions and with an atmosphere of security and social support has proven to be beneficial in several studies [235, 236]. We consider it unfortunate if divers are employed by short-term contracts, without stable and predictable working conditions.

On a general basis, unfavourable shift work and lack of rest may give rise to increased risk of a variety of conditions such as cardiovascular disease and possibly some cancers [208, 237, 238]. As for saturation diving, such work conditions should therefore be reduced to a minimum and the diver must be guaranteed sufficient rest during the saturation period as well as sufficient intervals between saturation periods. For dives in the 80-225 msw range the time between saturations will be doubled. Furthermore, bottom time will be shortened as described previously.

16.2 PTSD

Posttraumatic stress disorder (PTSD) is one of the few diagnoses where a triggering event is a necessary diagnostic criterion. A traumatic event is one in which the person experiences, witnesses, or is confronted with an event or events that involve actual or threatened death, serious injury, threat to the physical integrity of self or others accompanied by intense fear, horror, or helplessness. Persons exposed to trauma may temporarily or over time be bothered with re-experiencing of the trauma, avoidance and have a high degree of vigilance.

The development of PTSD symptoms after a trauma is a normal reaction to an abnormal event. Studies of severe traumatic events show that almost everyone develops PTSD symptoms shortly after the stressful event. However, the post-traumatic stress symptoms usually decrease or diminish with time [239], and most people exposed to severe trauma recover within days, weeks, or a few months. In the US, one-year prevalence of PTSD is estimated to be in the order of 5% [240].

As for occupational divers, we are aware of only two publications in peer-reviewed journals.

Sixty-six Navy divers participating in a rescue operation after a TWA-crash in New York in 1996 were exposed to the deceased, working in an isolated environment and experienced a significant physical strain [161]. The operation was reported as the most stressful job experience in their career, where retrieving body parts from deceased children was the most stressful part.

After the assignment, the rescue divers reported anxiety during flights to a greater degree than a control group of fifty-nine divers from the same teams, but this anxiety diminished a few months afterwards. There were no significant differences in the reporting of posttraumatic stress symptoms when the two groups were compared [241]. None of the divers showed stress symptoms, such as depression or anxiety problems, and did not abuse drugs. They had not increased absenteeism from work after the assignment.

Training in the navy was indicated as the main factor increasing the ability to master the assignment, followed by having telephone contact with family and that the assignment had meaning [241].

The rescue divers had fewer PTSD symptoms compared to non-diving rescuers participating in, for example, the “Alexander Kielland” accident [239]. The Norwegians who participated after that accident had not been trained for rescue operations in advance of the catastrophe. These factors may have increased the stress load for the Norwegian rescuers [239].

In a cross-sectional study of 206 rescue divers in Ireland, experienced rescuers reported fewer PTSD-symptoms than those without special experience [242]. The study had a high response rate (75%), but selection problems in the form of "survivor bias" and other methodological problems, could not be excluded.

In sum, work experience and training, as well as social support, high work commitment, and time to prepare rescue work, may reduce the risk of PTSD-symptoms [242].

In December 2004, The Occupational Medical Department at Haukeland University Hospital issued the report "Health status of former North Sea divers" to the Ministry of Labour and Social Affairs [89]. Former North Sea divers referred to the hospital department by a doctor or the local health insurance office due to suspicion of diving-related disease were included in this study. They answered questions about former traumas and number of accidents/near accidents, and interviews about dramatic and intimidating events in their careers as divers. Furthermore, traumatic stress and mental symptoms were mapped using IES-R, MMPI-2 - a revision of "The Minnesota Multiphasic Personality Inventory" (MMPI) - and a semi-structured interview.

Almost all the 74 divers reported exposure to life-threatening events during their career and the authors concluded that a significant number of the divers met the criteria for PTSD [89]. The prevalence of PTSD in this group was two to ten times higher than that of military personnel with combat experience, and two to three times higher than seen among police and firefighters [239].

The report from Haukeland hospital is affected by selection bias since the divers were included after referral by a doctor or the health insurance office. The subjective reporting of both exposure and outcome has been indicated as a source of bias both in research and in decision-making related to compensation claims, but this is not accounted for in the report from Haukeland [89].

Methodological problems and pitfalls, such as misclassification/bias, are encountered in many studies of PTSD in the workplace. Even selection of diagnostic tools affects the prevalence of PTSD symptoms, and there is consistently a higher prevalence of PTSD symptoms by the use of questionnaires, compared to structured interviews [239]. Thus, interpretation of the results must always be done with caution.

16.3 Conclusion and recommendations for health surveillance of PTSD

A good organisational and psychosocial work environment, special training in handling potentially traumatising events, and follow-up after a serious incident, can contribute to protect against PTSD-development. People with mental problems prior to the accident along with poor social support may be particularly prone to develop PTSD.

Accordingly, it is important to develop a sound working environment and an organisation that follows up its staff, promotes social support from colleagues and managers, and work systematically with the training of employees [239].

Any episode of a serious incident/accident taking place during the saturation dive must be reported and asked for in post-saturation examination and in the 3-year follow-up interview.

17 EXISTING GUIDELINES ON HEALTH SURVEILLANCE OF COMMERCIAL DEEP DIVERS

17.1 Introduction

There are many recommendations for health examination of commercial divers. These are issued by national legislative bodies as well as professional organisations such as EDTC [243] and ADCI [244]. The UK HSE standard for medical examination of commercial divers [25] is commonly applied in jurisdictions not enforcing national regulations. However, these standards are focused on fitness to dive, aspects related to safety of the diving operation and the diver's safety rather than health surveillance. To identify standards for health surveillance of commercial divers we completed a literature search on January 11th, 2021. A Pubmed search for the term "diving health surveillance" resulted in 281 reports. The titles and abstracts were screened to find publications on health surveillance programs. Several reports referred to skeletal, pulmonary, neurological, cardiovascular and oto-neurological effects of diving. Relevant studies have been referred to in their respective chapters in this report. Based on abstracts from the result of this search we identified three studies detailing contents of a health surveillance program for divers [151, 245, 246]. These three reports were reviewed in full-text. The Polish regulations for diving [151] prescribe x-ray imaging of shoulder, hip and knee joints ("long-bone X-ray) every four years. New Zealand has established a system for fitness-to-dive certification based on an initial and 5-yearly comprehensive medical examinations with intervening annual questionnaires. An earlier report from New Zealand [247] concluded that the 5-yearly comprehensive medical examination hardly contributed to identifying other health problems than those already recognised in the annual health surveillance questionnaire. The follow-up study published 2016 [245] reviewed 5178 health certificates issued to 2187 divers over a 5-year period. Recognising the comprehensive medical examination as the "gold standard" for fitness-to-dive examination, the annual questionnaire had a sensitivity of 85%, specificity of 99% and accuracy of 99%. The most recent work of this group [246] included the results from an internet-based multi-choice satisfaction questionnaire submitted to New Zealand professional divers. A total of 914 divers responded and out of these 85% reported satisfaction with the existing diver health certification system.

Though these studies use the term health "surveillance", they are all related to health certification (fitness to dive) rather than genuine long-term health surveillance systems. The exception for this is the Polish requirement for periodic skeletal X-ray examinations. In our opinion, these imaging studies are of limited value as basis for a health surveillance system. We completed a Google search on "Program health surveillance divers", but this search did not identify any program for health *surveillance*, though many reports related to health effects of diving were listed.

Diving contractors operating on the Norwegian Continental Shelf have established company internal procedures for health surveillance of divers. These procedures are not publicly available, but generally comprise a yearly questionnaire and 3-yearly examinations with a medical interview, spirometry, and audiometry.

We have found two reports, written in Norwegian language, detailing the contents of a health surveillance program for commercial deep diving. These are discussed below.

17.2 Nutec Report 20-94

Norsok U-100 [2] states that for diving deeper than 180 msw, the divers shall be followed up with health examinations as specified in Nutec report 20-94 [2] or equivalent. Available in Norwegian language only, the last revision of this report was issued in 1996. The Nutec report details a health surveillance programme aiming to identify any work-related injury at an early stage, preferably while the findings are subclinical, i.e. before they cause subjective symptoms. The report includes a comprehensive battery of examinations and tests to be performed on general health and specified organ systems. It is specifically stated that the examination programme shall be administered by the employer's occupational health service, and the examinations shall be performed by relevant specialists. Examinations shall be done up to 12 months before the dive in order to establish a baseline and repeated within one month after the dive.

The Nutec report divides the examinations into the following categories

- A general health examination including a medical interview, a specified clinical examination, radiological examinations of long bones (voluntary) and blood analyses to assess changes in liver and bone marrow.
- The neurologic examination including a detailed medical interview, a clinical examination and electroencephalography (EEG).
- A clinical neuropsychological examination including a detailed medical interview and a specified battery of neuropsychological tests
- An examination of the cardiovascular and pulmonary organ systems including spirometry, CO-diffusion, direct measurement of oxygen uptake and ECG. Chest X-ray with 3 projections to be done every 3 years.
- An Ear-Nose-Throat (ENT) examination including medical interview, clinical examinations, and audiometry. Supplemental examinations if indicated.

One of the main challenges with the Nutec report is the unclear distinction between assessment of fitness to dive and assessment of potential health effects from the diving. In addition to a description of the examinations to be performed, each organ chapter of the report contains detailed specifications of absolute and relative contraindications for further deep diving. The purpose of the examinations is therefore not clear: is it to ensure that the diver is fit to dive, is it to inform the diver about findings with potential consequences for his further career or is it to give the employer feedback regarding health effects on a group level? In our opinion, a system for risk-based health examinations should cover the two last questions, whereas fitness to dive should be covered by a separate certification examination. The distinction between risk-based health examinations and certification examinations is important both from a legal and a medical perspective.

The Nutec-report states that the doctor responsible for the health examinations acts as expert for the employer ("sakkyndig") and therefore is not subjected to the legal duty of confidentiality. Further, it says that the occupational health service has a duty to inform the employer of potential medical consequences if the examinations reveal illness/injury that may develop or worsen with further deep diving. In our opinion, the doctor responsible for the examinations cannot act as expert for the employer, and thus must comply with the duty of confidentiality. We also believe that the diver will be more likely to report any symptoms or

other issues if the information is not passed on to the employer. This should not, however, preclude reporting of aggregated results on group-level to the employer. Finally, we would be reluctant about giving the diver advice regarding his/her future career based on subclinical findings in medical examinations. There is generally little or no knowledge about the significance of subclinical findings in medical examinations and how likely they are to escalate with continued diving exposure.

17.3 The "Haukeland Report"

The report «Lungemedisinsk og nevrologisk forundersøkelse (baseline) og oppfølgingsundersøkelse i forbindelse med operasjonell dypdykking i dybdeområdet 180-225 meter» was issued by the Norwegian Centre for Maritime Medicine and Diving Medicine commissioned by the Norwegian Safety Authority (PSA) in January 2020 and it is available on the PSA webpages in Norwegian language [248]

The report contains recommendations for examination of the central nervous system and lung function for commercial divers participating in saturation diving in the depth range 180-225 msw. Accordingly, examinations shall be conducted shortly before the dive to establish a baseline and repeated 3-5 weeks after the dive. It is specified that assessment of medical fitness to dive shall be verified by other examinations and is therefore not a part of the scope of the report.

The report recommends the following examinations:

- A standardised High Pressure Nervous System (HPNS) test battery to be performed regularly during the dive. A questionnaire to map symptoms related to HPNS during the dive and "for the weeks following the dive" (number of weeks not specified).
- Neurological examinations: Detailed clinical neurological examination, standard EEG with flicker stimulation and a specified battery of neuropsychological tests to detect signs of mild cognitive impairment.
- Lung function examinations: Spirometry including forced vital capacity (FVC), forced expiratory volume in one second (FEV_1) and peak expiratory flow (PEF). Work-load test with direct measurement of peak oxygen uptake (VO_2max). Measurement of pulmonary diffusion capacity or transfer factor for CO.

Despite the statement that fitness to dive is outside the scope of the examinations, the authors specify minimum acceptable pre-dive values for spirometry parameters, VO_2max and pulmonary diffusion capacity. However, no guidance is given to interpret post-dive values or changes from baseline for any of the examinations.

The risk of underreporting of symptoms is mentioned in the report. Employees who depend on a health certificate and/or are not permanently employed are less likely to report symptoms due to fear of negative reactions from employer or colleagues. To mitigate this risk, the authors recommend that the medical examinations are performed by a specialist who are trusted by the divers. This is a questionable approach to the problem. Selecting specialists based on the divers' trust is not practically feasible, nor will it ensure validity or quality of the examinations. It is crucial that individual results from the examinations have no consequences for the diver's health certificate or chances of further employment. Medical confidentiality with respect to individual data is an absolute prerequisite for reliable results. Furthermore, it is important that the diving occupational health service has access to all

results in order to give feedback to the diving contractor on group level of any trends in post-dive findings.

Regarding the organ specific examinations, we agree that a standard test battery to detect signs of HPNS should be done in the early bottom phase of diving operations beyond 180 msw. Due to the fact that HPNS symptoms and findings may persist after the dive we consider it appropriate to repeat these HPNS tests after finished decompression. We further agree that the divers should be questioned about any subjective symptoms potentially linked to HPNS both during and after the dive.

The clinical neurological examinations described in the “Haukeland Report” are detailed, and all changes, regardless of apparent triviality, shall be described. There is little or no knowledge about the significance of subclinical neurological findings with respect to prognosis with or without further exposure to diving, and the report does not give guidance on how minor changes in the neurological examinations should be interpreted.

The neuropsychological test battery “…contains a selection of tests from an established and good validated test battery”. The authors state that it has been applied in a previous study and could be administered in approximately 2h. However, the “validity” term is not discussed in detail. It is not known whether the battery has been validated for screening of CNS disorders in general, for specific brain organic disorders or long-term CNS injuries in divers. Interpretation of the suggested extensive neuropsychological test battery will require the competency of a neuropsychologist. We recommend a limited neuropsychological test battery, aimed to identify HPNS-related sub-clinical, unrecognised, and underreported cognitive dysfunction.

In the present report, we have discussed the value of lung diffusion measurements in the lung chapter. In our opinion, this examination is not indicated after diving in the 180-225 msw depth range. We have shown that the total oxygen exposure in deep saturation diving is lower than for shallower diving due to time limitations as specified in industry standards and regulations. Measurement of VO_2max is in our opinion a test to verify fitness to dive, it has no place in a protocol for risk-based health *surveillance* after deep diving.

For further discussions regarding neurological examinations including EEG, neuropsychological examinations, and lung examinations after diving in the depth range 180-225 msw we refer to the specific sections of the current report.

18 DISCUSSION

18.1 Criteria for defining the contents of the health surveillance programme

We have discussed, in section 7 the main principles for risk assessment related to health effects of diving. We have explained that the main focus for safe diving operations is the preventive measures (left side of the bow-tie model) and that health surveillance mainly will be a consequence reducing measure. The diver should be medically fit to dive to avoid injuries and illnesses. The contents of the health examination of divers is described in existing official guidelines [249].

The contents of a health surveillance programme could potentially be affected by the selection of divers recruited for diving 180-225 msw. Other authors (e.g. [99, 112]) have suggested that proper medical selection is important to reduce the likelihood of neurological and neuropsychological impairment after deep dives. However, selection of divers is outside the scope of this report and will not be discussed in further detail.

The purpose of the health surveillance programme is ideally to confirm that established barriers are efficient to avoid negative health effects. If health effects have occurred, the employer should be advised to consider improvement of the working (diving) procedures and the occupational health service should consider need for further medical examinations. The diver should be advised on the extent and consequences of the findings.

The utilisation of health *surveillance* data to identify exposure factors causing any untoward health effects will either require large data sets (many divers, dives and varying exposures) or large order effects appearing shortly after the dive. It is unrealistic to expect, based on previous experience, that the number of dives ranging 180-225 msw in the future will be sufficient to allow identification of *mechanisms* underlying health effects attributable to the *diving depth* of such dives. If the health surveillance program identified a large number of symptoms and findings after a dive ranging 180-225m, beyond that being observed after shallower dives, it may however suggest deficiencies of the operational procedures and argument for a (temporary) hold in such deeper diving.

Extended health surveillance of divers participating in dives ranging 180-225 msw could be used to identify pre-symptomatic findings after the deep dive. In our opinion, this would be the main benefit of an extension of the existing program. We have discussed in detail, in section 10-15 of the present report, the current knowledge of health effects on main organ systems caused by diving. For each of these organ systems we have discussed means to identify untoward health-effects at a pre-symptomatic stage. We have considered the examinations (tests) based on:

- Sensitivity: The ability for the test to detect illness
- Specificity: The ability for the test to exclude illness in healthy divers
- Positive predictive value: The expected fraction of positive tests that will identify divers with illness. (If the prevalence (occurrence) of illness is low, the positive predictive value will usually be very low unless the specificity is very high).
- Side effects, convenience, cost, and burden on the health care system

Our recommendations for health surveillance are based on a scientific approach to these criteria. The “precautionary principle” [16] calls for precautionary measures when scientific evidence is uncertain and the stakes are high. We believe that the present careful review and

the conclusions we present are compliant with this principle. To cite Persson [16]: “The interpretation of the Precautionary Principle does not say anything about what kind of actions to take when extra precaution is called for, but it does provide a clear and practically useful list of circumstances that call for extra precaution and that is not subject to the most common objections to the Precautionary Principle.” We have designed the health surveillance programme based on the principles of Koh [250]. We agree that the scientific evidence is uncertain, but we claim that any medical test imposed on the diver should be assessed based on the four criteria listed above.

19 RECOMMENDED HEALTH SURVEILLANCE PROGRAMME

19.1 Introduction

In the following sections we have detailed the contents of the health assessment recommended for divers participating in dives ranging 180-225 msw. We have included the mandatory and legally required fitness to dive examinations. These are not health surveillance in the strict sense but serve as a first barrier for detecting illness affecting the safety as well as the health of the diver.

It is important to note that the suggested health surveillance programme *is based on divers who have no signs or symptoms of injury or illness*, i.e. they are presumed healthy. If there are indications of injury or illness related to the diving exposure, further investigations should be carried out as decided by the medically responsible doctor for the diving contractor.

The recommended regime for health surveillance differs little from the established health surveillance programme for saturation diving down to 180 msw. As mentioned in section 18, we have found no documentation that an increase in maximum diving depth from 180 to 225 msw, with the mitigating measures required by regulations and standards, increases the risk of illness or injury to an extent that warrants a more extensive surveillance programme. This conclusion is in line with the NUI 94-20 report [4], chapter 4, where it is stated that from a medical perspective there is no reason for conducting other examinations for divers involved in deep diving than for divers involved in “ordinary” diving.

19.2 Concerns and caveats

Participation in health surveillance programmes is generally voluntary (except for certification/selection examinations). Still, we suggest that participation should be a prerequisite for manned underwater operations in the depth range 180-225 msw, and that this is implemented in an agreement between the diver and the employer.

Information based on questionnaires or interviews has other types of challenges. There is a risk of under-reporting of health challenges and health reactions when diving. The extent of under-reporting of health or safety-relevant topics is likely to be affected by organisational conditions surrounding diving [251]. We would like to reiterate the concerns previously discussed in section 8. The type of employment contract for the diver (permanent or temporary employment), the management's attitude for handling reports on risks and improvements, and the impact of any result from the health *surveillance* on future health *certification* for diving are examples of such conditions.

Any method for health surveillance thus has methodological limitations. We have discussed these in the report. To improve the validity of self-reported health complaints we recommend a balanced approach: We recommend a questionnaire / interview-based procedure, and at the same time point out organisational prerequisites that should be present for the information that emerges to be as reliable as possible. We recommend a supplement of a limited number of neuropsychological tests after the dive to compensate for potential under-reporting of persisting HPNS-related symptoms.

19.3 Health examinations to be performed independent of diving depth

For the sake of completeness, we would like to repeat that these examinations should take place – independent of diving depth:

- Fitness to dive examination. Annual health **certificate examination** to be performed by an approved doctor and in accordance with national standards, e.g. IS-1879E [24] or MA1 [25].
- A **pre-saturation examination**/interview of the diver is performed by the hyperbaric nurse on board the diving vessel before the diver is cleared to enter the chamber. We recommend the use of Pre-Diving Medical Check Form as detailed in IMCA D 061 Guidance on Health, Fitness and Medical Issues in Diving Operations.
- A **post-saturation health examination** and medical interview shall be performed by the hyperbaric nurse on board the diving vessel during or immediately after the bend watch period (24 hours after surfacing). The objective should be to identify immediate health effects of diving such as skin and ear infections, barotraumas, and symptoms of decompression illness. There should be a structured clinical interview covering irregularities of the dive, accidents, and complaints in addition to any health issues. Any (suspected) irregularities, either in the interview or the examinations, should be reported to the RCDD who will decide if further actions are needed. We recommend the use of Post-Diving Medical Check Form as detailed in IMCA D 061 Guidance on Health, Fitness and Medical Issues in Diving Operations.
- A long-term health monitoring programme. This programme consists presently of two parts:
    - The diver should fill in the IMCA/Norwegian Oil and Gas Association **questionnaire** on a yearly basis for at least 3 years after exposure. The questionnaire comprises questions about previous work history, lifestyle, diving career, employment, occupational exposures, incidents and signs and symptoms of health effects that may be related to work. There is one entrance questionnaire completed upon employment (ideally) and a follow-up questionnaire completed annually. The questionnaires are enclosed in Appendix 4. The incoming questionnaires contain confidential medical information and shall be stored in the employee's record in the company occupational health service's files. The diver may bring these with him/her in case of a change of employer. The occupational health services shall follow up the diver with supplementary actions if there is a positive response to certain questions in the questionnaire. Procedures for actions based on the incoming information in the completed entrance and follow-up questionnaires are enclosed in Appendix 4. We recommend that the questionnaire is revised to include questions related to neurological impairment.
    - The health examination should take place every 3 years. This examination is performed to uncover, as far as possible, signs and symptoms of long-term health effects potentially related to exposure at work. The examination shall be managed by the occupational health service of the diving contractor (the employer) and all results shall be assessed by the RCDD. The results are defined as confidential medical information and shall be stored in the employee's record in the company occupational health service's files. The diver shall be informed about the outcome

and given access to examination results and may bring these with him/her in case of a change of employer. The health examination presently includes:

- Medical interview about exposure situations/incidents that are known to be indicators of possible (sub-) acute and chronic health effects and of symptoms that may indicate such problems.
- A test of hearing acuity by pure tone audiometry. This test should include a determination of hearing threshold on both ears at frequencies 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz.
- A lung function test (spirometry). FEV_1 and FVC should be the main parameters in the assessment of potential long-term health effects.

- Following the interview and medical tests, the RCDD shall assess the need for any further medical examinations. If further examinations are recommended, the RCDD shall see to that the diver is informed and offered such examinations.

19.4 Extended health surveillance of divers participating in dives to 180-225 msw

In addition to the examinations listed in chapter 19.3, divers participating in dives ranging 180-225 msw should be followed up by HPNS tests before, during and after the dive to ensure that they are fit to work at pressure and to confirm that any HPNS symptom or finding has subsided after finished dive.

The HPNS tests should take place immediately before the dive, during any pauses in compression deeper than 150 msw, at bottom “depth” (isopressure) and 24-48h after finished dive.

The HPNS tests should include a questionnaire for HPNS symptoms, tests for tremor, hand grip strength and a selection of neuropsychological test. The neuropsychological tests should as a minimum include testing of:

- Executive function (e.g. Trail making B, WAIS Digit span backward, Stroop Colour Word Interference test)
- Attention (e.g. Trail making A, Digit span Forward)
- Memory (e.g. Benton Visual Retention Test, California Verbal Learning Test, Wechsler Memory Scale)

The occupational health service (OHS) should consult a specialist in clinical neuropsychology in the preparation of the HPNS and neuropsychological test battery. At least one recognised clinical neuropsychological test should be applied for assessment of each of the areas executive functions, attention and memory. The OHS should consider need for additional tests to assess any HPNS impairment. Tests results should be reviewed by the OHS and the neuropsychologist. Changes suggesting CNS affection should be followed up.

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21 APPENDIX 1 SCOPE OF WORK FOR THE WORKING GROUP

The scope of the project is to prepare a proposal for a long-term health surveillance programme for commercial divers participating in Statoil diving operations in the depth range of 180-225 meters sea water (msw). Although basically intended for Statoil operations, the surveillance programme will be available through an open report and can be utilised by other stakeholders for diving operations in this depth area. This may include operations in the oil and gas industry or contingency diving operations as part of general public preparedness.

The programme shall be risk-based, i.e. examinations shall be performed to reveal adverse health effects of diving in this range of sea water. Health examinations for project-specific exposures (e.g. chemical contaminants) is outside the scope for this project.

The health surveillance programme shall comprise suitable examination methods for detecting relevant health effects. A suitable method should be specific, sensitive, easy to perform and interpret, safe, non-invasive, and acceptable.

The health surveillance programme shall be administrated by the diving contractor's occupational health service. The Responsible Competent Diving Doctor (RCDD) shall assess all results and if necessary refer the diver to further examinations. All results shall be maintained in the physician's (RCDD) files.

The proposal shall describe the examinations relating to one saturation exposure in the relevant depth range. The issue of additional exposures to similar depths in the follow-up period should be addressed.

The working group shall describe organizational framework conditions and working environment factors that may affect the need for health surveys and the content of these surveys.

It is a prerequisite that the diving operation is performed in accordance with DPR-001 and that the divers have passed a medical selection process as described in DPR-006 prior to the diving operation. Selection of divers and testing for high pressure nervous syndrome (HPNS) is not a part of the scope.

The proposed health surveillance programme shall be published in an open report. DPR-001 and DPR-006 shall be appended to the report. Revision of these documents is not a part of the scope, but any suggestions for improvements will be considered.

The work done by the working group shall be reviewed by a reference group comprising representatives from the diving industry, safety delegates representing the divers, the petroleum safety authorities and other stakeholders for relevant offshore diving. All suggestions from the reference group shall be considered by the working group before publication of the final report. Any dissent within the working group or between the working group and members of the reference group shall be recorded in the final report.

The working group will have teleconference meetings and "in-person"-meetings as required.

Members of the working group
Marit Skogstad, the National Institute of Occupational Health (STAMI) (Leader)
Lars Ole Goffeng, STAMI
Karl-Christian Nordby, STAMI
Stein Indseth Modahl, Inco AS/TechnipFMC
Jan Risberg, NUI AS
Olav Sande Eftedal, Equinor ASA

22 APPENDIX 2 SCOPE OF WORK FOR THE REFERENCE GROUPS

The reference group shall review the proposal from the working group for a long-term health surveillance programme for commercial divers participating in diving operations in the depth range of 180-225 meters sea water (msw). All suggestions from the reference group shall be considered by the working group before publication of the final report. Any disagreements between the working group and participants in the reference group shall be described in the final report. The composition of the reference group shall be described in the final report, but members of the reference group will not be given co-authorship of the report.

Members of the reference group
Karl-Christian Nordby, the National Institute of Occupational Health (STAMI) (Leader)
Gro Stakkestad, Equinor ASA
Olav Hauso, the Petroleum Safety Authority Norway
Martin Heer, the Norwegian Labour Inspection Authority
Janne Dahle-Melhus, County Governor of Rogaland
Kari Troland, Norsk senter for maritim- og dykkemedisin, Haukeland University Hospital
Einar Flaa, TechnipFMC
Dag Atle Ask, Subsea7
Leif Morten Rasch, Industri Energi
Bård Humborstad, Repsol Norway
John Hjelle, Mediteam/Subsea7
Joar Gangenes, the Norwegian Oil and Gas Association
Arnfinn Anfindsen, Norsok U Expert Group, Standards Norway

23 APPENDIX 3 AUTHORS' EXPERIENCE, AFFILIATIONS AND CONFLICTS OF INTEREST

Jan Risberg is employed as a diving physician, PhD and contributed to this report as a part of his employment at NUI. NUI was compensated for his worktime and travel costs by Equinor. Jan Risberg is additionally a consultant in hyperbaric medicine at Haukeland University Hospital, Department of Occupational Medicine. He is contracted as a diving medical advisor for several on-shore and offshore diving contractors as well as oil and gas operators on the Norwegian Continental Shelf. He was until Feb 1st 2021 - employed as the head of Submarine and Diving Medicine in the Norwegian Armed Forces Joint Medical Services. Neither his personal opinions nor the ones of this report should be construed as committing for those of his employers or clients.

Lars Ole Goffeng is employed as a research scientist at National Institute of Occupational Health and contributed to the completion of this report as an independent psychologist with a background within neuropsychology and accident prevention. He was not compensated for his worktime, had no other costs in connection with the contributions in the report, and has no formal employment in on-shore or offshore diving contractor companies or oil and gas operators on the Norwegian Continental Shelf offshore. The viewpoints and conclusions presented in this report should be construed as representing his knowledge and opinions as an independent psychologist, not representing his employer's viewpoints.

Marit Skogstad is employed as a researcher, senior physician, MD, PhD, at the National Institute of Occupational Health in Oslo, Norway. She contributed to the completion of this report as an independent physician with special skills in occupational medicine and hyperbaric medicine where she has several publications, also in peer reviewed journals. She has not been compensated for her worktime, had no other costs in connection with the contributions in the report, and has no formal employment in on-shore or offshore diving contractor companies or oil and gas operators on the Norwegian Continental Shelf offshore. As an occupational physician and diving doctor in Occupational Health Services, she has issued several health certificates for commercial divers. The viewpoints and conclusions presented in this report should be construed as representing her knowledge and opinions as an independent physician with special skills in occupational medicine and hyperbaric medicine, not representing her employer's viewpoints.

Olav Sande Eftedal is employed by Equinor ASA as Leading Physician with diving medicine as one area of responsibility. He is a specialist in occupational medicine and dr. Philos in diving medicine and is currently chairman of the Diving Medical Advisory Committee (DMAC). He has 30 years of experience from diving related work; operationally, clinically and from research and development. Equinor is a major offshore oil and gas operator and has a potential use for diving operations in the depth range 180-225 msw. Eftedal's contributions to this report have been made as a part of the job as diving physician for Equinor.

Stein I. Modahl works for and owns Inco a.s. He is a board-certified specialist in occupational medicine and brings more than 35 years of experience from the Norwegian and International Offshore Oil Production and Diving Industry as an occupational physician to the work group. Among his previous roles is being the doctor in charge of medical activities in Amoco's operations in Europe and North Africa. Prior to being contracted as the RCDD of TechnipFMC Norway, a position from which he has supervised several international diving projects on depths deeper than 225 msw, he has held similar positions for Comex, Oceaneering and Stena Diving. He has been active in numerous Industry committees and can look back on a Chairmanship in the OLF Medical Committee. Presently he is still active in DMAC where he is a long-standing member. His company is still under contract with TechnipFMC, and Inco a.s. has been reimbursed by Equinor for work done by Modahl on this project.

24 APPENDIX 4 HEALTH SURVEILLANCE QUESTIONNAIRES

24.1 Entrance questionnaire

Questionnaire number ☐☐☐☐☐

Health Surveillance for Professional Divers Working in the Offshore Oil and Gas Industry

Entrance Questionnaire

International Marine Contractors Association

Version 3.2

February 2009

Health Surveillance Questionnaire for Professional Divers

Introduction

This is a yearly, voluntary questionnaire concerning your health. The information will be filed as a part of your medical file. At any time you can withdraw your consent to participate in this surveillance. In such a case your information will be filed but not used for company purpose – like statistics. The information will only be handled by the company Health Service and the Occupational Health Doctor. The purpose of the questionnaire is to detect early signs of medical problems that are known to be associated with diving. By doing this, preventative measures can be taken and undue illness avoided.

In case of need for individual follow up the Occupational Health Doctor will contact you.

This is quite a long questionnaire as it allows your occupational health doctor to understand your entire career to date. Any subsequent questionnaire will not be so comprehensive.

Please answer the questions as instructed and otherwise by placing a *cross or number* in the box. If you make a mistake place a single line through the incorrect answer and put a cross or number in the box of the correct answer. Where asked "Yes – number of times" please enter the number of times that you have experienced the problem or issue.

Confidentiality

The information that you provide in this form will be used in two ways:

1 - Your Occupational Health Service will use the information under strict confidence to provide work related health surveillance. Any other use of your information that includes your personal identification details can only take place with your written permission. Information which identifies you will not be passed on to line management without your permission. You are free at any time to have a copy of your occupational health record.

2 - Health surveillance records are a very important source of information. In the future there might be interest for research on the information gathered on long term effects in divers. No information will be used outside the Occupational Health Service without a specific consent from you. In research cases page two of the questionnaire will be removed so the diver is "un-identified", and only given a company code.

To be entered by Occupational Health Service Company ☐☐ Code ☐☐☐ ☐☐

Coding of the form allows use of the information without your identity details. Coding information is held by your Occupational Health Service and allows you to track your data through any subsequent study of anonymised data. Coding will be filled in by your Occupational Health Service

SECTION 1 PERSONAL DETAILS (please print or use block capitals)

1.1 - Surname _____

1.2 - First names _____

1.3 - Gender **Male** ☐ **Female** ☐

1.4 - Date of birth (dd/mm/yyyy) ☐☐ / ☐☐ / ☐☐☐☐

Health Surveillance Questionnaire for Professional Divers

To be entered by Occupational Health Service Company ☐☐ Code ☐☐☐ ☐☐

TODAY'S DATE (dd/mm/yyyy) ☐☐ / ☐☐ / ☐☐☐☐

SECTION 2 LIFESTYLE

Your lifestyle has important implications for your overall health and some factors need to be considered in the interpretation of the questionnaire. Please give the details requested.

2.1 - Which of the following best describes your *current* work status?

Self employed working for a single diving company only	Self employed working for more than one diving company only	Self employed and also working outside the diving industry	Salaried diver with a single diving company
☐	☐	☐	☐

2.2 - How much do you currently weigh? ☐☐☐ kg or ☐☐ st ☐☐ lbs

2.3 - How tall are you? ☐☐☐ cm or ☐ ft ☐☐ ins

2.4 – How old are you? ☐☐ years

2.5 - Have you smoked more than 100 cigarettes IN TOTAL in your life? No ☐ Yes ☐

2.5.1 - if yes, complete the following:

Current Smokers		**Ex-Smokers** In what year did you stop smoking?	☐☐☐☐
How many *years* in total have you smoked?	☐☐	How many *years* in total did you smoke?	☐☐
How many *cigarettes* do you smoke per day?	☐☐	How many *cigarettes* did you smoke per day?	☐☐

2.6 - During the last 12 months, how often have you drunk 8 units or more on any one occasion? (8 UNITS are equivalent to 4 pints of normal strength beer, lager or cider OR 8 small glasses of wine OR 8 shots of spirit)

Never	More than 20 times a month	10-20 times a month	1-9 times a month,	If LESS than monthly how many times a year?
☐	☐	☐	☐	☐☐

SECTION 3 OCCUPATIONAL HISTORY

Every occupation has its own particular health implications. It would be helpful, therefore, for your occupational health doctor to have details of your career to date.

3.1 - Present employment

Please describe each job.
If you work as a diver in different sectors (see section 4.5), please enter each separately.

Job number	Job description	Industry	Start year	Weeks per year
1				
2				
3				
4				
5				

3.2 - Jobs worked in the past – from leaving school (if you have worked as a diver in different sectors please enter these separately)

Job number	Job description	Industry	Start year	Finish year
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

SECTION 4 DIVING

Details of the diving you do is useful to find whether any health issue is related to the diving that you do. Where asked for estimates of number of dives, these can be approximate.

Definitions

Air or Nitrox – dives using nitrogen or oxygen mixtures
Mixed gas – dives using helium and/or hydrogen with any equipment including rebreathers

SCUBA – dives using self contained underwater breathing apparatus using air and/or oxygen
SurDO$_2$ – dives using surface decompression with oxygen breathing
Surface supplied – dives using surface supplied air or nitrox

Mixed gas bounce – Surface orientated dives using helium/oxygen or helium/nitrogen/oxygen
Saturation – Pressure chamber orientated diving with divers stored at pressure

4.1 - Duration of diving career

In what year was your FIRST professional dive?	☐☐☐☐
When did your LAST professional dive end (mm/yyyy)	☐☐ / ☐☐☐☐

4.2 - Surface orientated air or nitrox diving

Number of Air / Nitrox Dives

Number of dives	SCUBA	SurDO$_2$	Surface supplied
none	☐	☐	☐
1 - 100	☐	☐	☐
101 – 500	☐	☐	☐
501 - 1000	☐	☐	☐
more than 1000	☐	☐	☐
Estimate total number of dives	☐☐☐☐	☐☐☐☐	☐☐☐☐

Depth of Air or Nitrox Dives

Metres of sea water	never	occasionally	a lot
less than 30	☐	☐	☐
30-50	☐	☐	☐
more than 50	☐	☐	☐

4.3 - Surface orientated mixed gas diving

Number of Mixed Gas Bounce Dives	
none	☐
1 - 100	☐
101 - 500	☐
more than 500	☐
Estimate total number of dives	☐☐☐

Depth of Mixed Gas Bounce Dives			
Metres of sea water	never	occasionally	a lot
less than 80	☐	☐	☐
80-120	☐	☐	☐
more than 120	☐	☐	☐

4.4 - Chamber orientated mixed gas diving

How many times have you surfaced from saturation? ☐☐☐☐

Number of Days in Saturation	
Total number of **days** in saturation	
none	☐
1 - 300	☐
301 - 1000	☐
more than 1000	☐
Estimate total number of days	☐☐☐☐

Depth of Saturation Dives			
Metres of sea water	never	occasionally	a lot
less than 100	☐	☐	☐
100-180	☐	☐	☐
more than 180	☐	☐	☐

4.5 - What diving sectors have you worked in?

	In the past year		More than a year ago	
Offshore – oil industry	Yes ☐	No ☐	Yes ☐	No ☐
Coastal or inshore – not oil industry	Yes ☐	No ☐	Yes ☐	No ☐
Shellfish	Yes ☐	No ☐	Yes ☐	No ☐
Scientific / archaeological	Yes ☐	No ☐	Yes ☐	No ☐
Police	Yes ☐	No ☐	Yes ☐	No ☐
Media	Yes ☐	No ☐	Yes ☐	No ☐
Recreational instructor	Yes ☐	No ☐	Yes ☐	No ☐
Military	Yes ☐	No ☐	Yes ☐	No ☐
Hyperbaric chamber internal attendant	Yes ☐	No ☐	Yes ☐	No ☐
Compressed air work (caissons/tunnelling)	Yes ☐	No ☐	Yes ☐	No ☐

4.6 – Recreational diving

Have you ever dived recreationally? Yes ☐ No ☐

If YES complete the rest of section 4.6.

If NO go to section 4.7

list start year ☐☐☐☐

when was the last time? (mm/yyyy) ☐☐ / ☐☐☐☐

4.7 - Recreational surface orientated air or nitrox diving

Number of Air / Nitrox Dives

Number of dives	SCUBA	Surface supplied
none	☐	☐
1 - 100	☐	☐
101 – 500	☐	☐
501 - 1000	☐	☐
more than 1000	☐	☐
Estimated total number of dives	☐☐☐	☐☐☐

Depth of Air or Nitrox Dives

Metres of sea water	never	occasionally	a lot
less than 30	☐	☐	☐
30-50	☐	☐	☐
more than 50	☐	☐	☐

4.8 – Recreational surface orientated mixed gas diving

Number of Mixed Gas Bounce Dives

none	☐
1 - 100	☐
101 - 500	☐
more than 500	☐
Estimated total number of dives	☐☐☐

Depth of Mixed Gas Bounce Dives

Metres of sea water	never	occasionally	a lot
less than 80	☐	☐	☐
80-120	☐	☐	☐
more than 120	☐	☐	☐

It is important that your occupational health doctor knows whether you have suffered any accidents, illnesses or symptoms relating to your diving

4.9 – Accidents, illness and symptoms related to diving

(A symptom is any sensation or change in bodily or mental function)

While working as a diver have you suffered from any of the following?	No	Yes – number of times
1 - Neurological decompression illness?	☐	☐☐
2 - Cerebral gas embolism?	☐	☐☐
3 - Pain only decompression illness?	☐	☐☐
If yes for 1, 2 or 3, was recompression or treatment gas at pressure given?	☐	☐☐
Underwater explosion	☐	☐☐
Loss of consciousness while under pressure	☐	☐☐
Drilling mud skin burn	☐	☐☐
Contaminated breathing gas	☐	☐☐
Underwater explosion	☐	☐☐
Partial drowning	☐	☐☐
Illness preventing you from working during a saturation dive	☐	☐☐
Symptoms of any kind during decompression or within six hours after surfacing not identified as decompression illness or cerebral gas embolism?	☐	☐☐
If yes give details:		

Diving related bone necrosis can cause arthritis of the hip or shoulder joint causing some of the symptoms in section 4.9.1

4.9.1 - At any time

Do you get pain in the groin when walking?	Yes ☐	No ☐
Do you get pain in the hip when walking?	Yes ☐	No ☐
Do you get pain in the knee when walking?	Yes ☐	No ☐
Does one leg feel shorter than the other?	Yes ☐	No ☐
Do you walk with a limp?	Yes ☐	No ☐
Do you get pain in the shoulder with activity?	Yes ☐	No ☐
Do you get stiffness in the shoulder?	Yes ☐	No ☐

SECTION 5 NOISE

Excess noise is an important and preventable cause of hearing impairment.

5.1 - In any jobs that you have had to date including diving

Was noise intrusive - like a busy street, vacuum cleaner or crowded restaurant - for most of the working day?	Yes ☐	No ☐
Did you work in a noisy industry, e.g. construction, demolition or road repair; woodworking; plastics processing; engineering; textile manufacture; general fabrication; forging, pressing or stamping; paper or board making; canning or bottling; foundries?	Yes ☐	No ☐
Did you have to raise your voice to have a normal conversation when about 2 m apart for at least part of the day?	Yes ☐	No ☐
Did noise hinder the use of a communications system?	Yes ☐	No ☐
Were there noises because of impacts (e.g. hammering, drop forging, pneumatic impact tools etc), explosive sources such as cartridge-operated tools or detonators?	Yes ☐	No ☐
Did you use noisy powered tools or machinery for over half an hour a day?	Yes ☐	No ☐
Did you have muffled hearing at the end of the day, even if it was better by the next morning?	Yes ☐	No ☐
Have you ever been exposed to gunfire or explosions?	Yes ☐	No ☐
If yes, was this regular exposure to gunfire or explosions?	Yes ☐	No ☐

5.2

Which of your jobs, including diving, had any of the levels of noise described in section 5.1 above? (insert job numbers from sections 3.1 and 3.2)			

5.3 - While diving, what location had any of the levels of noise described in section 5.1?

	Never	A little of the time	Some of the time	Most of the time	All of the time
In the water	☐	☐	☐	☐	☐
In the bell	☐	☐	☐	☐	☐
in the welding habitat	☐	☐	☐	☐	☐
in the living chambers	☐	☐	☐	☐	☐

Wearing hearing protection can materially reduce the risk of hearing impairment in the workplace

5.4 – Hearing protection

In your noisy jobs (from section 5.2) did you wear hearing protection?	All of the time	☐
	Most of the time	☐
	Some of the time	☐
	A little of the time	☐
	Never	☐

Certain symptoms may indicate early hearing loss and may indicate that you have an audiogram for further assessment

5.5 – Symptoms of hearing loss and previous hearing problems

Do you have difficulty with your hearing?	Yes ☐	No ☐
Do you have the radio or television on louder than the rest of the family?	Yes ☐	No ☐
Do you have difficulty in deciding where sounds come from?	Yes ☐	No ☐
Do you have difficulty with telephone conversations with either ear?	Yes ☐	No ☐
Do you suffer from wax in the ears?	Yes ☐	No ☐

5.6 – Other ear problems

Have you ever suffered from -	dizziness or vertigo?	Yes ☐	No ☐
	pain in the ears?	Yes ☐	No ☐
	running ears?	Yes ☐	No ☐
	abscess in the ear?	Yes ☐	No ☐
	pseudomonas ear infection (pyo)?	Yes ☐	No ☐
	any other ear infection?	Yes ☐	No ☐
	ear injury or barotrauma?	Yes ☐	No ☐
	perforated ear drum?	Yes ☐	No ☐
	noises or ringing in the ears?	Yes ☐	No ☐

SECTION 6 VIBRATION

6.1

Have you ever used hand-held vibrating tools, machines or hand held processes in your job?	Yes ☐	No ☐

If NO go to section 7. If YES continue to section 6.2

Hand Arm Vibration Syndrome

Upper limb exposure to vibration can lead to hand arm vibration syndrome (HAVS) which is also known as vibration white finger. It is a disorder which affects the blood vessels, nerves muscles and joints of the hand, wrist and arms which can become severely disabling if ignored.

HAVS can be avoided by controlling exposure to vibration.

HAVS is reversible if detected early and further exposure to vibration controlled.

Signs to look out for are:

- pain, tingling or numbness in the fingers, hands, wrists and arms;
- in the cold and wet, fingers go white, then blue, then red and are painful;
- you can't feel things with your fingers;
- loss of strength in hands.

6.2 - In any jobs that you have had to date did you operate

Hammer action tools		
hammer action tools for more than about one hour per day?	Yes ☐	No ☐
If no, then for more than about 15 minutes per day?	Yes ☐	No ☐
Rotary or other action tool		
rotary or other action tool for more than about four hours per day?	Yes ☐	No ☐
If no, then for more than about one hour per day	Yes ☐	No ☐

6.3

In which jobs, including diving, did you operate hand-held power tools, hand-guided powered equipment or powered machines which process hand held materials. (insert job numbers from sections 3.1 and 3.2)			

6.4

When was the year of first exposure ☐☐☐☐ When was the last time you used them? (mm/yyyy) ☐☐/☐☐☐☐

6.5

Do you have any tingling of the fingers lasting more than 20 minutes after using vibrating equipment?	Yes ☐	No ☐
Does one or more of your fingers go numb more than 20 minutes after using vibrating equipment?	Yes ☐	No ☐
Do you have tingling of the fingers at any other time?	Yes ☐	No ☐
Do you wake at night with pain, tingling, or numbness in your hand or wrist?	Yes ☐	No ☐
Have your fingers gone white on cold exposure?	Yes ☐	No ☐
(White means a clear discoloration of the fingers with a sharp edge, often followed by a red flush.)		
If Yes, do you have difficulty rewarming them when leaving the cold?	Yes ☐	No ☐
Are you experiencing any other problems with the muscles or joints of the hands or arms?	Yes ☐	No ☐
Do your fingers go white at any other time?	Yes ☐	No ☐
Do you have difficulty picking up very small objects e.g. screws or buttons or opening tight jars?	Yes ☐	No ☐

Previous injury and certain medical conditions and treatments can cause the same symptoms as exposure to vibration and may make an individual more sensitive to the effects of upper limb vibration exposure.

6.6

Have you ever had a neck, arm or hand injury or operation? Yes ☐ No ☐

If so give details

_____

_____

_____

6.7

Have you ever had any serious diseases of joints, skin, nerves, heart or blood vessels? Yes ☐ No ☐

If so give details

_____

_____

_____

6.8

Are you on any long-term medication? Yes ☐ No ☐

If so give details

_____

_____

_____

SECTION 7 SOLVENTS AND CHEMICALS

7.1 - While diving (in the water, bell, welding habitat or living chambers) have you experienced

	In the water		In the bell		in the welding habitat		in the living chambers	
	No	Yes – number of times	No	Yes – number of times	No	Yes – number of times	No	Yes – number of times
1 petrochemical smell	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
2 hydrogen sulphide smell	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
3 any other smell	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
4 irritation of eyes	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
5 gritty taste in mouth	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
6 lung irritation/cough	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
7 skin irritation	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
8 headache	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
9 nausea	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
10 dizziness	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
11 light-headedness	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
12 loss of consciousness	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐

7.2

Skin exposure to solvents or chemicals is a preventable cause of occupational dermatitis. Could you answer the questions below to help your occupational health doctor to assess any problem

Do you have asthma?	Yes ☐	No ☐
Did you have asthma as a child?	Yes ☐	No ☐
Were you wheezy as a child?	Yes ☐	No ☐
Have you ever had hay fever?	Yes ☐	No ☐
Have you ever had eczema?	Yes ☐	No ☐

7.3 - Have you had any of the following on the skin of your fingers, hands, forearms, toes, feet or legs?

redness and swelling	Yes ☐	No ☐
cracking of skin	Yes ☐	No ☐
small skin blisters/bubbles/vesicles	Yes ☐	No ☐
flaking or scaling of skin	Yes ☐	No ☐
itching with cracks or splits in the skin	Yes ☐	No ☐
skin infection	Yes ☐	No ☐
spots, redness or swelling of any other part of the body	Yes ☐	No ☐

7.4

Do you currently have any of the symptoms mentioned in section 7.3	Yes ☐	No ☐
Did you suffer any of these problems for more than three weeks	Yes ☐	No ☐
Did any of these problems occur more than once	Yes ☐	No ☐
Did you suffer any of these problems with diving	Yes ☐	No ☐
Did you suffer any of these problems with your other work	Yes ☐	No ☐
Does your skin improve with time away from work	Yes ☐	No ☐
Have you taken time of work because of your skin	Yes ☐	No ☐

7.5 – Drilling mud

	No	Yes number of times
While working as a diver have you found drilling mud inside your diving suit at the end of a dive or shift	☐	☐☐☐

SECTION 8 WELDING

Welding, especially with materials such as stainless steel, is associated with some health effects. Please answer the questions in this section to allow assessment of your exposure to welding fume and welding accidents.

8.1

Have you ever worked as a welder?	Yes ☐ No ☐
If YES:	
list start year	☐☐☐☐
when was the last time you welded? (mm/yyyy)	☐☐/☐☐☐☐
how many years have you worked as a welder	☐☐

If you have worked as a welder please complete the following sections. If not , please go to section 9.

8.2 - What <u>percent</u> of your welding was done in the following work areas?

	Percent	Never
Outdoors?	☐☐☐ %	☐
Indoors in a well ventilated area?	☐☐☐ %	☐
In a small, poorly ventilated area?	☐☐☐ %	☐
In a pressurised welding habitat)?	☐☐☐ %	☐
Wet welding – welding in water while diving	☐☐☐ %	☐

8.3

After a welding shift	Never	A little of the time	Some of the time	Most of the time	All of the time
Do you cough up brown or black sputum?	☐	☐	☐	☐	☐
Do you blow brown or black stuff into your handkerchief from your nose?	☐	☐	☐	☐	☐

8.4 -Over what percent of your welding career have you used the following personal protective breathing equipment while welding?

	Percent	Never
Simple dust mask	☐☐☐ %	☐
Filter respirator (e.g 3M disposable masks)	☐☐☐ %	☐
Filter canister respirator (strap-on mask with replaceable filter canister)	☐☐☐ %	☐
Atmosphere supply respirator (e.g. Aga mask)	☐☐☐ %	☐
Other, please name: _____	☐☐☐ %	☐

8.5 -At work, have you used any of the following techniques

if yes: how many years and days per year on average have **you used the techniques?**

Please estimate

	Yes	No	Years	Days per year
Manual Metal Arc (MMA)	☐	☐	☐☐	☐☐☐
Metal Inert Gas (MIG)	☐	☐	☐☐	☐☐☐
Tungsten Inert Gas (TIG)	☐	☐	☐☐	☐☐☐
Oxyfuel (e.g. oxyacetylene)	☐	☐	☐☐	☐☐☐
Flux Cored Arc (FCW)	☐	☐	☐☐	☐☐☐
Flame or Arc Metal cutting	☐	☐	☐☐	☐☐☐
Other, please name _____	☐	☐	☐☐	☐☐☐

8.6 - While working as a welder have you suffered any of the following accidents

	No	Yes – number of times
Major electric shock	☐	☐☐
Burns (including radiation burns)	☐	☐☐
Eye damage (e.g. arc eye, flash, radiation, foreign body)	☐	☐☐
Metal fume fever	☐	☐☐
Ear damage (for example a perforated eardrum)	☐	☐☐

8.7 - While working as a welder or within six months of working as a welder have you suffered any of the following health effects

	No	Yes – number of times
Cough	☐	☐☐
Tight chest	☐	☐☐
Wheeze	☐	☐☐
Chest infection, bronchitis or pneumonia	☐	☐☐
Chest, jaw or arm pain when walking, climbing stairs or running	☐	☐☐

SECTION 9 FURTHER COMMENTS

9.1 – Previous questionnaires

	No	Yes number of times
Have you filled one of these questionnaires before?	☐	☐☐☐

That completes the questionnaire. Thank you for completing it. If you have any further health concerns that you wish to detail please do so below.

GLOSSARY

arthritis
inflmmation of joints causing pain, disability and joint destruction 9
asthma
respiratory disorder characterised by wheezing 15
Entrance
This is the first of a series of health surveillance questionnaires 1
necrosis
tissue death 9
sputum
a substance such as saliva, phlegm or mucus coughed up from the respiratory tract 17
Symptoms
A symptom is any indication of physical or mental abnormality..... 8
units
1 unit is 8 g or 10 ml of pure alcohol. 3
Wheeze
a high pitched whistling noise coming from the chest on breathing out 19
wheezy
making a high pitched whistling noise from the chest when breathing out 15

24.2 Follow-up questionnaire

Questionnaire number ☐☐☐☐☐

Health Surveillance for Professional Divers Working in the Offshore Oil and Gas Industry

Follow-up Questionnaire

International Marine Contractors Association

Version 1.1

February 2009

Questionnaire number ☐☐☐☐

Health Surveillance Questionnaire for Professional Divers

Introduction

This is a yearly, voluntary, follow up questionnaire concerning your health. The information will be filed as a part of your medical file. At any time you can withdraw your consent to participate in this surveillance, in such a case your information will be filed but not used for company purpose – like statistics. The information will only be handled by the company health service and occupational health doctor. The purpose of the questionnaire is to detect early signs of medical problems that are known to be associated with diving. By doing this, preventative measures can be taken and undue illness avoided.

In case of need for individual follow up the occupational health doctor will contact you

Please answer the questions as instructed and otherwise by placing a *cross or number* in the box. If you make a mistake place a single line through the incorrect answer and put a cross or number in the box of the correct answer. Where asked "Yes – number of times" please enter the number of times that you have experienced the problem or issue.

Confidentiality

The information that you provide in this form will be handled in the following manner:

1 - Your occupational health service will use the information under strict confidence to provide work related health surveillance. Any other use of your information that includes your personal identification details can only take place with your written permission. Information which identifies you will not be passed on to line management without your permission. You are free at any time to have a copy of your occupational health record.

2 - Health surveillance records are a very important source of information. In the future there might be interest for research on the information gathered on long term effects in divers. In such cases a letter will be sent to each diver for consent. No information will be used outside the Occupational Health Service without as specific consent from you. In research cases page two of the questionnaire will be removed so the diver is "un identified", and only given a company code.

To be entered by Occupational Health Service Company ☐☐ Code ☐☐☐ ☐☐

Coding of the form allows use of the information without your identity details. Coding information is held by your Occupational Health Service and allows you to track your data through any subsequent study of anonymised data. Coding will be filled in by your Occupational Health Service

SECTION 1 PERSONAL DETAILS (please print or use block capitals)

1.1 - Surname _____

1.2 - First names _____

1.3 - Gender **Male** ☐ **Female** ☐

1.4 - Date of birth (dd/mm/yyyy) ☐☐ / ☐☐ / ☐☐☐☐

Health Surveillance Questionnaire for Professional Divers

To be entered by Occupational Health Service Company ☐☐ Code ☐☐☐ ☐☐

TODAY'S DATE (dd/mm/yyyy) ☐☐ / ☐☐ / ☐☐☐☐

SECTION 2 LIFESTYLE

Your lifestyle has important implications for your overall health and some factors need to be considered in the interpretation of the questionnaire. Please give the details requested.

2.1 - Which of the following best describes your *current* work status?

Self employed working for a single diving company only	Self employed working for more than one diving company only	Self employed and also working outside the diving industry	Salaried diver with a single diving company
☐	☐	☐	☐

2.2 - How much do you currently weigh? ☐☐☐ kg or ☐☐ st ☐☐ lbs

2.3 - How tall are you? ☐☐☐ cm or ☐ ft ☐☐ ins

2.4 – How old are you? ☐☐ years

2.5 - Have you smoked more than 100 cigarettes IN TOTAL in your life? No ☐ Yes ☐

2.5.1 - if yes, complete the following:

Current Smokers		**Ex-Smokers** In what year did you stop smoking?	☐☐☐☐
How many *years* in total have you smoked?	☐☐	How many *years* in total did you smoke?	☐☐
How many *cigarettes* do you smoke per day?	☐☐	How many *cigarettes* did you smoke per day?	☐☐

2.6 - During the last 12 months, how often have you drunk 8 units or more on any one occasion? (8 UNITS are equivalent to 4 pints of normal strength beer, lager or cider OR 8 small glasses of wine OR 8 shots of spirit)

Never	More than 20 times a month	10-20 times a month	1-9 times a month,	If LESS than monthly how many times a year?
☐	☐	☐	☐	☐☐

SECTION 3 OCCUPATIONAL HISTORY

Every occupation has its own particular health implications. It would be helpful, therefore, for your occupational health doctor to have details of your career to date.

3.1 - Present employment

Please describe each job.
If you work as a diver in different sectors, please enter each separately.

Job number	Job description	Industry	Start year	Weeks per year
1				
2				
3				
4				
5				

SECTION 4 DIVING

Details of the diving you do is useful to find whether any health issue is related to the diving that you do. Where asked for number of dives, these can be approximate estimates.

Definitions

Air or Nitrox – dives using nitrogen or oxygen mixtures
Mixed gas – dives using helium and/or hydrogen with any equipment including rebreathers

SCUBA – dives using self contained underwater breathing apparatus using air and/or oxygen
SurDO_2 – dives using surface decompression with oxygen breathing
Surface supplied – dives using surface supplied air or nitrox

Mixed gas bounce – Surface orientated dives using helium/oxygen or helium/nitrogen/oxygen
Saturation – Pressure habitat orientated diving with divers stored at pressure

4.1

When did your LAST professional dive end (mm/yyyy)	☐☐ / ☐☐☐☐

4.2 - Surface orientated air or nitrox diving since your last questionnaire

Number of Air / Nitrox Dives	number of dives
SCUBA	☐☐☐
SurDO$_2$	☐☐☐
Surface supplied	☐☐☐

Depth of Air or Nitrox Dives	
Metres of sea water	number of dives
less than 30	☐☐☐
30-50	☐☐☐
More than 50	☐☐☐

4.3 - Surface orientated mixed gas diving since your last questionnaire

Number of Mixed Gas Bounce Dives	
number of dives	☐☐☐

Depth of Mixed Gas Bounce Dives	
Metres of sea water	number of dives
less than 80	☐☐☐
80-120	☐☐☐
more than 120	☐☐☐

4.4 - Chamber orientated mixed gas diving since your last questionnaire

How many times have you surfaced from saturation? ☐☐☐☐

Number of Days in Saturation	
Total number of **days** in saturation	
number of days	☐☐☐☐

Depth of Saturation Dives	
Metres of sea water	number of dives
less than 100	☐☐☐
100-180	☐☐☐
more than 180	☐☐☐

4.5 - What diving sectors have you worked in since your last questionnaire?

Offshore – oil industry	Yes ☐	No ☐	Recreational instructor	Yes ☐	No ☐
Coastal or inshore – not oil industry	Yes ☐	No ☐	Military	Yes ☐	No ☐
Shellfish	Yes ☐	No ☐	Hyperbaric chamber internal attendant	Yes ☐	No ☐
Scientific / archaeological	Yes ☐	No ☐	Compressed air work (caissons/tunnelling)	Yes ☐	No ☐
Police	Yes ☐	No ☐	Media	Yes ☐	No ☐

4.6 – Recreational diving since your last questionnaire

Have you dived recreationally since your last questionnaire?	Yes ☐	No ☐
If YES complete the rest of section 4.6.		
If NO go to section 4.7		

4.7 – Recreational surface orientated air or nitrox diving since your last questionnaire

Number of Air / Nitrox Dives	
	number of dives
SCUBA	☐☐☐
Surface supplied	☐☐☐

Depth of Air or Nitrox Dives	
Metres of sea water	number of dives
less than 30	☐☐☐
30-50	☐☐☐
More than 50	☐☐☐

4.8 – Recreational surface orientated mixed gas diving since your last questionnaire

Number of Mixed Gas Bounce Dives	
number of dives	☐☐☐

Depth of Mixed Gas Bounce Dives	
Metres of sea water	number of dives
less than 80	☐☐☐
80-120	☐☐☐
more than 120	☐☐☐

It is important that your occupational health doctor knows whether you have suffered any accidents, illnesses or symptoms relating to your diving

4.9 – Accidents, illness and symptoms related to diving since your last questionnaire

(A symptom is any sensation or change in bodily or mental function)

Have you suffered from any of the following since your last questionnaire?	No	Yes – number of times
1 - Neurological decompression illness?	☐	☐☐
2 - Cerebral gas embolism?	☐	☐☐
3 - Pain only decompression illness?	☐	☐☐
If yes for 1, 2 or 3, was recompression or treatment gas at pressure given?	☐	☐☐
Underwater explosion	☐	☐☐
Loss of consciousness while under pressure	☐	☐☐
Drilling mud skin burn	☐	☐☐
Contaminated breathing gas	☐	☐☐
Underwater explosion	☐	☐☐
Partial drowning	☐	☐☐
Illness preventing you from working during a saturation dive	☐	☐☐
Symptoms of any kind during decompression or within six hours after surfacing not identified as decompression illness or cerebral gas embolism?	☐	☐☐
If yes give details:		

Diving related bone necrosis can cause arthritis of the hip or shoulder joint causing some of the symptoms in section 4.9.1

4.9.1 At any time

Do you get pain in the groin when walking?	Yes ☐	No ☐
Do you get pain in the hip when walking?	Yes ☐	No ☐
Do you get pain in the knee when walking?	Yes ☐	No ☐
Does one leg feel shorter than the other?	Yes ☐	No ☐
Do you walk with a limp?	Yes ☐	No ☐
Do you get pain in the shoulder with activity?	Yes ☐	No ☐
Do you get stiffness in the shoulder?	Yes ☐	No ☐

SECTION 5 NOISE

Excess noise is an important and preventable cause of hearing impairment.

5.1 - In any of your current jobs

Is noise intrusive - like a busy street, vacuum cleaner or crowded restaurant - for most of the working day?	Yes ☐	No ☐
Do you work in a noisy industry, e.g. construction, demolition or road repair; woodworking; plastics processing; engineering; textile manufacture; general fabrication; forging, pressing or stamping; paper or board making; canning or bottling; foundries?	Yes ☐	No ☐
Do you have to raise your voice to have a normal conversation when about 2 m apart for at least part of the day?	Yes ☐	No ☐
Does noise hinder the use of a communications system?	Yes ☐	No ☐
Are there noises because of impacts (e.g. hammering, drop forging, pneumatic impact tools etc), explosive sources such as cartridge-operated tools or detonators?	Yes ☐	No ☐
Do you use noisy powered tools or machinery for over half an hour a day?	Yes ☐	No ☐
Do you have muffled hearing at the end of the day, even if it was better by the next morning?	Yes ☐	No ☐
Are you ever been exposed to gunfire or explosions?	Yes ☐	No ☐
If yes, is this regular exposure to gunfire or explosions?	Yes ☐	No ☐

5.2

Which of your jobs, including diving, had any of the levels of noise described in section 5.1 above? (insert job numbers from sections 3.1)			

5.3 - While diving, what location had any of the levels of noise described in section 5.1?

	Never	A little of the time	Some of the time	Most of the time	All of the time
In the water	☐	☐	☐	☐	☐
In the bell	☐	☐	☐	☐	☐
in the welding habitat	☐	☐	☐	☐	☐
in the living chambers	☐	☐	☐	☐	☐

Wearing hearing protection can materially reduce the risk of hearing impairment in the workplace

5.4 – Hearing protection

In your noisy jobs (from section 5.2) do you wear hearing protection?	All of the time	☐
	Most of the time	☐
If no noisy jobs got to section 5.5	Some of the time	☐
	A little of the time	☐
	Never	☐

Certain symptoms may indicate early hearing loss and may indicate that you have an audiogram for further assessment

5.5 – Symptoms of hearing loss and previous hearing problems

Do you have difficulty with your hearing?	Yes ☐	No ☐
Do you have the radio or television on louder than the rest of the family?	Yes ☐	No ☐
Do you have difficulty in deciding where sounds come from?	Yes ☐	No ☐
Do you have difficulty with telephone conversations with either ear?	Yes ☐	No ☐
Do you suffer from wax in the ears?	Yes ☐	No ☐

5.6 – Other ear problems since your last questionnaire

Have you suffered from -	dizziness or vertigo?	Yes ☐	No ☐
	pain in the ears?	Yes ☐	No ☐
	running ears?	Yes ☐	No ☐
	abscess in the ear?	Yes ☐	No ☐
	pseudomonas ear infection (pyo)?	Yes ☐	No ☐
	any other ear infection?	Yes ☐	No ☐
	ear injury or barotrauma?	Yes ☐	No ☐
	perforated ear drum?	Yes ☐	No ☐
	noises or ringing in the ears?	Yes ☐	No ☐

SECTION 6 - VIBRATION

6.1

Have you been using hand-held vibrating tools, machines or hand held processes in your job since your last questionnaire?	Yes ☐	No ☐

If NO or more than 2 years since your last exposure go to section 7. If YES or less than 2 years since your last exposure continue to section 6.2

Hand Arm Vibration Syndrome

Upper limb exposure to vibration can lead to hand arm vibration syndrome (HAVS) which is also known as vibration white finger. It is a disorder which affects the blood vessels, nerves muscles and joints of the hand, wrist and arms which can become severely disabling if ignored.

HAVS can be avoided by controlling exposure to vibration.

HAVS is reversible if detected early and further exposure to vibration controlled.

Signs to look out for are:

- pain, tingling or numbness in the fingers, hands, wrists and arms;
- in the cold and wet, fingers go white, then blue, then red and are painful;
- you can't feel things with your fingers;
- loss of strength in hands.

6.2 – Since your last questionnaire have you operated

Hammer action tools		
hammer action tools for more than about one hour per day?	Yes ☐	No ☐
If no, then for more than about 15 minutes per day?	Yes ☐	No ☐
Rotary or other action tool		
rotary or other action tool for more than about four hours per day?	Yes ☐	No ☐
If no, then for more than about one hour per day	Yes ☐	No ☐

6.3 - If you have used any hand-held power tools, hand-guided powered equipment or powered machines which process hand held materials since your last questionnaire

In which jobs, including diving, did you operate them (insert job numbers from sections 3.1)			

6.4

Do you have any tingling of the fingers lasting more than 20 minutes after using vibrating equipment?	Yes ☐	No ☐
Does one or more of your fingers go numb more than 20 minutes after using vibrating equipment?	Yes ☐	No ☐
Do you have tingling of the fingers at any other time?	Yes ☐	No ☐
Do you wake at night with pain, tingling, or numbness in your hand or wrist?	Yes ☐	No ☐
Have any of your fingers gone white on cold exposure?	Yes ☐	No ☐
(White means a clear discoloration of the fingers with a sharp edge, usually followed by a red flush.)		
Have you noticed any change in your response to your tolerance of working in the cold?	Yes ☐	No ☐
Are you experiencing any other problems in your the hands or arms?	Yes ☐	No ☐
Do you have difficulty picking up very small objects e.g. screws or buttons or opening tight jars?	Yes ☐	No ☐
Has anything changed about your health since your last questionnaire?	Yes ☐	No ☐
If YES please describe:		

SECTION 7 SOLVENTS AND CHEMICALS

7.1 – Since your last questionnaire, while diving (in the water, bell, welding habitat or living chambers) have you experienced

		In the water		In the bell		in the welding habitat		in the living chambers	
		No	Yes – number of times	No	Yes – number of times	No	Yes – number of times	No	Yes – number of times
1	petrochemical smell	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
2	hydrogen sulphide smell	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
3	any other smell	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
4	irritation of eyes	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
5	gritty taste in mouth	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
6	lung irritation/cough	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
7	skin irritation	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
8	headache	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
9	nausea	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
10	dizziness	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
11	light-headedness	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐
12	loss of consciousness	☐	☐☐	☐	☐☐	☐	☐☐	☐	☐☐

Skin exposure to solvents or chemicals is a preventable cause of occupational dermatitis. Could you answer the questions below to help your occupational health doctor to assess any problem

7.3 - Have you had any of the following on the skin of your fingers, hands, forearms, toes, feet or legs since your last questionnaire?

redness and swelling	Yes ☐	No ☐
cracking of skin	Yes ☐	No ☐
small skin blisters/bubbles/vesicles	Yes ☐	No ☐
flaking or scaling of skin	Yes ☐	No ☐
itching with cracks or splits in the skin	Yes ☐	No ☐
skin infection	Yes ☐	No ☐
spots, redness or swelling of any other part of the body	Yes ☐	No ☐

7.4

Do you currently have any of the symptoms mentioned in section 7.3	Yes ☐	No ☐
Did you suffer any of these problems for more than three weeks	Yes ☐	No ☐
Did any of these problems occur more than once	Yes ☐	No ☐
Did you suffer any of these problems with diving	Yes ☐	No ☐
Did you suffer any of these problems with your other work	Yes ☐	No ☐
Does your skin improve with time away from work	Yes ☐	No ☐
Have you taken time of work because of your skin	Yes ☐	No ☐

7.5 – Drilling mud

	No	Yes number of times
While working as a diver have you found drilling mud inside your diving suit at the end of a dive or shift since your last questionnaire	☐	☐☐☐

SECTION 8 WELDING

Welding, especially with materials such as stainless steel, is associated with some health effects. Please answer the questions in this section to allow assessment of your exposure to welding fume and welding accidents.

8.1

Have you worked as a welder since your last questionnaire?	Yes ☐ No ☐
If NO go to section 9. If YES continue below.	
when was the last time you welded? (mm/yyyy)	☐☐ / ☐☐☐☐

8.2 - Since your last questionnaire, what <u>percent</u> of your welding was done in the following work areas?

	Percent	Never
Outdoors?	☐☐☐%	☐
Indoors in a well ventilated area?	☐☐☐%	☐
In a small, poorly ventilated area?	☐☐☐%	☐
In a pressurised welding habitat)?	☐☐☐%	☐
Wet welding – welding in water while diving	☐☐☐%	☐

8.3

After a welding shift	Never	A little of the time	Some of the time	Most of the time	All of the time
Do you cough up brown or black sputum?	☐	☐	☐	☐	☐
Do you blow brown or black stuff into your handkerchief from your nose?	☐	☐	☐	☐	☐

8.4 -since your last questionnaire have you used the following personal protective breathing equipment while welding?

	Percent	Never
Simple dust mask	☐☐☐ %	☐
Filter respirator (e.g 3M disposable masks)	☐☐☐ %	☐
Filter canister respirator (strap-on mask with replaceable filter canister)	☐☐☐ %	☐
Atmosphere supply respirator (e.g. Aga mask)	☐☐☐ %	☐
Other, please name: _____	☐☐☐ %	☐

8.5 -Since your last questionnaire, at work, have you used any of the following techniques

if yes: on how many days have you used the techniques?

Please estimate

	Yes	No	Days
Manual Metal Arc (MMA)	☐	☐	☐☐☐
Metal Inert Gas (MIG)	☐	☐	☐☐☐
Tungsten Inert Gas (TIG)	☐	☐	☐☐☐
Oxyfuel (e.g. oxyacetylene)	☐	☐	☐☐☐
Flux Cored Arc (FCW)	☐	☐	☐☐☐
Flame or Arc Metal cutting	☐	☐	☐☐☐
Other, please name _____	☐	☐	☐☐☐

8.6 - Since your last questionnaire, while working as a welder have you suffered any of the following accidents

	No	Yes – number of times
Major electric shock	☐	☐☐
Burns (including radiation burns)	☐	☐☐
Eye damage (e.g. arc eye, flash, radiation, foreign body)	☐	☐☐
Metal fume fever	☐	☐☐
Ear damage (for example a perforated eardrum)	☐	☐☐

8.7 - While working as a welder or within six months of working as a welder have you suffered any of the following health effects, since your last questionnaire?

	No	Yes – number of times
Cough	☐	☐☐
Tight chest	☐	☐☐
Wheeze	☐	☐☐
Chest infection, bronchitis or pneumonia	☐	☐☐
Chest, jaw or arm pain when walking, climbing stairs or running	☐	☐☐

SECTION 9 FURTHER COMMENTS

9.1 – Previous questionnaires

	No	Yes number of times
Have you filled one of these questionnaires before?	☐	☐☐☐

That completes the questionnaire. Thank you for completing it. If you have any further health concerns that you wish to detail please do so below.

GLOSSARY

arthritis
inflmmation of joints causing pain, disability and joint destruction 9
asthma
respiratory disorder characterised by wheezing 15
Entrance
This is the first of a series of health surveillance questionnaires 1
necrosis
tissue death 9
sputum
a substance such as saliva, phlegm or mucus coughed up from the respiratory tract 17
Symptoms
A symptom is any indication of physical or mental abnormality..... 8
units
1 unit is 8 g or 10 ml of pure alcohol. 3
Wheeze
a high pitched whistling noise coming from the chest on breathing out 19
wheezy
making a high pitched whistling noise from the chest when breathing out 15

Questionnaire number ☐☐☐☐☐

24.3 Actions from OHS based on questionnaire responses

Health Surveillance Questionnaire for Professional Divers

SECTION 10 ACTIONS REQUIRED BY OCCUPATIONAL HEALTH TEAM FROM THE ENTRANCE QUESTIONNAIRE

(not for circulation to employees)

Action may be taken on any of the information supplied by the employee by the occupational health team. The actions stated below, however, should be regarded as obligatory.

Section	Employee response	Action required
4.9	Any positive response	Consider obtaining further information from diver with occupational health review if required, especially if the event was recent and without any OH review.
4.9.1	Any positive response	Occupational health review
5.5	Positive response from any of the first four questions	Occupational health review Audiogram assessment in addition to any regular background health surveillance by audiometry
6.2	Positive response regarding exposure to hammer tools for more than one hour per day or rotary tools for more than four hours per day	Occupational health review for hand arm vibration syndrome as this is above the statutory limit for vibration exposure
6.5	Any positive response	Occupational health review
7.1	Positive response to questions 4-12	Consider obtaining further information from diver with occupational health review if required, especially if the event was recent and without any OH review.
7.3	Any positive response	Occupational health review
7.4	Any positive response	Occupational health review
8.7	Any positive response	Occupational health review

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Health Surveillance Questionnaire for Professional Divers

SECTION 10 ACTIONS REQUIRED BY OCCUPATIONAL HEALTH TEAM FROM THE FOLLOW-UP QUESTIONNAIRE

(not for circulation to employees)

Action may be taken on any of the information supplied by the employee by the occupational health team. The actions stated below, however, should be regarded as obligatory.

Section	Employee response	Action required
4.9	Any positive response	Occupational health review if one has not already been performed
4.9.1	Any positive response	Occupational health review
5.5	Positive response from any of the first four questions	Occupational health review Audiogram assessment in addition to any regular background health surveillance by audiometry
5.6	Any positive response	Occupational health review if one has not already been performed
6.2	Positive response regarding exposure to hammer tools for more than one hour per day or rotary tools for more than four hours per day	Occupational health review for hand arm vibration syndrome as this is above the statutory limit for vibration exposure
6.4	Any positive response	Occupational health review
7.1	Positive response to questions 1-3	Consider obtaining more information and OH review if necessary
7.1	Positive response to questions 4-12	Occupational health review if one has not already been performed.
7.2	Any positive response	Occupational health review
7.3	Any positive response	Occupational health review

8.6	Any positive response	Occupational health review if one has not already been performed.
8.7	Any positive response	Occupational health review