Scandpower
Risk Management AS

Analysis of Risk in Manned Underwater Operations

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Date 4 August 2005
Client Statoil, Norsk Hydro, Esso

Scandpower
Risk Management AS
P.O. Box 3, N-2027 Kjeller, Norway
www.scandpower.com
Tel.: + 47 64 84 44 00
Fax: + 47 64 84 44 11

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Title:

ANALYSIS OF RISK IN MANNED UNDERWATER OPERATIONS

Client: Statoil, Norsk Hydro, Esso

Client specification:

This study shall present a description of the risk for fatalities and serious diseases for divers involved in the current activities in the Norwegian Sector

Summary:

See Chapter 1, Executive Summary

Key words	Name		Signature
	Prepared by:	Tore Sagvolden Agathe Holmefjord Kai D. Olshausen, Jan Skriver	Tore Sagvolden Olshausen
	Reviewed by:	J.K. Lund/O. Silkoset	Jan K. Lund
	Approved by:	B.I. Bakken	[signature]

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1. EXECUTIVE SUMMARY

Scandpower Risk Management AS (Scandpower) has carried out a risk evaluation of professional petroleum-related offshore diving in the Norwegian Sector. This report aims at presenting a risk description for present-day divers which is as objective as possible. The study also proposes risk-reducing measures. The main focus is on saturation diving since this is the diving method most widely used today.

In this study, risk is defined as risk to the divers themselves, not to supporting personnel. Furthermore, risk is defined as risk for serious injuries or fatalities, either during diving or as long-term effects, at later stages.

Collection and Analysis of Statistical Material

The study started with a collection and analysis of statistical material on the extent of diving and the number and type of reported incidents. Data were obtained on both saturation diving and, to a lesser extent, surface-oriented diving. The main sources of information have been the NPD (Norwegian Petroleum Directorate) and the HSE (UK Health and Safety Executive) for the Norwegian and the UK Sectors respectively. Data as far back as 1975 are included in order to analyze historical trends. Fortunately, diving fatalities have become rare events and during many years there were no recorded fatalities at all. Consequently, the fatal accident rate shows very large fluctuations when calculated on a yearly basis. For detecting historical trends it is therefore preferable to calculate averages over several years.

In the table below some key results observed for saturation diving in the Norwegian Sector are presented.

Time period	Number of man-hours in saturation	Number of fatalities during diving	Observed fatal accident rate 1)	Number of decompression illnesses	Observed rate of decompression illness 1)	Number of near misses	Observed rate of near misses 1)
1974 - 1978	431,000	2	0.46	Unknown	-	Unknown	-
1979 - 1983	933,000	4	0.43	85	9.1	Unknown	-
1984 - 1988	1,135,000	1	0.09	26	2.3	Unknown	-
1989 - 1993	890,000	0	0	10	1.1	81	9.1
1994 - 1998	345,000	0	0	0	0	30	8.7
1999 - 2003	240,000	0	0	1	0.4	16	6.7

1) Number per 100,000 man-hours in saturation

Note that even though the last diving fatality occurred in 1987 and, hence, the fatal accident rate has been equal to zero for certain time periods, this does not mean that the probability of getting a fatal accident (i.e. the risk) in these periods has been zero. The number of near misses reported (127 incidents since 1989) is an illustration of this fact. (A near miss is a dangerous situation which, under slightly different circumstances, could have led to a fatality or a serious personal injury).

Prediction of Risk during Diving

To predict risk is to estimate the probability of an unwanted event to happen. A widely used measure of risk is the Fatal Accident Rate or FAR, defined as the number of fatalities per 100 million hours. A probability estimate based on an observation of zero accidents introduces large statistical uncertainties. When using the last historical observed fatal accident statistics to make a prediction of the risk level, i.e. to obtain an expression for the risk for present-day diving, one has to take into account these uncertainties. Strictly speaking, one can for example only state that the FAR-value expected on the basis of zero observed fatalities during the 1989 - 2003 period (1,475,000 man-hours in saturation) is less than 156 with a probability of 90 %.

In order to reduce the statistical uncertainty combined statistics for the UK and Norwegian sectors were used. This can be justified since diving procedures, diving techniques, ways of organization, etc. are similar in both sectors. Also, the diving activity in the UK Sector is much larger than in the Norwegian Sector and combining the two improves the statistical confidence considerably. For the 14-year interval 1990 - 2003, the combined statistics give an estimate of the present day FAR of 27 for saturation diving. This value is based on three fatalities (in the UK sector) and 10,940,379 man-hours in saturation (UK and Norway together). The statistical uncertainty is shown in the table below.

Predicted present-day Fatal Accident Rate (FAR) for saturation diving		
Lower 5% limit	Mean	Upper 95 % limit
7	27	71

The time interval 1990 - 2003 was chosen because from 1990 onward saturation diving rules and procedures were fairly constant and risk in connection with the activities both on Norwegian and UK sectors, is judged relevant for present day activities.

The frequency of other incidents (decompression illnesses, other injuries and near misses) were also calculated. They occur much more frequently than fatalities and they are therefore better suited as risk indicators for year-to-year risk management purposes.

Long-Term Health Effects

Long-term health effects have received much attention in connection with complains from pioneer divers (divers who were active in the period 1965-1990). This study has extracted some key results from three main sources ("Lossius Report", "Haukeland Report", "HSE ELTHI Report"). The three mentioned reports applied different methods both with respect to the selection of the groups to be analyzed and the types of examination. In addition Scandpower has conducted interviews with researchers, diving experts and divers in order to collect additional information. On this basis we have extracted observations judged to be well founded and relevant for diving risk.

Concerns about the health status among pioneer divers in the Norwegian Sector lead to a decision by the Norwegian Parliament in June 2000 to appoint an independent Commission of Enquiry to investigate all circumstances related to diving in the Norwegian Sector in the "pioneer period", under the chairmanship of Judge Petter A. Lossius.

The Lossius Commission analyzed questionnaires which were returned by 235 divers out of a total of 365 divers contacted. A large proportion of these were no longer active as divers.

The "Haukeland examination" examined 81 out of 115 divers who were referred to Haukeland University Hospital because of their health complaints. This, therefore, was a less representative sample of the diver population as compared to the Lossius investigation. In this group the proportion of active divers was very low. The Haukeland examination consisted of questionnaire analysis of self-reported symptoms and medical conditions, as well as objective measurements and tests. No reference group was examined and results were mainly compared to the general public.

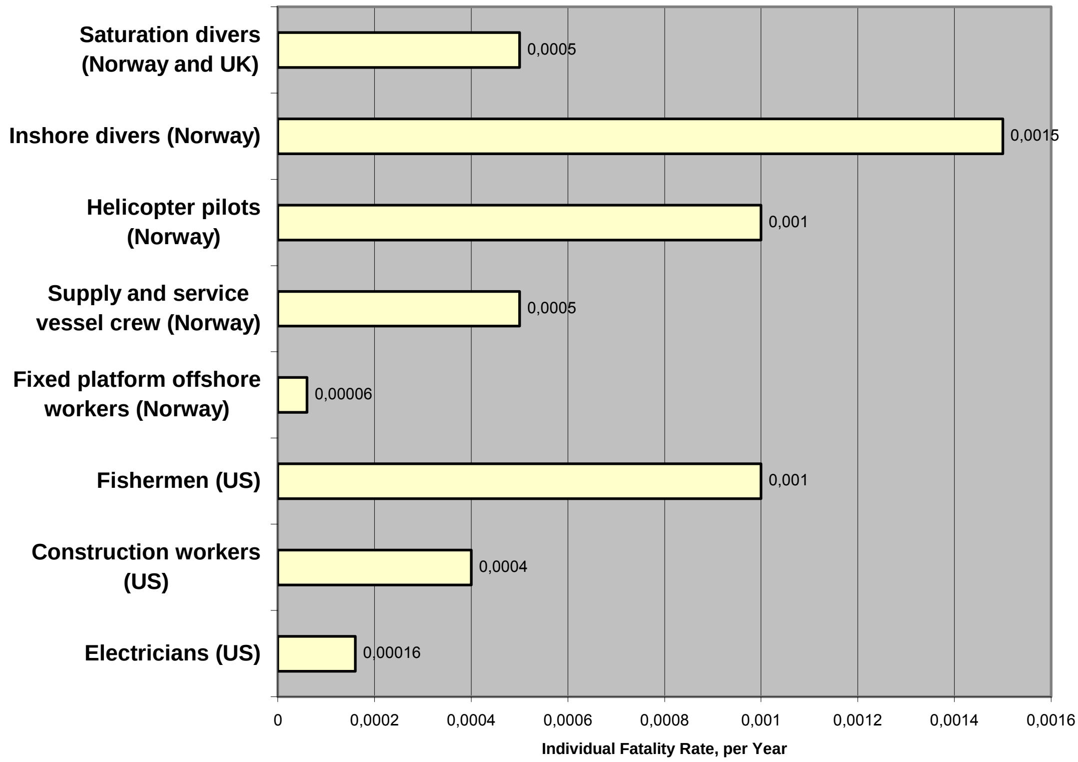
The "HSE ELTHI" researchers sent questionnaires to almost 3,000 divers of whom 1,754 responded. After an elimination of some respondents for different reasons 1,540 were included in the questionnaire analysis. For comparison also 1,035 offshore workers with comparable demographic data were selected for questionnaire analysis. The questionnaire analysis was supplemented and controlled by clinical examination (detailed questionnaires and objective measurements) of a representative 10 % sample from each group. The proportion of divers in the "HSE ELTHI Study" that were still active in their profession was much higher and their average age lower than in the Lossius study.

Acceptance Criteria

In order to discuss the "acceptability" of present day fatality risk during diving it is standard methodology to evaluate risk in other professions and activities and, on this basis, to develop acceptance criteria. The regulations require that criteria are established both for personnel on a facility as a whole and for groups of personnel which are particularly risk exposed. Criteria for particularly risk exposed personnel are in fact in use in other parts of the offshore industry today. Statoil, for example, has in several projects used FAR = 25 as an upper limit for offshore workers who are most exposed to risk. Instead of a criterion per hour it is often more meaningful to use a criterion per year. Using the normal number of hours an offshore worker is exposed per year and removing some contributions not directly work-related such as helicopter transportation, the FAR value of 25 can be converted to an individual risk per annum (IRPA) of approximately 0.0006. Hence, these values are also used in this study as an "upper acceptability limit" for saturation divers.

The acceptance criterion established by Statoil as an average value for all personnel groups on offshore installations is FAR < 10. The decision on which criteria to use for risk control of diving activities has to be taken by the companies responsible for the activity.

For comparison it is also of interest to look at fatality rates for other professions:



With the present registration methods and know-how, it was not possible to determine the fatality rates for divers caused by long-term health effects.

Causes for Diving Incidents

In order to analyze the causes for diving incidents almost 400 incident reports from the "SYNERGI" data bases were examined with respect to reported direct causes and root causes. Direct causes were classified into five man-related causes and four technology-related causes. Root causes were classified into seven organization-related causes. This allows the determination of the distribution between all MTO elements (Man - Technology - Organization). For the direct causes a distribution of 62 % man-related and 38 % technology-related causes was found.

The analysis of the 400 "SYNERGI" reports was supplemented by in-depth analysis of the investigation reports of three selected incidents.

Risk Model

For the purpose of identifying how fatality risk during diving can be reduced a risk model was proposed. The model utilizes the cause distributions determined by the incident report analysis. Each direct cause (man or technology-related) was given a weight factor corresponding to its percentage occurrence in the distribution. In addition, each direct cause was characterized by a status factor describing the quality for aspects related to the cause at a given point in time (all status factors are normalized to one at the present status). The product of the weight factor and the status factor is proportional to the risk contribution of a particular direct cause. The effect of risk reduction measures can be identified and demonstrated with the risk model. A panel of experts can use the model to propose the most cost effective ways for risk reduction.

External Risk Factors

Organizations are influenced by external risk factors; i.e. acts, regulations, national and international standards, market conditions, new research and development, management system audits and customer requirements, etc. These external risk influencing factors are of importance to the organization's management of risk.

To assess what impact these external risk factors have had, expert input from the reference group was used. The goal was to identify and clarify which risk influencing factors were pertinent and which had less impact to the total risk picture.

Suicides

The suicide rate among divers, both in Norway and the UK, has been reported to be high. In Norway the suicide rate for certain time periods is reported to be up to 12 times higher and in the UK up to 3 times higher than for the general population of the same sex and age in Norway. The study briefly looks into the background of the reported suicide rates and possible influencing factors.

Risk Management

The diving industry is in a special situation with challenges requiring special risk management efforts. The diving industry can in this respect be described as follows:

- It is strongly governed by demand and the market situation
- It is demanding on technological and human resources
- It is by its nature an industry with a high risk potential (humans under water), in particular for immediate fatality risk, but also for long-term health effects
- It operates at a low or even sub-critical activity level in the Norwegian sector
- It is an international industry and as such difficult to adapt to special requirements and Norwegian risk management practices
- It suffers from very limited recruitment of new diving personnel and lacks educational possibilities in Norway
- The effort put into technological development in recent years has been limited
- There is still a lack of scientific knowledge of diving limitations w.r.t. both immediate and long-term health effects. This is a challenge in particular when operational requirements shall be established for deep diving while maintaining the so-called precautionary principle
- The extensive use of short-term contracts makes it difficult to achieve improvements in work performance, safety culture and follow-up of health aspects.

Conclusions and Observations

The study results can be categorized as related to immediate risk during diving and long-term health effects. For immediate risk the study team has been able to draw firm conclusions on the basis of the statistical analysis performed. For long-term health effects the basis has been interviews and review of existing documents leading to observations that are judged to be well founded. The conclusions and observations are presented below.

Immediate Risk during Diving

- The observed fatality rates have decreased substantially from 1975 to 1987. After 1987 no fatalities have occurred in Norwegian waters

- Risk predictions based on zero observations (fatalities) and low exposure time have large uncertainties. In order to reduce the uncertainty and to obtain a description of present day fatality risk during saturation diving, the UK and Norwegian statistics were combined resulting in a best estimate of FAR = 27. The FAR value corresponds to an individual risk per annum of 0.0005

- The best estimate for the present day fatality risk level for saturation diving is found to be roughly equal to the risk level used in this study as an "upper acceptability limit"

- History shows that large improvements have been achieved since the 1970’s and 1980’s both with respect to immediate fatality risk and, in particular, with respect to decompression illness

- Due to the environment where diving is performed, safe operations rely on several critical factors w.r.t. equipment, diving procedures and human performance. Failures may easily have serious consequences for the divers. Controlling these risk elements puts special requirements on the industry.

Long-term Health Effects

- There is still a need for more knowledge about the factors which may cause long-term health effects and the way diving operations could be optimized to limit risk for the diver

- Divers have experienced long-term health effects which are statistically more severe or more frequent than in control groups or the general public. This applies both to self-reported symptoms such as forgetfulness and loss of concentration, to clinical tests such as findings from clinical/neurological examinations, and to symptoms and conditions determined by objective measurements such as lung performance, etc.

- Studies and expert opinions differ to which degree the long-term health effects reduce the Health Related Quality Of Life (HRQOL). The "HSE ELTHI Study" showed no significant reduction of HRQOL for divers, neither for the physical nor the mental component of the HRQOL-test while the "Lossius Report" indicates otherwise. Note that the "HSE ELTHI Study" contains a much higher fraction of still active divers than the "Lossius Report"

- The impact on long-term health effects from the present diving activities is judged to be reduced as compared to early experience, due to reduced frequencies of reported Decompression Illness (DCI) and life threatening incidents, which in turn may cause Post Traumatic Stress Disorder (PTSD)

- Decompression illness (DCI) is a contributing factor to long-term health effects but not a prerequisite. Avoiding DCI will reduce the risk for long-term health effects but not completely eliminate them

- The correlation between risk and diving depth is uncertain. There is still insufficient knowledge about all risk aspects of deep diving. There are indications that the importance of stricter selection of divers and improved diving procedures increases with diving depth. An important work task has been initiated by the oil companies to investigate further the results and experience from performed deep dives in order to further qualify and improve diving procedures

- The report AGDy 2000+ presents recommendations from a working group for proper handling of the challenges experienced in the diving industry. The recommendations cover improvements related to personnel, vessel/equipment, level of activity and specialist competence. The oil companies (Norsk Hydro and Statoil) inform that these recommendations are followed-up as a basis for the further development of the diving industry. The recommendations can result in significant improvements in the safety of diving operations. The work session method proposed in this report could be used to pursue and prioritize the recommendations given.

- The statistical basis for establishing quantitatively the observed long term health effect of diving has been weak. Further work is required to establish confidence in historical statistics on e.g. the rate of disablement and suicide among divers to be able to compare the rates with corresponding rates in the general public. If found required such work should be done in cooperation with NPD and Rikstrygdeverket. It is anticipated that such work could improve the mutual understanding of the challenges in the diving industry

Recommendations

Scandpower has identified the following recommendations as part of the present study:

<u>Immediate Risk during Diving</u>

- The present fatality risk level was found to be roughly equal to the risk level used in this study as an "upper acceptability limit". The ambition expressed by the Authorities and the oil companies is to further reduce the risk level.

    Therefore it is recommended to initiate further work to continue the process of identifying cost effective risk-reducing measures. In this study a work session method is proposed with an expert panel to identify and quantify risk-reducing measures. It is also recommended to analyze further the "near misses" reported to NPD since 1990, as part of this work

- Understanding and controlling risk at a high level in the organization is an important step towards risk reduction. The use of fatality risk acceptance criteria and risk analysis are beneficial in this respect.

    Therefore it is recommended that the oil companies and contractors formalize acceptance criteria for immediate fatality risk to be used for

diving activities. Since fatalities are very rare events fatality rates are not suited for day-to-day risk control purposes. Hence, it is recommended that the industry also establishes risk management routines which aim at limiting the frequencies of reportable incidents (e.g. rate of near misses and rate of injuries)

- The criteria for reporting of diving incidents to the NPD differ from the criteria applied in other parts of the petroleum industry. This makes comparison of observed incident rates difficult.

  Therefore it is recommended to evaluate if reporting criteria for diving incidents can be adjusted to suit criteria applied elsewhere in the petroleum industry.

<u>Long-term Health Effects</u>

- The statistical basis for establishing quantitatively the long-term health effects of diving has been - and still is - weak.

  Therefore it is recommended to improve the basis for future statistics on long–term health effects of diving. In cooperation with Rikstrygdeverket and NPD it should be established a system for determining the rate of disablement of divers in order to compare this rate with the corresponding rate in the general public. Already established systems for the general public could be used.

- Proper debriefing after incidents may reduce the risk of Post Traumatic Stress Disorder.

  Therefore it is recommended to evaluate the current practice and routines applied in the diving industry, also in the light of both experience in other comparable professions (e.g. among firemen and pilots), and of other knowledge on the effect of debriefing

- The employment and working conditions of divers are found to be important for the ability to improve HSE matters. Observations made are:

  * There are large individual differences between divers regarding their ability and suitability to withstand the physiological and psychological stresses in connection with diving

  * In some interviews it was stated that there is a fear to report hazardous incidents and possible individual health effects of diving. This fear is related to the possibility of not being rehired in the case of hazardous incidents, and to the possibility for loss of the diving certificate and, thus, of job and income, in the case of health effects

  * Supervisory activities performed by the Authorities and incident statistics since 1990 indicate that the potential for learning from experience is not fully utilized. The supervisory activities also indicate that training in regulations and familiarization to the operations are weak points. It is anticipated that the use of short-term contracts and personnel hired from project to project limits efficient implementation of improvements.

Therefore it is recommended to:

- **Improve the routines for medical screening, selection and follow-up both for individual particularly demanding diving tasks and for diving career as a whole**

- **Evaluate alternative employment conditions and post diving career plans to improve reporting of hazardous incidents and health effects as well as assuring continuity in improvements of work performance**

2. INTRODUCTION

2.1 Background and Mandate

This study has been carried out by Scandpower Risk Management on behalf of the three oil companies Esso, Norsk Hydro and Statoil. The contract partner for the work has been Statoil. The work has been performed during the period September 2003 to July 2005.

Diving activity in the Norwegian Sector is frequently debated in the mass media. Personal experiences and strong opinions are often highlighted in the media. Additionally expert opinions are supporting divergent conclusions. This has caused the diving industry to struggle with a public image of high personnel risk and insufficient risk management.

With this background the goal of this study has been to present an objective description of the risk for fatality and serious disease for divers involved in the current activities in the Norwegian Sector. To achieve this goal the study has used recognized methods and data for performing risk analysis.

The project has been conducted as an independent analysis with an open dialogue with, and extensive involvement of, experts, labor unions, employees, and other organizations.

Following an introductory project phase the following mandate was established for the project:

- The project will evaluate the risk and the management of risk involved with the present manned underwater operations in the Norwegian Sector. The risk aspect will cover risk for serious injuries or fatalities, either during diving or as long-term effects at a later stage

- The operations to be considered are petroleum related activities in the Norwegian Sector excluding inshore operations. The operations of interest are surface-oriented diving and saturation diving down to a maximum depth of 250 meters. Although the risk will be considered for these specific activities possible influence on the risk from other typical activities performed by the divers will be considered. The risk will be presented to illustrate both the risk per activity and the resulting typical risk exposure for a diver

- The management of risk will primarily be compared to requirements given by NPD. Risk management in comparable industrial activities will also be considered where this can provide state of the art contributions

- The risk level will be established based on available statistics, modeling of trends and expert opinions. The experience base will cover, as far as possible the Norwegian Sector as well as the British Sector. The risk will be evaluated and compared to requirements for petroleum activities and risk in other industrial activities in order to classify the current level of risk

- Recommendations for improvements will be given where needed

- Key characteristics of the project:
    * An independent analysis. The role of the reference group will be to ensure access to and utilization of relevant and balanced information sources
    * An open process which allows for the industry to give input to the work and access to the results
    * A study which relies heavily on existing and available information and data sources.

2.2 Project Organization

The project organization is shown in Figure 2.1 below.

The project work was organized and performed by the "Key Project Team". The role of the "Reference Group" has been to ensure access to and utilization of available information and data sources. Periodic meetings have been held with the "Reference Group" to achieve this goal. Other information sources and expert input has been applied on a broad basis with the aim of assuring a balanced input of information from different sources. Meetings, interviews and other communication, as found appropriate, has been arranged. A "Review Committee" has been established comprising senior employees of Scandpower to assure sufficient independence of the work performed.

The Key Project Team consists of experts in areas such as:

- Risk analysis
- Accident statistics
- Safety management
- Accident investigation
- Organizational and regulatory aspects
- Psychosocial and human factors.

This implies that competence related to the specifics of diving activities has been covered by use of the "Reference Group" and the other "Information Sources".

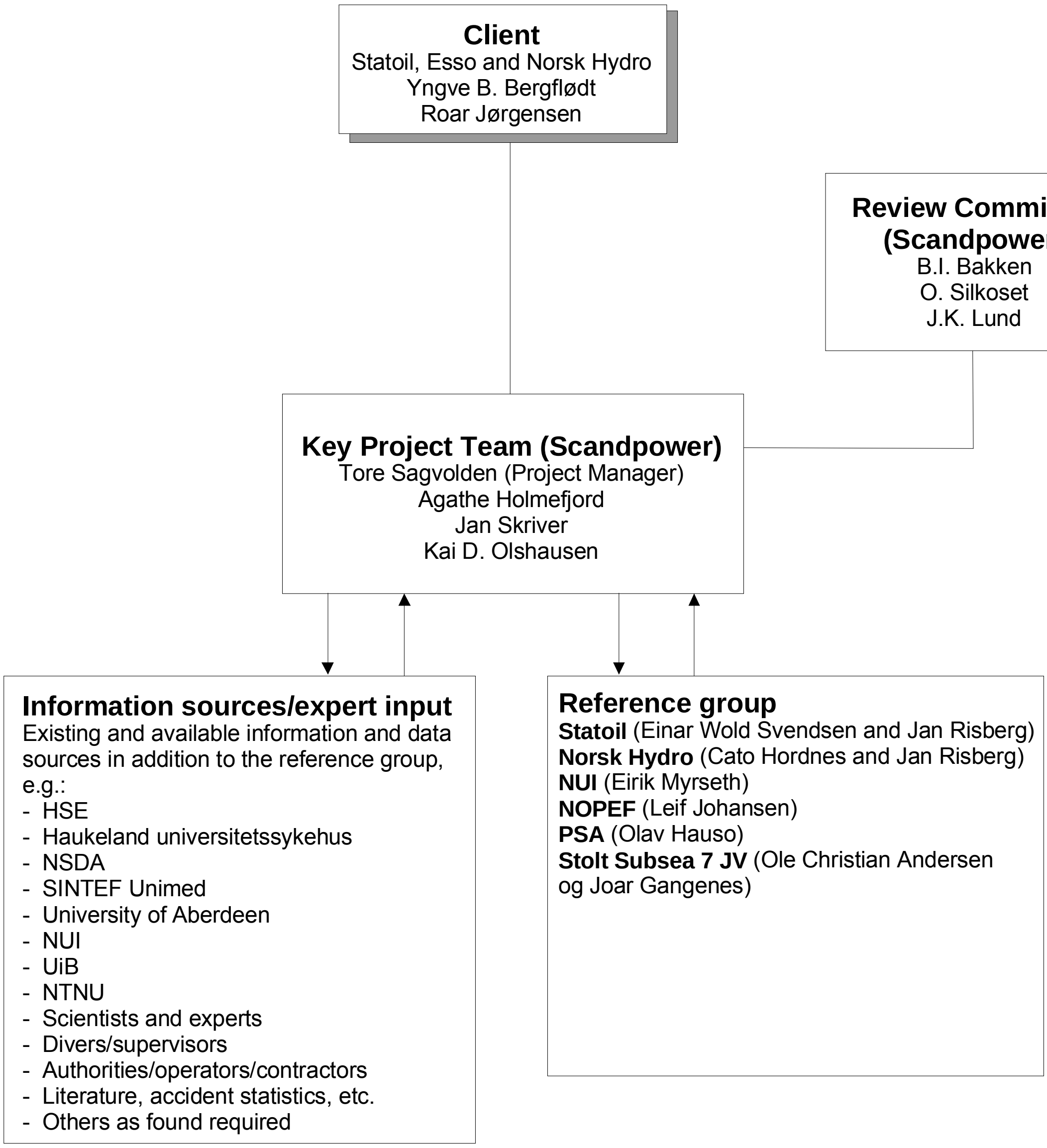


Figure 2.1: Project Organization

2.3 Sources of Information

Information for the present project has been collected in the period up to summer 2004 from various sources to ensure a good basis for the project. In addition to the reference group these sources include:

- **Interviews and meetings**
  - National Hyperbaric Centre in Aberdeen (Ian Mackenzie, 16.10.2003)
  - Unimed Scientific Ltd, Aberdeen (Valery Flook, 16.10.2003, received presentations on: "A physiological Model of Decompression", "Do you really need to carry all those bottles?", "Is it a good idea to do more than one dive a day", "The risk of decompression problems in Hyperbaric Attendants")
  - Liberty, Aberdeen University (Stephen Watt, 16.10.2003)
  - Visit to the Diving Vessel Seaway Osprey (mobilization in Aberdeen). Interview with diving superintendent Daniel Thorvaldsson, 17.10.2003
  - NOPEF (Leif Johansen, 20.10.2003)

  * Nordsjødykkeralliansen NSDA (Henning Haug, 20.10.2003, Knut Ørjaseter, 03.02.2004)
  * Active divers: Are Urheim, (Subsea 7), Harald Klinge, (Subsea 7), Jon Are Hvalby (Stolt Offshore), 11.11.2003
  * Alf Brubakk - NTNU, St. Olavs Hospital, Trondheim, 26.11.2003
  * Kari Todnem - Avdeling for klinisk nevrofysiologi, St. Olavs Hospital, Trondheim, 24.11.2003
  * David Elliot, 21.01.2004
  * Diving seminar in Bergen, November 2003
  * Norsk Undervannsintervensjon - NUI (Eirik Myrseth, Arvid Hope, Vidar Fondevik, Kåre Segadal, Alf Schønhardt, 29.10.2003)
  * The Public Inquiry into the Pioneer Divers, Stortinget, 10 November 2003
  * Haukeland universitetssykehus (Marit Grønning, 13.02.2004)
  * NPD/PSA (Øyvind Lie, Jon Arne Ask)
  * UiB (Einar Thorsen)

- **Informal contacts by telephone, e-mail etc.**
  * Svein Eidsvik (Sjøforsvaret)
  * Flymedisinsk institutt (Per Årva)
  * Arbeidstilsynet (Jens Brynestad)
  * HSE (Chris Sherman)
  * IMCA (Jane Bugler)
  * Liberty, Aberdeen University (John Ross).

A large amount of documents have been collected and reviewed as part of the project. These include:

- **Incidents and statistics:**
  * SYNERGI reports from Statoil, 1996-2003
  * SYNERGI reports from Stolt-Subsea 7 Joint Venture, 1999-2003
  * SYNERGI reports from Stolt Offshore, 1999-2003
  * "Report from the dive database - DSYS 2001" (NPD 2002)
  * "ODs årsrapporter"
  * "Experience & Employment Profile of Diving Personnel, Profile for 2000" (IMCA January 2003)
  * "Statistics of Fatal Injuries2002/03" (HSE 2003)
  * "Accident Statistics for fixed Offshore Units on the UK Continental Shelf 1991-1999" (HSE 2002)
  * "Risikovurdering av selskapets dykkeaktiviteter" (Statoil, 1 June 1994)
  * M. G. Welham: "Health Survey of Commercial Divers (A Preliminary Study)" MaTSU P3204, (Centre for Health and Risk Management, Loughborough University of Technology, 1996)
  * "Accident Causation and contributing factors. A Study of Diving Accidents in the UK Offshore Oil and Gas Industry from 1978 to 1995". (Loughborough University of Technology, 1997)
  * Marit Skogstad: "Hvor farlig er yrkesdykking" (Arbeidervern, 2000; (2), s. 7)
  * "Unofficial Diving Accident Statistics - Norway" (Jan Risberg, NUI 2003)
  * "Diving Fatalities - Offshore Oil and Gas" (UK statistics with description of each event 1971 - 2001, HSE 2003)
  * "Utvikling i risikonivå - norsk sokkel - Hovedrapport Fase 3 - 2002" (NPD 2003)
  * "Utvikling i risikonivå - norsk sokkel - Pilotprosjektrapport" (NPD 2001)

- **Physiology, medicine and health:**
  * Alf O. Brubakk, Tom S. Neuman (Eds.): "Bennett and Elliott's Physiology and Medicine of Diving", 5th Edition, ISBN 0-020-2751-2, Elsevier Science, 2003
  * D. H. Elliott, R. E. Moon: "Long term Health Effects of Diving, in: Physiology and Medicine of Diving", Chapter 21, p. 585- 604, 4th Edition)
  * Alf Brubakk et al.: "A histhopathologic and immunocytochemical Study of the Spinal Cord in amateur and professional Divers" (Undersea and Hyperbaric Medicine, 1994, Vol. 21, No. 4, 391-402)
  * Alf Brubakk et al.: "Effect of oxygen Tension and Rate of Pressure Reduction during Decompression on central Gas Bubbles" (The American Physiological Society 1998, http://www.jap.org) (incl. letter to Stortinget's kommunalkomité, 26 November 2003)
  * Kari Todnem et al.: "Influence of occupational upon the nervous System: An epidemiological Study" (British Journal of Industrial Medicine, 1990, 47:708-714)
  * Kari Todnem et al.: "Immediate nourological Effects of Diving to a Depth of 360 Metres" (Acta Neurol. Scand., 1989, 80:333-340)
  * Kari Todnem et al.: "Nerve Conduction Velocity in Man during deep Diving to 360 msw" (Undersea Biomedical Research, 1989, Vol. 16, No. 1:31-40)
  * Kari Todnem et al.: "Akutte og kroniske effekter på nervesystemet ved dypdykking" (Tidsskrift for Den norske lægeforening, 1993, 113:36-39)
  * Kari Todnem et al.: "Neurologisk trykkfallsyke" (tidsskrift for Den norske lægeforening, 1991, 111:2091-2094)
  * Kari Todnem et al.: "Neurological long term Consequences of deep Diving" (British Journal of Industrial Medicine, 1991, 48:258-266)
  * Kari Todnem et al.: "Electroencephalography, evoked potentials and MRI Brain Scans in Saturation Divers. An epidemiological Study" (Electroencephalography and clinical Neurophysiology, 1991, 79:322-329)
  * Kari Todnem et al.: "Visual Evoked and Brain Stem Auditory Evoked Potential in Divers" (Aviation, Space, and Environmental Medicine, October 1991: 982-985)
  * Kari Todnem et al.: "Analysis of neurological Symptoms in deep Diving: Implications for Selection of Divers" (Undersea Biomedical Research, 1990, Vol. 17, No. 2, 95-107)
  * Angus Hickish: "Neuro-behavioural Impairment after neurological Decompression Illness" (HSE Research Report 017, 2002)
  * "Health Survey of commercial Divers" (Loughborough University of Technology - 1996)
  * "Helsestatus hos tidligere Nordsjødykkere", rapport til Sosialdepartementet (Haukeland universitets sykehus, Yrkesmedisinsk avdeling, July 2003)
  * "Retningslinjer for helseundersøkelse av yrkesdykkere" (Statens Helsetilsyn, August 2000)
  * "Long Term Health Effect of Diving" (Godøysund, Norge, June 1993)

- **Work environment:**
  * "Kartlegging av arbeidsmiljø blant norske dykkere i Nordsjøen" (NUTEC and UiB, May 1986)
  * "Kartlegging av arbeidsmiljøet til et utvalg norske dykkere" (Tone Bergan, 1994)
  * "Attitudes to safety culture among professional divers" (HSE 2003)
  * "Arbeidsmiljøkartlegging - innaskjærs dykking" (NUI 1999)

- **Safety management:**
  * "Tilsynsrapporter 1990 -2003" (NPD)
  * "Forskrift til arbeidsmiljøloven - dykking" (Arbeidstilsynet 2002)
  * NPD regulations (2003)
  * "Helse og sikkerhet i dykkevirksomheten" (Kommunaldepartementet, November 1993)
  * "Report AGdy 2000 +" (Statoil, September 2001)
  * "Bemannede undervannsoperasjoner" (NORSOK standard U-100N, August 1999)
  * Input from NOPEF - Various memos, letters, articles from 1990 - 2003)
  * "Diving Operations - Manned Underwater Operations Instructions" (Stolt Offshore 2003)

- **Various reports:**
  * St. meld. nr. 47 "Gransking av pionerdykkernes forhold i Nordsjøen" (AAD, 27 June 2003)
  * NOU 2003:5 "Pionerdykkerne i Nordsjøen" (Lossius, 31 December 2002)
  * "US Navy Diving Manual"
  * "Kommentarer til statistiske analyser i NOU 2003:05 - Pionerdykkerne i Nordsjøen" (Trygve Almøy & Erik Romstad, Norges landbrukshøgskole, 2003)
  * "Intern rapport 250 msw treningsdykk" (Statoil experience report following the training dives at NUI in October 2002)
  * "Norway/UK Regulatory Guidance for Offshore Diving" (NURGOD) (issued by IMCA December 2003)
  * "Rapport fra LOs dykkerutvalg" (dated 1 June 2004).

2.4 Definitions and Abbreviations

Refer to NORSOK Standard U100 N for the definitions of diving terminology, Ref. /1/, and to NORSOK Standard Z013 for the definitions of risk analysis terminology, Ref. /2/.

Additional definitions and abbreviations used in this report are presented below.

AAD	Arbeids- og administrasjonsdepartementet
ALAPS	Armstrong Laboratories Aviation Personality Survey
BMI	Body mass index
British Sector	The British Sector of the North European waters, mainly the North Sea
CI	Confidence interval (usually 95%)
CNS	Central nervous system
CREAM	Cognitive reliability and error analysis method
DCI	Decompression illness
DCS	Decompression sickness
DP	Dynamic positioning
DSV	Diving Support Vessel
DSYS	PTIL's Diving Data Base
EDTC	European Diving Technology Committee
EEG	Electroencephalography
ELTHI	Examination of Long Term Health Impact of Diving
EPA	Environmental Protection Agency (US)
FAR	Fatal Accident Rate = number of fatalities per 100 million hours of exposure
FEF	Forced expired flow

FEV	Forced expired volume
FVC	Forced vital capacity
GP	General public
HAZOP	Hazard and Operability Study
HiB	Høyskole I Bergen (Bergen University College)
HPIP	Human performance investigation process
HPNS	High pressure nervous syndrome
HRQOL	Health related quality of life
HSE	Health and Safety Executive (UK)
IES	Impact of event scale
IMCA	International Marine Contractors Association
INPP	Institut National de Plongee Professionnelle (French National Diving Institute - Marseille)
IPRC	International Radiation Protection Commission
IRPA	Individual risk, per annum
JV	Joint Venture
MCS	Mental component summary score
MD	Medical Doctor
MMPI	Minnesota multiphase personality inventory
MRI	Magnetic Resonance Imaging
msw	Meter of sea water
MTO	Man, Technology, Organization
NACE	Nomencalature general des activitée economiques dans le Communauté Européenne
NBH	Norwegian Board of Health
NOPEF	Norsk olje og petrokjemisk fagforbund
NORSOK	Styrking av norsk sokkels konkurranseposisjon
NOS	Norwegian Official Statistics
NOU	Norges offentlige utredninger
Norwegian Sector	The Norwegian Sector of the North European waters, mainly the North Sea
NPD	Norwegian Petroleum Directorate (Oljedirektoratet)
NSDA	North Sea Diver Alliance
NTNU	Norges tekninsk naturvitenskapelig universitet
NUI	Norsk Undervannsintervensjon (NUTEC until 1998) (former Norsk Undervanns Institutt)
NURGOD	Norway/UK regulatory guidance for offshore diving
OD	Oljedirektoratet
OHLS	Oxford Healthy Lifestyle Survey
OLF	Oljeindustriens Landsforening
OR	Odds ratio
OSW	Offshore worker
P300	Cognitive response test
PCS	Physical component summary score
Pioneer Period	1965 to 1990
PRS	Pipeline repair system
PSA	Petroleum Safety Authority (Petroleumstilsynet)
PTIL	Petroleumtilsyn
PTSD	Post traumatic stress disorder
r	Rate of covariation
RIF	Risk influencing factor
RTV	National Insurance Administration (Rikstrygdeverket)
SD	Standard deviation
SDS	State Diving School

SER	Somato-sensoric induced response
SFT	Statens forurensningstilsyn (State Pollution Control Authority)
SIC	Standard industrial classification
SJA	Safe Job Analysis
SKI	Svensk kärnkraftinspektion
SLS	Safety Line System
SMR	Standard mortality ratio
SSB	Statistisk sentralbyrå
Sv	Sievert (radiation dose)
UiB	Universitetet I Bergen (Bergen University)
UK	United Kingdom
UN	United Nations

2.5 English and Norwegian Names

Table 2.1: English and Norwegian Names

English	Abbr.	Norwegian	Abbr.
Norwegian Petroleum Directorate	NPD	Oljedirektoratet	OD
Petroleum Safety Authority	PSA	Petroleumstilsynet	PTIL
Norwegian Board of Health	NBH	Helsetilsynet	
Official Statistics of Norway		Norges offisielle statistikk	NoS
Statistics Norway		Statistisk sentralbyrå	SSB
National Insurance Administration		Rikstrygdeverket	RTV
State Diving School	SDS	Statens dykkerskole	SDS
Bergen University College		Høyskolen I Bergen	HiB
Bergen University		Universitetet I Bergen	UiB
Norwegian Labor Directorate		Arbeidsdirektoratet	
Norwegian Underwater Intervention	NUI	Norsk undervannsintervensjon	NUI

3. SHORT DESCRIPTION OF THE DIVING INDUSTRY

3.1 General

Petroleum related diving activity in the Norwegian Sector started with the development of oil and gas resources in 1966. Divers are mainly used for construction, inspection, maintenance and repair work. Until 1993 there was a high activity level in the Norwegian Sector with divers working on long-term contracts. In later years the activity level has been low with many of the divers working on day rate contracts.

Due to the low activity, the recruitment of new divers to the industry is very low, and an ageing of the work force is reported to be an increasing challenge. Today 2-4 diving vessels are operating periodically in the Norwegian Sector typically with a mixed international diving crew. The divers are often British or Norwegian.

Several sources describe different aspects of the diving industry. Three authoritative sources are recommended for familiarization with the industry and its challenges:

- NOU 2003-5 "Pionerdykkerne i Nordsjøen" - Ref. /3/
- Alf O. Brubakk, Tom S. Neuman (Eds.): "Bennett and Elliott's Physiology and Medicine of Diving", 5th Edition, ISBN 0-020-2751-2, Elsevier Science, 2003, Ref. /4/
- "Helse og sikkerhet i dykkevirksomheten" - Report dated 02.11.1993 from "Kommunaldepartementets utvalg om helse og sikkerhet i dykkevirksomheten" by Marit Kromberg et al. , Ref. /5/

This chapter gives a brief overview of some characteristic aspects and historical developments relevant for the diving activity in the Norwegian Sector in particular, and for the diving industry in general. These characteristics are presented below as an introduction and familiarization for the reader of this report.

3.2 Diving Methods

Below is a description of typical diving methods that have been used in connection with petroleum related activities in the Norwegian Sector.

Surface-oriented Diving

Surface-oriented diving is a common name for diving methods where the dive starts with the diver entering the water at surface level and returning to the surface after having completed his tasks and the decompression. Decompression normally takes place in the water, with the diver breathing air while he is ascending, but it might in some cases take place in a diving chamber placed on the diving platform. This is called "surface-oriented diving using surface decompression". It allows for the use of oxygen to speed up the elimination of inert gas that has dissolved in the body tissues during the dive. This advantage must, however, be balanced against the toxic effects of oxygen in the short and long-term.

The breathing medium during the dive is in most cases air, but it can also be mixed gas, such as nitrox (nitrogen and oxygen) or heliox (helium and oxygen), or in some cases pure oxygen. Pure oxygen is mainly used for military purposes. Depth limitations depend on the oxygen content versus inert gas content in the breathing gas. For pure oxygen diving, the maximum depth limit is 6 msw due to the toxicity of oxygen. For air diving one has to take into consideration the narcotic effect of nitrogen, resulting in a practical depth limitation of approximately 60 msw.

There are two methods of surface-oriented diving that have been used in petroleum related diving:

- Self contained underwater breathing apparatus (SCUBA). This is a method where the diver carries his breathing gas on his back and is completely autonomous, except for the use of a safety line to the surface. The method is today used mainly for recreational diving, but also for rescue diving and some professional diving tasks
- Surface supplied diving, meaning that the breathing medium (air or mixed gas) is supplied to the diver through a hose from storage (or compressor/pump) on the surface. Standard hard hat diving is typical for this method. This category includes surface oxygen decompression diving, with limited degree of decompression in the water, the rest in a decompression chamber at the surface (breathing 100 % oxygen).

After the introduction of NPD's provisional requirements, a diving bell has been required for all diving deeper than 50 msw in connection with the petroleum industry. The regulations also banned the use of SCUBA diving in the offshore environment.

Bell Bounce Diving

Bell bounce diving was introduced very early in the process of developing the oil industry. The method includes a closed diving bell which can withstand both external and internal pressure. A bounce dive starts with the divers (normally 2) entering the bell at the surface. The bell is then sealed from external pressure by means of an external bottom door and lowered to the depth where work is to be performed, maintaining surface pressure inside the bell during decent. After positioning the diving bell correctly the divers will observe the structure to be worked on and plan the job from inside the bell. The divers then pressurize the bell from a gas supply either stored on the bell itself or through a hose from the surface. When the pressure inside the bell equals the pressure on the outside, the external bottom door of the bell can be opened and the diver can leave the bell to perform his tasks. Upon completion of the work tasks, the diver returns to the bell, the bell is sealed from the external pressure by means of an internal bottom door and the bell is recovered to the deck of the diving vessel, maintaining bottom pressure inside the bell during the ascent. Decompression may start during the ascent. At the surface the diving bell is connected to a pressure chamber, the pressure difference between the bell and the chamber is equalized and the divers can enter the chamber where they stay for the rest of the decompression.

The depth limitation for this method results from the time required for decompressing versus the time available for working. Typically one could spend ½ hour under pressure (from start of pressurization to start of decompression). For operation at approximately 200 msw this resulted in approximately 10 - 15 minutes of effective in-water time and between 30 and 40 hours of decompression time.

Due to the limited time available for actual work, bounce diving is not very effective. It also increases the risk of accidents, due to the stress involved in trying to complete complicated tasks in a very short time. As a result, saturation diving was introduced in the Norwegian Sector in 1974/75 and soon became the preferred method. Today bounce diving is no longer used in the Norwegian Sector. Although decompression times are longer for saturation diving, also the time available for the diver to perform his work is a lot longer or, in fact, not limited by decompression related issues at all.

Saturation Diving

Saturation diving is a further development of the bounce diving technique. Physiologist found that after a prolonged stay (typically 24 hours) at depth, divers tissues were saturated with inert gas. Therefore the decompression duration is the same whether he stays under pressure for 24 hours or for 24 days. A saturation diving system therefore consists of a chamber complex, i.e. several chambers in which the divers can live, sleep, eat, shower etc. for periods of up to several weeks. At regular intervals, normally for 6 - 8 hours each 24 hour period, they leave the chambers by means of the diving bell to perform work at the worksite.

The divers are normally saturated at a depth slightly shallower than the working depth and enter the diving bell from the chambers at this depth. The bell is then sealed off from the chambers, disconnected and lowered to the working depth. During the descent, the diving bell pressure is adjusted to correspond to the working depth pressure so that the bell bottom door can be opened and divers can enter the water. Excursions up or down relative to the saturation depth may be performed. After completing their "working day", the divers return to the diving bell, and the process is reversed bringing the divers back to the chambers and their saturation depth. After their predefined working period, which in Norway today is limited to 14 days maximum, the divers are decompressed back to surface pressure in a decompression chamber which contains all necessary facilities for a prolonged decompression, typically lasting for 7-8 days from a saturation depth of approx 150 msw.

Saturation divers today normally work in teams of three, with 4 teams covering a day. This gives each team a 6 hour working dive per day, during which 2 divers actually work in the water, while the third diver stays in the diving bell monitoring and assisting the other two divers. Typically up to 18 divers may be kept under pressure for about 20 days in the chamber complex.

The diving bell is operated by a handling system, normally consisting of a trolley, a cursor, a main winch, guide wires and a main umbilical. The main umbilical supplies the diving bell and the divers with electrical power, gas, heat and means of communication. Gas analysis and depth monitoring is also performed through the main umbilical. The monitoring, control and handling of the diving bell is conducted from "The Dive Control". The status of the chamber complex is constantly monitored and controlled from "The Saturation Control".

The divers in the water are supported with gas, heat, communication and light through diver umbilicals. The length of the diver umbilical is normally limited to 45 m. Dispensation for increased length of the umbilical up to 60 m may be given based on performed risk analysis (Ref. /1/). Excursions up or down relative to the saturation depth may be performed.

The breathing media used for saturation diving can be air, nitrox or heliox, depending on depth. Dives have also been performed using tri-mix (oxygen, helium and nitrogen) and bi-mix consisting of oxygen and neon. For the deepest dive performed so far (701 msw), a tri-mix consisting of oxygen, helium and hydrogen was used.

Experimental saturation dives have been performed at 701 msw, but the deepest routine operational diving is being performed at approximately 300 msw offshore of Brazil.

3.3 Diving Depth

Typical diving depths for offshore operational diving have increased with the oil and gas industry moving into deeper and deeper waters. Initial activities in the Norwegian Sector required diving to approximately 70 msw. However, depths increased rapidly as new fields were explored (Frigg 100 msw (1971), Norwegian Brent (later Statfjord) 150 msw (1973)). The saturation diving method was taken into use in the Norwegian sector in 1973/74, and became the dominating diving method after the introduction of purpose-built Diving Support Vessels (DSV) early in 1975.

In 1975 the French diving company Comex performed an operational dive down to 326 msw. In 1977 the US company Taylor Diving performed several operational dives down to 320 msw. In Brazil diving is presently regularly performed down to 300 msw.

Experimental diving has been performed among other places in USA, France, Japan, Sweden Switzerland, Germany, UK and Norway. In 1977 Comex performed a wet ("lock-out") dive to 501 msw and in 1981 a dry chamber dive was performed to 686 msw at Duke University USA (Ref. /17/). In 1998 Comex in Marseille performed a wet ("lock-out") dive to 534 msw and they performed the deepest known dry chamber dive to date in 1992 to a depth of 701 msw, Ref. /6/.

The "Norwegian Underwater Institute" - NUI was established by the Norwegian authorities and DNV in 1976 to perform research on diving medicine/physiology and technology and to educate diving personnel and diving specialists. From 1980 to 1990 nine onshore trial dives were performed in NUI's hyperbaric facilities, ranging in depth from 218 msw to 504 msw. The dive to 504 msw was performed in 1981 and is still the deepest dive in cold (4 ^{o}C) water. Research was funded partly through national research funds and partly by the industry. Norwegian authorities pulled out of NUI in 1983 and were replaced as owners by the Norwegian oil companies Statoil, Hydro and Saga. After 1990 the only dive deeper than 120 msw performed at NUI was a verification and training dive in 2002 to 250 msw. This dive resulted in some unexpected and undesirable health effects that are currently being investigated.

In 1985 NPD commissioned a study regarding time limitations in a hyperbaric evacuation situation from NUTEC in Bergen. Among the conclusions drawn in the study, Ref. NUTEC report 34-85, one says that for diving deeper than 180 msw, there should be two hyperbaric lifeboats, or at least two different pressure compartments in the lifeboat pressure chamber, available on the DSV, so that divers on different pressure levels could be evacuated simultaneously. As only one DSV, the Seaway Pelican, which was being built at that time, fulfilled these criteria, 180 msw was considered the practical diving depth limitation in the Norwegian Sector at that time, Ref. /7/.

Common requirements for a number of important parameters in decompression tables covering depths down to 180 msw, were introduced by NPD in 1990. These requirements were implemented in the NORSOK standard U-100 (Ref. /1/) when this standard came into use in the year 2000. The NORSOK standard is now recommended by NPD as the standard to be used for diving in the Norwegian sector. For deeper diving, NORSOK U-100 recommends that a NUTEC report (report 36/92) should be used in developing diving procedures to cover the depth range 180 - 360 msw. Such procedures must be developed, tested and verified by the user.

The 180 msw division is partly linked to the practical need and partly to the requirement for evacuation of the diving crew from the pressure chambers to a hyperbaric rescue vessel within 30 minutes. Another consideration is the observed threshold for onset of HPNS (High pressure nervous syndrome) which might occur at about 150 msw or deeper depending on compression profile.

Operational dives deeper than 160 msw have been rare in Norwegian waters. This is due to the water depths (approximately 70 - 160 msw) of the oilfields developed with subsea installations that are dependent on diver intervention. Deep operational dives have mainly been performed in connection with pipe laying operations across the continental shelf (Statpipe 1983 - 84) and riser tie-ins to pipelines at Gullfaks C in 1989. Some sporadic diving activity down to approximately 200 msw was also performed from drilling rigs/vessels in the seventies and early eighties. For these diving operations, procedures developed by the diving contractors themselves were used.

As a contingency for the repair of important transportation oil and gas pipelines, Statoil and Norsk Hydro have developed and maintained a pipeline repair capability based on hyperbaric welding performed by divers. In crossing the Norwegian continental shelf, some of these pipelines rest at depths down to approximately 360 msw, and, as a result, a diving capability to 360 msw has been the goal.

Presently equipment has been developed (and is in the process of being built) which will enable remotely operated pipeline repair. This is scheduled to remove the need for diving capability for water depths in excess of 250 msw by the end of year 2004.

There will, however, still be a need for diver intervention, mainly in connection with oil and gas fields where divers are used for installation of new or modification of existing installations, and in connection with pipe laying. The practice has been that diver intervention was primarily used as contingency for unmanned operations. To ensure access to qualified resources (DSV, equipment, divers, procedures, etc.) that can perform this diving in a safe and efficient way, Statoil and Hydro have a strategy to utilize diving actively as a tool for subsea work in the depth range 0 - 250 msw. The reasoning behind this strategy is that a sustainable activity level is needed to ensure a "healthy" diving industry that can develop and improve both on human, technological and organizational issues.

In connection with complications after a simulated training/verification dive to 250 msw performed by Stolt Subsea 7 JV in the hyperbaric facility at NUI October 2002, the diving procedure used has been identified as one of the possible contributing factors. Consequently, Statoil and Hydro have decided that the procedure will not be used until the correct causes of the complications have been found and rectified. As this procedure has been the only accepted one for diving deeper than 180 msw, the two companies have in practice limited their use of diving to depths shallower than 180 msw until further notice.

In a letter from AAD ("Det Kongelige Arbeids- og Administrasjonsdepartementet") to NSDA (Nordsjødykkeralliansen), Ref. /8/, it is stated that NPD, for the time being, does not consider diving deeper than 180 msw to be justifiable.

3.4 Activity Level

The diving activity in the Norwegian Sector increased gradually from 1966 to 1980. In the period from 1980 to 1993 the activity level was high, although with considerable variation from year to year. During this period the number of active divers in the Norwegian Sector was reported to be between 500 and 1,800 (Ref. /17/). 400 divers were in 1981 registered by the Rogaland County Labor Office as working on the Norwegian Continental Shelf in peak seasons (Ref. /17/). In Ref. /5/ it is referred to about 200 - 250 active divers each year at this time. NPD has issued certificates for bell diving and for surface-oriented diving. Until 1990 NPD had issued 2,165 bell diving certificates and 351 certificates for surface-oriented diving (Ref. /9/), for divers of all nationalities. Of these, 327 bell diving certificates and 336 surface-oriented certificates, were issued to Norwegian divers.

Diving activity remained high up to 1993 with approximately 200,000 man-hours in saturation per year. In 1993 the activity dropped dramatically and, thereafter, the average activity level has been roughly 60,000 man hours in saturation per year, see Figure 3.1. This activity level corresponds to roughly 6 months per year of a diving support vessel in operation.

NOPEF refers to more than 100 divers employed on fixed/standard contracts prior to 1990 (Ref. /10/). The total number of divers was probably higher as many of the employers had a policy of employing day-rate or self-employed divers.

Today only a few (approximately 10) divers are employed in diving companies based in Norway. Almost all divers and diving support personnel are hired on short-term contracts or as "self employed" through the international diving companies UK organization. In later years also hiring through non European companies has become a normal operating procedure to reduce costs for the diving company.

The activity level for offshore surface-oriented diving has followed the same trend and the activity was in 1993 reduced from roughly 3,000 man-hours in water per year to 500 man-hours per year (on average).

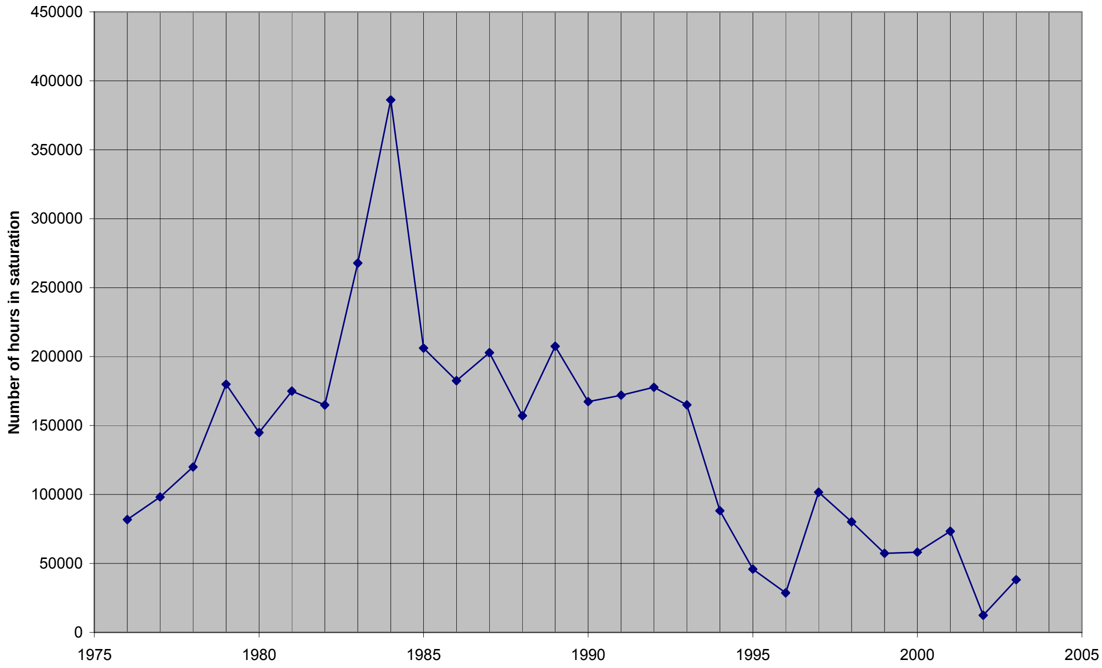


Figure 3.1: Saturation Diving Activity in the Norwegian Sector

The strong decrease in activity level was, according to the report, Ref. /11/, *".... largely due to the fact that most operating companies, including Statoil, decided to limit and finally abandon diving altogether within year 2000. This decision was partly based on a massive focus at that time, by some scientists and the media, on the danger related to diving and the potential of long-term health effect on divers. In addition there was a desire to push the development of diver less technology for the benefit of future extremely deep water developments where manned interventions are considered impossible".*

The Reference Group (see Chapter 2) has received information to the effect that Statoil and Norsk Hydro were the two companies who decided to limit and finally abandon diving as a tool. The basis for the decision was

- dramatic reduction in the need for underwater inspection of pipelines and offshore structures (one of the main activities for divers around 1990)
- improved availability and usability of alternative intervention methods such as ROVs
- negative focus in mass media on possible long-term health effects on divers.

The report (Ref. /11/) also states that the activity level in the Norwegian sector is considered not sustainable in the sense that it can not support a prosperous diving industry with a turnover that enables continuous improvement.

The activity level in the British Sector is reported to be roughly 5 to 10 times higher than the activity in the Norwegian Sector. The British Sector has also experienced a trend of reduced activity, although the change has not been as rapid as in the Norwegian Sector.

3.5 Diver Work Conditions

During the first 20-25 years of diving in Norway (1966 - 1990) most divers and diving support personnel were permanently employed in one of the several diving companies established in Norway. Divers on the DSVs that started operations in 1975 were "employed" on the vessel on the same general terms as regular Norwegian sailors at that time. The DSVs were for a large part hired in on long-term contracts with guaranteed activity by the oil companies. There was a requirement in all contracts stipulating a minimum "Norwegian content", i.e. Norwegian employees, supplies, support, etc. If the desired "Norwegian content" was not reached, the contract would not be approved by the Norwegian authorities.

Most oil companies today purchase diving services for particular short duration jobs rather than on a long term, year round basis as before 1990. This contributes to the lack of continuity in the industry as a whole. An exception to this is the Statoil contract (in cooperation with Hydro and Esso) for diving contingencies, which has long term duration, but with no guaranteed activity level.

A limited number of diving support vessels are qualified in accordance with Norwegian requirements for such vessels. The activity level in Norway alone is, however, not sustainable in itself, so that vessels and divers must operate internationally in order to survive. In particular there is a strong integration between operations on the Norwegian, Danish and British sectors. Because all diving companies operating in this area have their main offices and main activity in the UK, UK divers constitute the largest portion of the divers currently operating in the Norwegian Sector.

In this context it is of interest to note that in 1990 it was reported (Ref. /12/) that there was a requirement by the Unions in the UK that foreign divers should not constitute more than 10 % of divers on a diving contract. Such a requirement did not exist in the Norwegian Sector at that time and the typical situation here was that approximately 70 % of the divers were non-Norwegians.

3.6 Education

The Governmental National Diving School (Statens Dykkerskole - SDS) was established in 1980 for the purpose of educating bell divers. Prior to this all professional diver education was provided by the Norwegian Navy. In addition training (on the job training) was provided by the large international diving contractors, which also qualified such personnel for internal use. Divers were mostly recruited among ex-military personnel or recreational divers.

Diving certificates prior to 1980 were, hence, always related to surface-oriented diving with a depth limit of 60 msw. No depth limit has been given for bell diver's certificates.

Since 1996 no new bell divers have been educated in Norway. Other European schools have also greatly reduced their activity related to bell diving. In later years bell divers in Europe are mainly educated in the French National Institute in Marseilles. Here, 40-50 bell divers receive their education each year.

For diving in the Norwegian sector requirements for personnel qualification are specified in the NORSOK standard, Ref. /1/. The standard includes requirements for diving competence for:

- Diving Superintendent
- Diving Supervisor
- Life Support Supervisor and Life Support Technician
- Nurse
- Divers.

The divers are required to have certificates issued by the authorities in Norway or the UK, documenting education from approved schools and according to specific requirements which differentiate between saturation diving and surface-oriented diving. Divers with diving certificates issued prior to 1988 were granted dispensation from this requirement (Ref. /1/) and received certificates based on experience. NOU 2003:5 (Ref. /3/) reports that nearly 80 % of divers operating in the Norwegian sector in the pioneer period were educated at diving schools. All divers are required to have a valid certificate of medical fitness to dive, issued by a qualified doctor. The certificate is valid for a maximum of twelve months.

Supervisory personnel were also certified from about 1987, initially based on an IMCA standard adopted by NPD and later amended and incorporated into the NORSOK standard. A small number of training establishments has been authorized to provide courses for such personnel. The courses are followed by so called "on the job training" meaning that the trainee has to document a specified number of hours or days performing different activities. Certification of supervisory personnel is at present performed by IMCA, which will arrange examinations upon request.

3.7 International Industry

The diving industry today is an international industry where both diving vessels and divers are alternating between the Norwegian, the Danish, the UK and the Dutch sector as well as elsewhere in the world. The activity level in the Norwegian Sector is at present too low to sustain continuous operation of even one diving vessel. Therefore the Norwegian oil industry relies heavily on the international diving industry and in particular on the UK activity level in securing the availability of diving resources at large.

3.8 Development

A rapid development in diving methods, procedures and equipment took place during the pioneer period. In particular developments were significant in the period between 1982 and 1988 when several deepwater pipelines were built in Norwegian waters. From 1993, when the diving activity decreased rapidly in the Norwegian sector, the operational mode has been relatively stable. Improvements since 1990 have largely been related to stricter decompression procedures, implementation of safety management systems and safety assessment procedures and requirements for follow-up of health aspects for the divers.

3.9 Competence and Research

Diving activity is considered to be complex in nature providing a challenging environment to the diver. Despite considerable research and progress related to diving medicine, diving equipment, diving methods and diving procedures, both in Norway and internationally, the scientific foundation on which diving is based is still considered insufficient. Consequently it is recommended to further develop the scientific platform in cooperation with other branches of expertise (Ref. /11/).

Diving operations in connection with the petroleum industry have been the driving force for developments within the diving industry. Operational requirements with regards to depth and complexity have been rapidly increasing. This has been a challenge w.r.t. to developing sufficient competence as well as establishing sufficient suitable regulations for the activity.

3.10 Regulations

In 1974 the first diving rules in UK came into force. These rules were updated in 1977 and applied as guidance in the Norwegian sector until the NPD provisional diving rules came into force in 1978. The provisional rules were replaced by new regulations for manned underwater operations in 1991.

In 1991 a new common standard for decompression came into force in the Norwegian sector. This standard removed the use of decompression tables as an important competitive element in the industry and is considered to be a milestone improvement that is still valid. In 1993 the "Act of 4th February 1977 relating to worker protection and worker environment" came into force for divers in the Norwegian Sector.

The regulations relevant in the Norwegian Sector are described in greater detail in Chapter 8.2 of this report.

4. DIVING STATISTICS

4.1 Introduction

In this chapter factual information was collected and analyzed in order to quantify - to the best possible degree - the risk in connection with diving offshore, both in Norway (Chapter 4.2) and the UK (Chapter 4.4). Even though the main interest was on the present level of risk, the historical development is also important in order to understand the influence of factors determining the risk level. Therefore, data as far back as 1975 were included. Where possible, a distinction was made between saturation diving and surface related diving data, but not all sources of data make this distinction. For purposes of comparison, a short chapter (Chapter 4.3) with data from Norwegian inshore diving was also included. A discussion and summing up of the data is presented in Chapter 4.5.

The best statistical data are available for immediate effects (death, decompression illness, other injuries, near misses) which occur during or shortly after diving. But since serious long-term effects are a very important part of the risk picture some of the more important results in this area are presented in Chapters 4.6. Since suicide rate may be an indicator for the state of health and quality of life in general, also a review of known data on this aspect has been included in Chapter 4.7.

4.2 Norwegian Offshore Diving Statistics

4.2.1 Tabular Raw Data

The main source for Norwegian offshore diving statistics is the diving database DSYS established by the Norwegian Petroleum Directorate (NPD) in 1985. The data base contains information spanning from 1978 to the present day, but the data before 1985 are considered uncertain. A compilation of the data for 1985 to 2001 was published in 2002 Ref. /13/. Data for 2002 and 2003 were obtained from Ref. /14/. For the period up to and including 1986 data from NPD's Annual Report for 1990 were utilized, Ref. /15/. This annual report contains data back to 1978. Also before 1978 there have been some fatal diving accidents in the Norwegian Sector, as described in NOU 2003:5, Ref. /3/. The report contains (page 122, table 4.1) information on

- 1 fatal accident in 1967 (bounce dive)
- 2 fatal accidents in 1971 (1 bounce, 1 surface-oriented dive)
- 3 accidents resulting in 4 fatalities in 1974 (all bounce dives)
- 2 fatal accidents in 1975 (1 bounce, 1 saturation dive)
  (Information on type of dive from Ref. /16/).

The report, however, gives no information on the activity level or exposure in these years (number of hours in saturation). An estimate of activity level was obtained from Figure 4.1 in the book "Safety in Manned Diving", Ref. /17/. Using the curve there and the known exposure of 120,000 saturation man-hours in 1978 (Ref. /15/) the man-hours for 1975, 1976 and 1977 were estimated.

Numerical results extracted from the mentioned sources are given in Table 4.1 (saturation diving) and Table 4.2 (surface-oriented diving). The tables contain information on

- number of man-hours in saturation or in the water
- number of fatalities
- number of decompression illnesses (DCI)
- number of non-DCI injuries
- number of near misses.

Decompression illness (DCI) is a set of defined symptoms experienced by the diver during or right after completion of decompression, and confirmed by the diving physician as DCI.

The two last points are defined in Ref. /13/ as:

- **Non-DCI injury**: Any accident/incident which requires medical treatment, first aid or which entails absence from work into the next 12-hour shift, but excluding DCI cases
- **Near miss**: A near miss is a dangerous situation which could have been fatal or led to serious personal injury.

NOU 2003:5 (Ref. /3/) also contains information on 42 fatal accidents for which the available information is so uncertain that they are not included in our tables here. Only one of the 42 uncertain fatal accidents was in the Norwegian sector, in February 1967, at 40 m depth, during SCUBA diving.

Table 4.1: Number of Incidents for Saturation Diving, Norwegian Sector (Ref. /3/ and /13/ - /18/)

Year	Number of man-hours in saturation	Number of fatalities	Number of decompr. illness	Number of non-DCI injuries	Number of near misses
1975	70900	1 (sat.) 1)	Not known	Not known	Not known
1976	81800		Not known	Not known	Not known
1977	98200		Not known	Not known	Not known
1978	120000	1 (sat.) 2)	54	50	Not known
1979	180000		40	38	Not known
1980	145000		15	19	Not known
1981	175000		9	14	Not known
1982	165000		11	9	Not known
1983	267841	4 (sat.)	10	24	Not known
1984	386136		10	30	Not known
1985	206145		4 3)	31	Not known
1986	182573		4 3)	24	Not known
1987	202982	1 (sat.)	2	28	19
1988	157110		6	18	14
1989	207569		7	21	8
1990	167431		1	30	18
1991	172018			35	22
1992	177752			49	19
1993	165138		2	20	14

Year	Number of man-hours in saturation	Number of fatalities	Number of decompr. illness	Number of non-DCI injuries	Number of near misses
1994	88303			26	2
1995	45872			9	1
1996	28670			11	6
1997	101606			14	19
1998	80275			26	2
1999	57339			9	4
2000	58257			12	8
2001	73394			20	3
2002	12426		1	3	0
2003	38229			10	1

1) There was also one fatality in 1975 reported to occur during surface diving, info from Einar Wold Svensen in meeting 17.02.2004
2) The fatality in 1978 occurred in an inshore test dive to 320 msw, info from Olav Hauso, telephone 08.03.2004
3) The 4 incidents of DCI in 1985 and 1986 are according to Ref. /15/. According to Ref. /13/ the number is 2

Table 4.2: Number of Incidents for Surface-oriented Diving, Norwegian Sector (Ref. /13/)

Year	Number of man-hours in water	Number of fatalities	Number of decompr. illness	Number of non-DCI injuries	Number of near misses
1987	4774		2	4	7
1988	3322		2	5	3
1989	2858		2	4	2
1990	2704		2	2	2
1991	2060		1	3	
1992	4069			6	2
1993	1236			4	
1994	567			2	1
1995	206				
1996	77				1
1997	525			1	
1998	258			4	
1999	386		1 [1)]	2	
2000	52				
2001	52				
2002	0				
2003	25				

1) May be a case of DCI experienced in German sector, Ref. /18/

4.2.2 Graphical Presentation: Saturation Diving, Yearly Averages

A graphical presentation of the data in Table 4.1 for offshore saturation diving is shown in Figure 4.1 to Figure 4.5. The figures show for each year

- the number of incidents (yellow bars)
- the exposure, as the number of man-hours in saturation (red curve, right hand scale)
- the frequency, as the number of incidents divided by the exposure (blue curve, left hand scale).

Frequencies are expressed as incidents per 100 million man-hours in saturation in order to obtain numerical values which are familiar in risk analysis work. For example, the number of fatalities per 100 million work hours is called FAR, fatal accident rate.

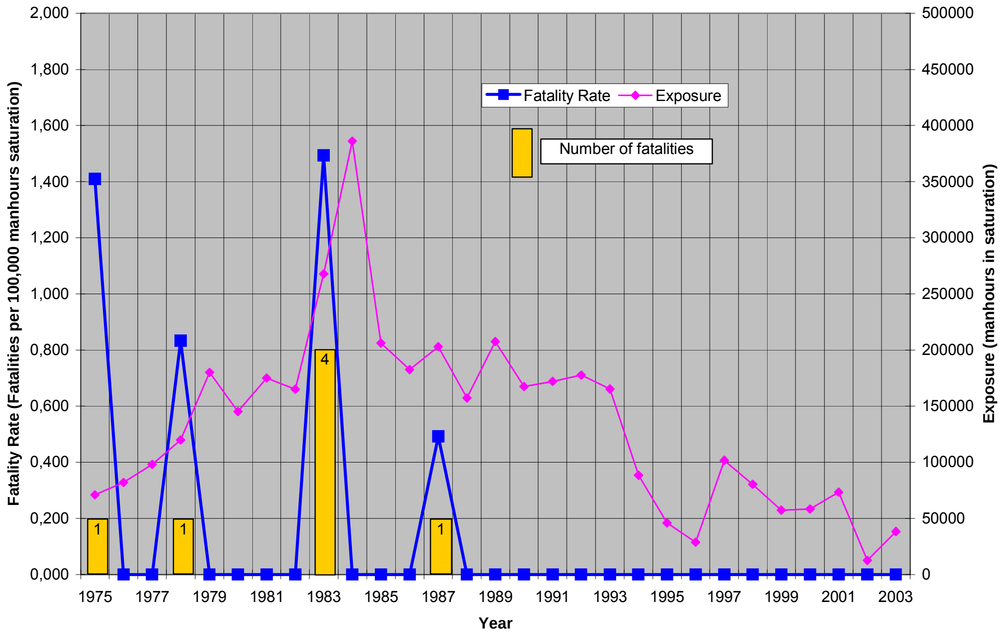


Figure 4.1: Fatality Frequencies for Saturation Diving, Yearly Averages

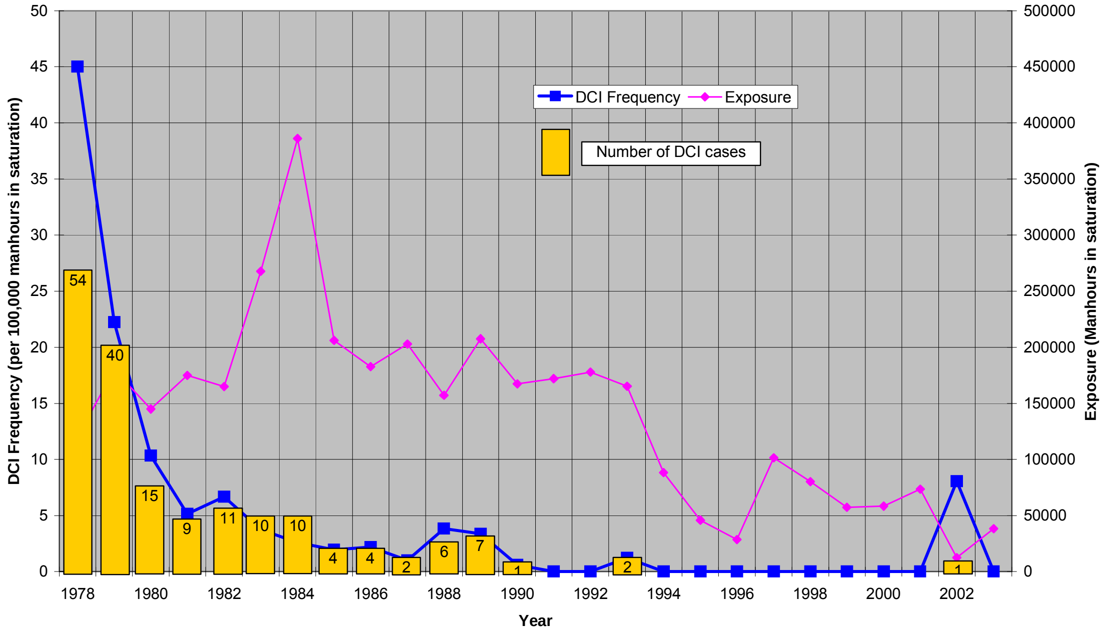


Figure 4.2: Decompression Illness (DCI) Frequencies for Saturation Diving, Yearly Averages

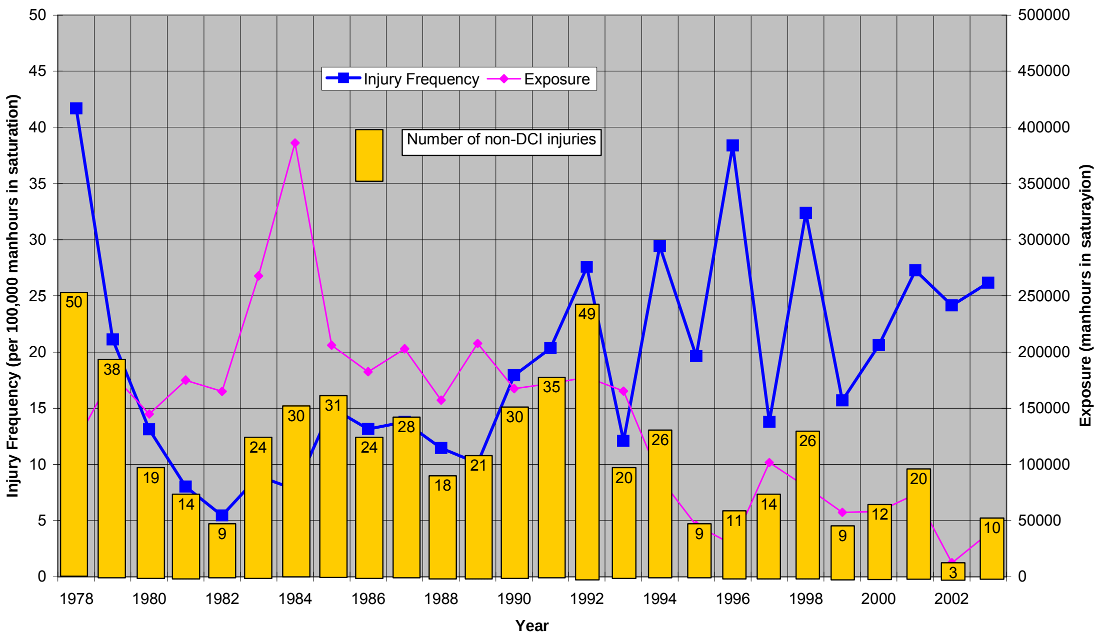


Figure 4.3: Non-DCI Injury Frequencies for Saturation Diving, Yearly Averages

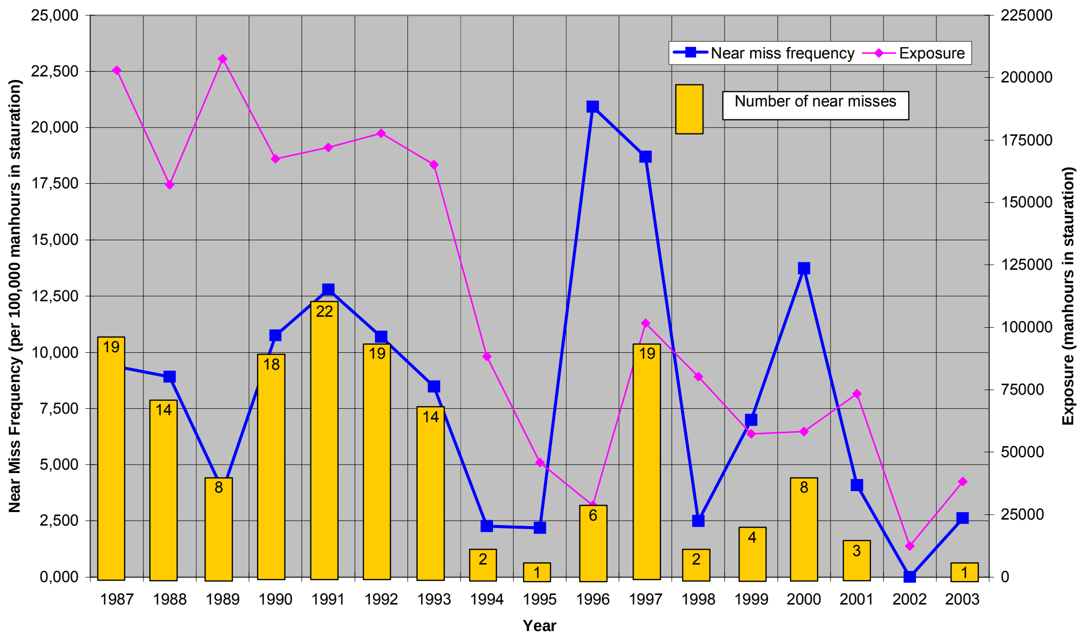


Figure 4.4: Near Miss Frequencies for Saturation Diving, Yearly Averages

4.2.3 Graphical Presentation: Offshore Surface-oriented Diving, Yearly Averages

Figure 4.5 and Figure 4.6 show the results for surface-oriented diving. (No fatalities recorded for surface oriented diving).

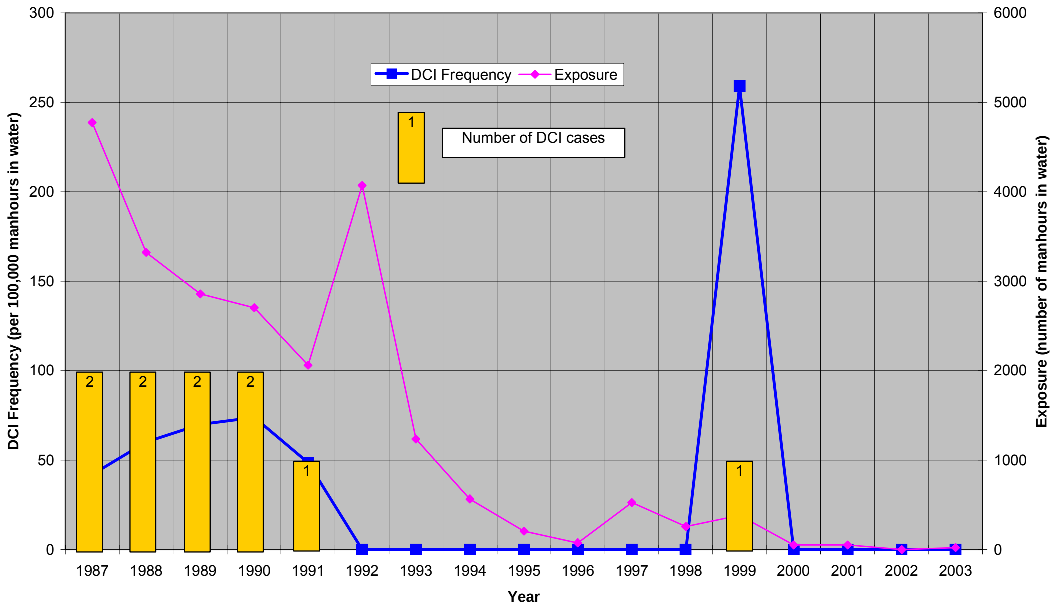


Figure 4.5: Decompression Illness (DCI) Frequencies for Offshore Surface-oriented Diving, Yearly Averages

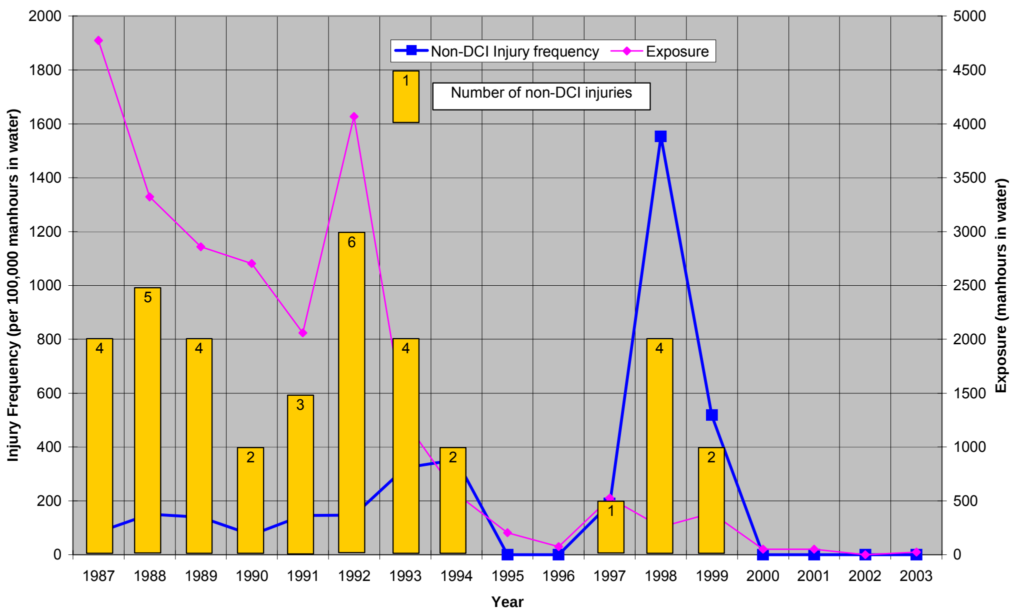


Figure 4.6: Non-DCI Injury Frequencies for Offshore Surface-oriented Diving, Yearly Averages

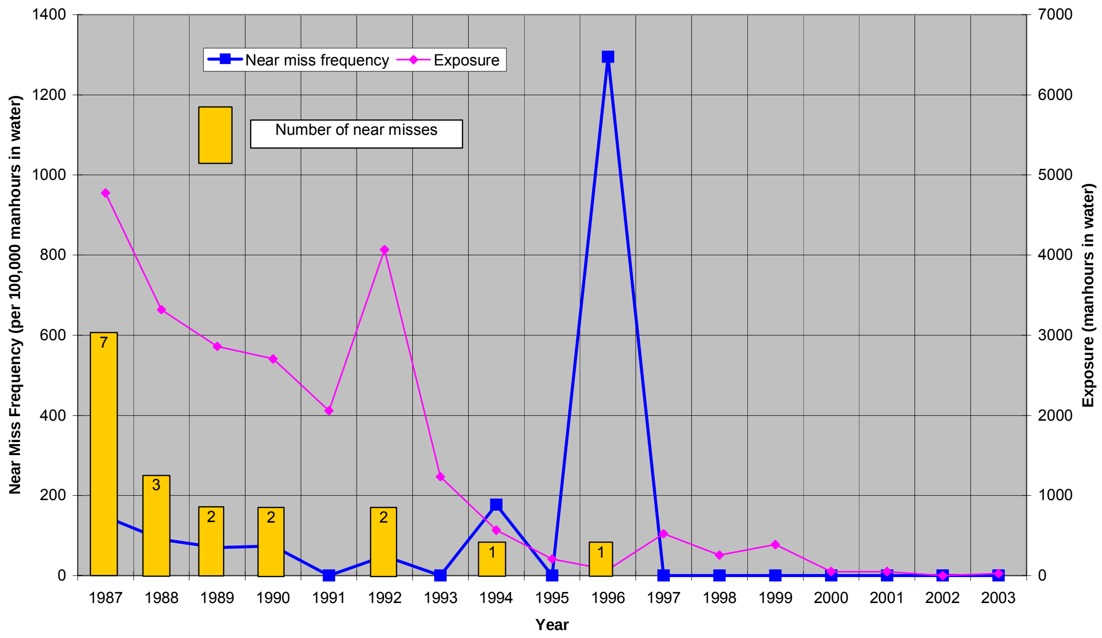


Figure 4.7: Near Miss Frequencies for Offshore Surface-oriented Diving, Yearly Averages

4.2.4 Graphical Presentation: Saturation Diving, 5 Year Moving Averages

Yearly averages are not the best way to show the results, for all purposes. There are many years with no or very few incidents. In this case it is justified to calculate means over more than one year in order to smooth out fluctuations and to show trends more clearly. In the following Figure 4.8 to Figure 4.11 5-year moving averages are shown for saturation diving. Note that the number of incidents is the sum for the whole 5-year period so that a single incident can occur in up to five different time intervals.

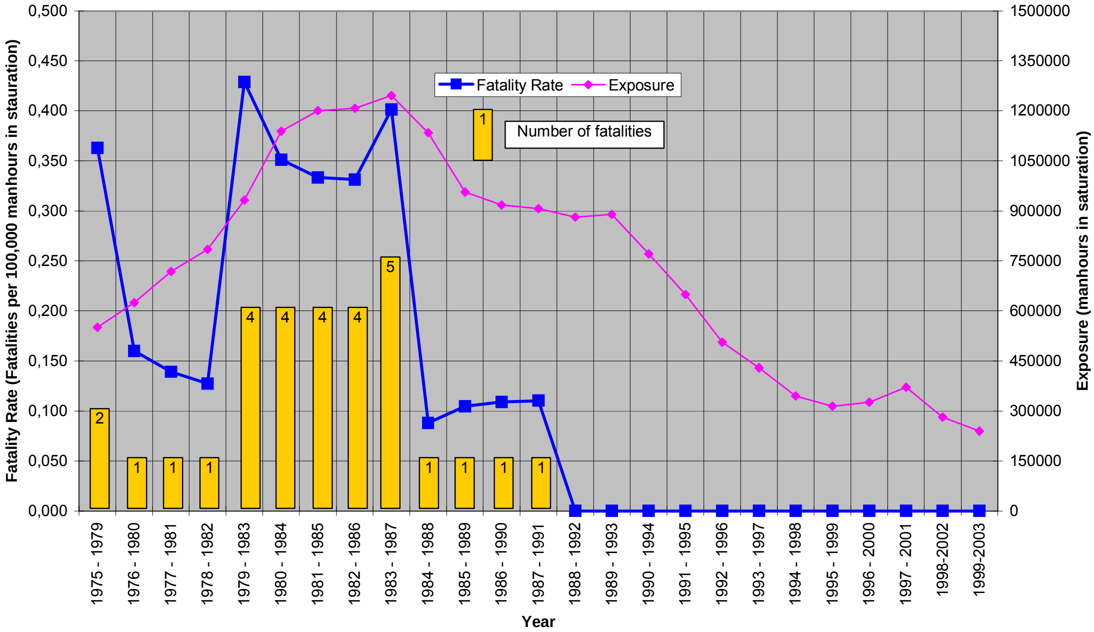


Figure 4.8: Fatality Frequencies for Saturation Diving, 5-Year Moving Averages

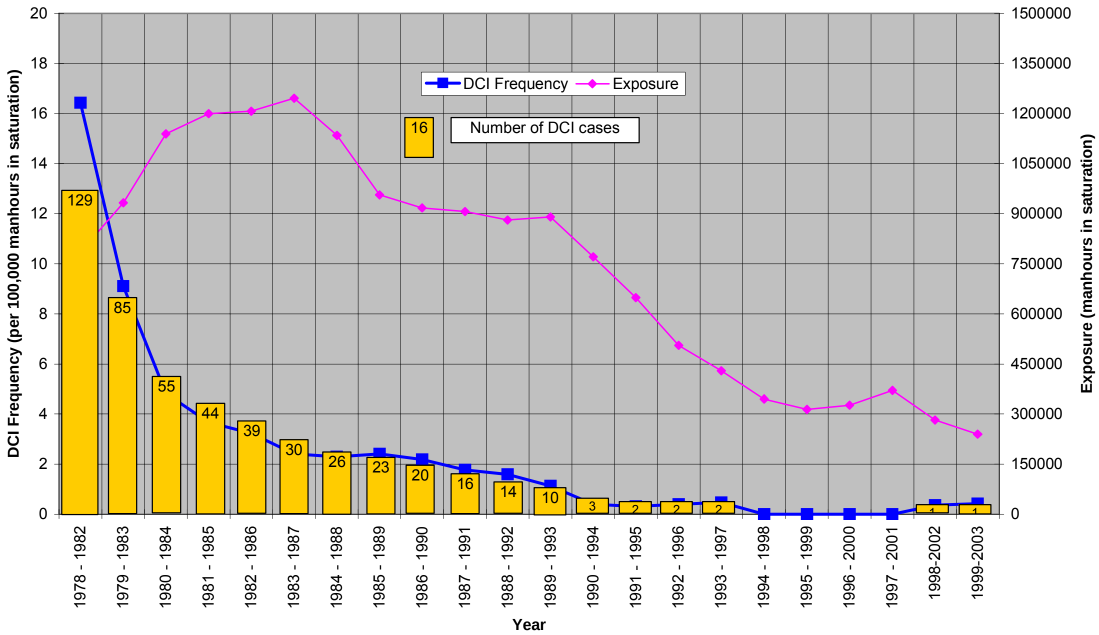


Figure 4.9: Decompression Illness (DCI) Frequencies for Saturation Diving, 5-Year Moving Averages

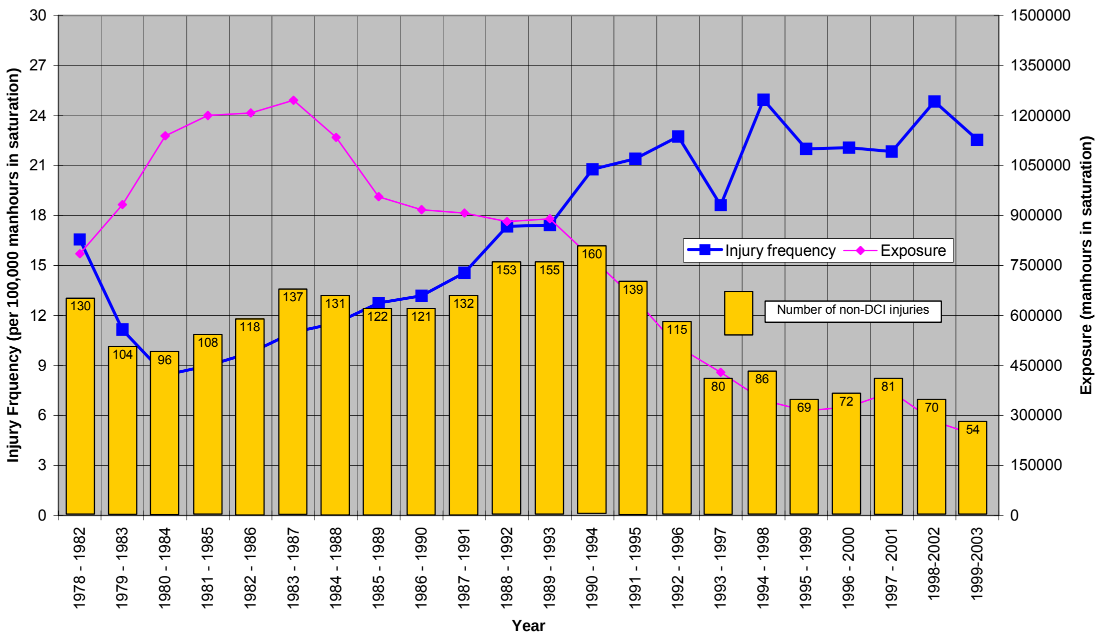


Figure 4.10: Non-DCI Injury Frequencies for Saturation Diving, 5-Year Moving Averages

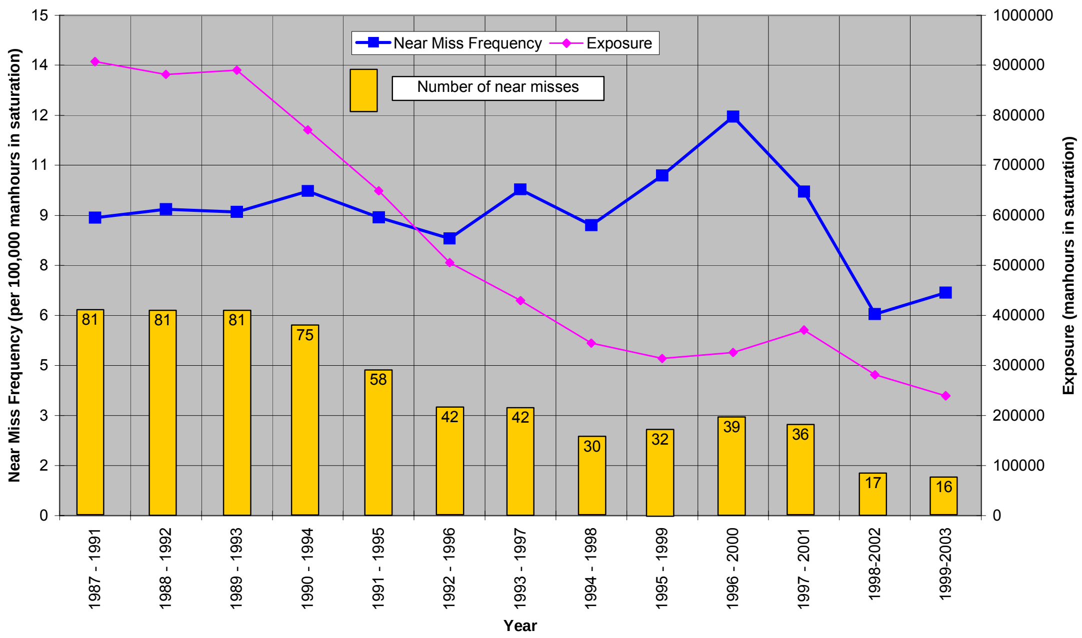


Figure 4.11: Near Miss Frequencies for Saturation Diving, 5-Year Moving Averages

4.2.5 Graphical Presentation: Saturation Diving, 10 Year Moving Averages

Figure 4.12 shows the 10-year averages for fatalities. The corresponding curves for decompression illness, non-DCI injuries and near misses are rather similar to the 5-year average curves.

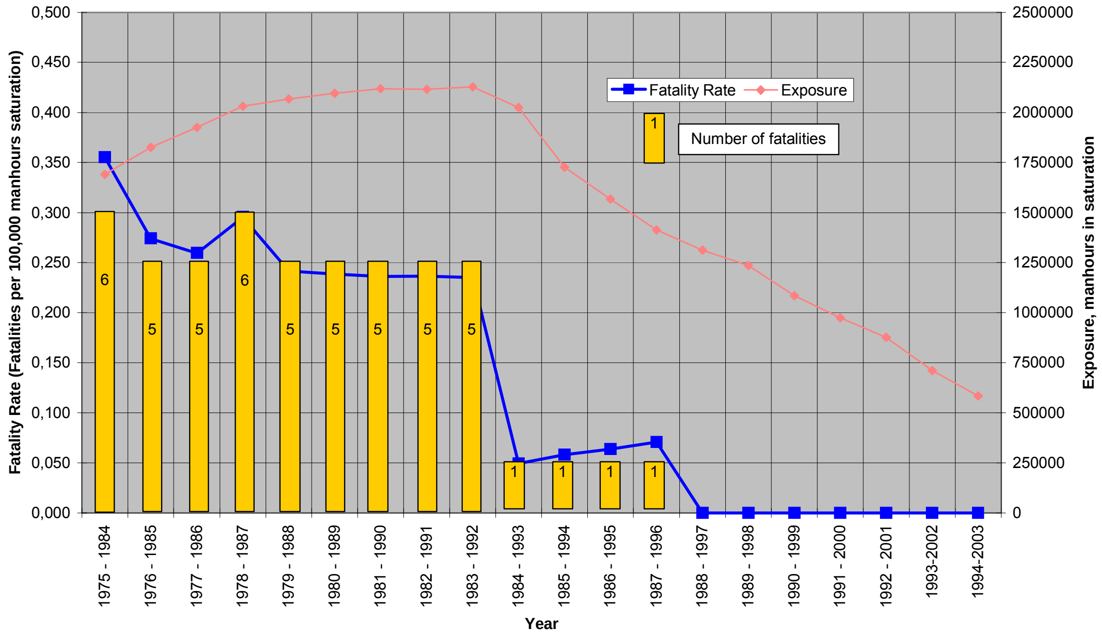


Figure 4.12: Fatality Frequencies for Saturation Diving,10-Year Moving Averages

4.2.6 Statistical Risk Predictions

The historical data presented above can be used to make predictions on the present risk level of diving, assuming that the operational mode at present is the same as in the time period from which the data were taken. Such predictions are uncertain due to the limited statistical data on which they are based. The smaller the number of incidents and the exposure (number of man-hours), the larger is the statistical uncertainty. Lower and upper 90 % confidence limits can be obtained using the χ^2-distribution method. This method can even be used if no incident has occurred at all in the time period in question, but in this case only a 1-sided upper estimate is given, meaning that the expected value is smaller than this estimate, with a probability of 90 %.

The statistical calculations were performed on the spreadsheets contained in Appendix A. The same spreadsheets were also used for preparing the graphical presentations shown above.

Table 4.3 and Table 4.4 show the results from the statistical prediction.

Table 4.3: Risk Predictions for Offshore Saturation Diving, Based on Different Averaging Intervals, Last Available Time Period

Incident type	Averaging interval		FAR (fatalities per 100 million man-hours in saturation)		
	No. of years	From - to	Lower 90 %	Mean	Upper 90 %
Fatalities	1	2003	-	-	6023
	5	1999-2003	-	-	961
	10	1994-2003	-	-	394
Decompression Illness	1	2003	-	-	6023
	5	1999-2003	21	417	1980
	10	1994-2003	9	171	812
Non-DCI injuries	1	2003	14192	26158	44370
	5	1999-2003	17738	22533	28267
	10	1994-2003	20727	23957	27565
Near Misses	1	2003	134	2616	12409
	5	1999-2003	4188	6677	10140
	10	1994-2003	6065	7872	10065

Table 4.4: Risk Predictions for Offshore Surface Oriented Diving, Based on Different Averaging Intervals, Last Available Time Period

Incident type	Averaging interval		Frequencies (per 100 million man-hours in the water)		
	No. of years	From - to	Lower 90 %	Mean	Upper 90 %
Fatalities	1	2003	-	-	9210352
	5	1999-2003	-	-	446439
	10	1994-2003	-	-	107178
Decompression illness	1	2003	-	-	9210352
	5	1999-2003	9945	193886	1220662
	10	1994-2003	2388	66547	220811
Non-DCI injuries	1	2003	-	-	9210352
	5	1999-2003	68900	387771	1220662
	10	1994-2003	218547	418919	731024
Near Misses	1	2003	-	-	9210352
	5	1999-2003	-	-	446439
	10	1994-2003	16541	93093	293047

For understanding the historical development of diving risk it is also useful to look at the non-overlapping 5-year averages, see Table 4.5.

Table 4.5: Historically Observed Event Rates for Saturation Diving (Non-overlapping 5 Year Periods)

Time period	Number of man-hours in saturation	Number of fatalities during diving	Observed fatal accident rate 1)	Number of decompression illnesses	Observed rate of decompression illness 1)	Number of near misses	Observed rate of near misses 1)
1974 - 1978	431,000	2	0.46	Unknown	-	Unknown	-
1979 - 1983	933,000	4	0.43	85	9.1	Unknown	-
1984 - 1988	1,135,000	1	0.09	26	2.3	Unknown	-
1989 - 1993	890,000	0	0	10	1.1	81	9.1
1994 - 1998	345,000	0	0	0	0	30	8.7
1999 - 2003	240,000	0	0	1	0.4	16	6.7

1) Number per 100,000 man-hours in saturation

4.3 Norwegian Inshore Diving Statistics

Even though this study was concerned with offshore diving, there was also a certain interest to look into inshore diving since there is a considerable amount of inshore diving activity, and lessons can be learned from this type of diving concerning risk influencing factors and the resulting overall risk level.

Norwegian inshore diving has been under the jurisdiction of the Norwegian Labor Directorate. They also receive the official reports on any incidents, accidents or fatalities, but they have - so far - not prepared a statistical analysis of these data. An unofficial statistical analysis has however been prepared by Norsk Undervannsintervensjon AS (NUI), Ref. /19/. This analysis contains data on fatalities and decompresssion illness for professional dives in the period 1990 to 2003. (It also contains data on recreational dives, but this was not treated in this study). Incident data are presented in Table 4.6.

Table 4.6: Number of Incidents for Diving Inshore in Norway (Ref. /19/)

Year	Number of fatalities	Number of decompression illness
1990	1	12
1991	1	8
1992	0	13
1993	0	6
1994	1	5
1995	0	3
1996	0	10
1997	0	5
1998	0	3
1999	1	0
2000	0	4
2001	0	4
2002	0	Not known
2003	1	Not known

Concerning the amount of diving, Ref. /19/, concludes that approximately 30,000 dives are carried out per year by inshore professional divers. For the 10-year period 1992 - 2003 this results in the following rates:

Fatalities: 3/300,000 = $1.0 \cdot 10^{-5}$ per dive
DCI: 53/300,000 = $1.8 \cdot 10^{-4}$ per dive

The average number of dives per diver year is given as 69 in Ref. /19/. However, a figure of 150 dives per year is more appropriate for full-time professional divers. With this we can calculate the yearly risk as

Fatalities: $1.5 \cdot 10^{-3}$ per year
Decompression illness: $2.7 \cdot 10^{-2}$ per year

In Chapter 4.2 we have also calculated rates per hour, either per hour in saturation, or per hour in the water. In order to get comparable results for inshore diving we assume an average duration per dive of 2 - 3 hours (uncertain estimate). This results in the following hourly rates:

Fatalities: $1 \cdot 10^{-5} / 2.5 = 4 \cdot 10^{-6}$ per hour in the water
Decompression illness: $1.8 \cdot 10^{-4} / 2.5 = 7.2 \cdot 10^{-5}$ per hour in the water

Or expressed per 100 million hours in the water:

Fatalities: 400 per 100 million hours in the water
Decompression illness: 7,200 per 100 million hour in the water

There is also some information on the type of inshore diving, namely

SCUBA diving	34.2 %
Surface-oriented diving	39.5 %
Helmet diving	19.7 %
Gas-mix diving	0.4 %
OD-O_2 diving	6.2 %

The distribution of the incidents for the different diving types is not known. But the figure of 7,200 decompression illnesses per 100 million hours in the water is much smaller than the figure of 66,547 per 100 million hours in the water found for the 10-year average of offshore surface-oriented diving. Please note that if we assume an average duration per dive of 1.25 hour instead of 2.5 hour the figure will increase from 7,200 to 14,400 decompression illnesses per 100 million hours in water for inshore diving.

4.4 UK Offshore Diving Statistics

In the UK relevant statistical material is not as easily available as in Norway. Data on the diver population and the number of deaths for Northern Europe and for the UK Sector were obtained from the HSE for 1971-1985, Ref. /20/. Exposure data for 1986-1990 were found in a report from the Loughborough University of Technology, Ref. /21/. Detailed exposure data have been obtained from The International Marine Contractors Association (IMCA), Ref. /22/, but only for one year (2000).

The data obtained are shown in Table 4.7.

Table 4.7: Fatalities 1980 - 2001 According to HSE (Ref. /20/)

Year	Northern Europe		British Sector		
	Number of divers	Number of fatalities	Number of divers	Number of fatalities total	Number of fatalities saturation 2)
1971	200	3	100	1	1
1972	300	1	200	1	1
1973	400	2	300	2	1
1974	800	10	500	5	4
1975	1000	9	600	6	6
1976	1500	9	800	9	6
1977	2000	5	1000	3	2
1978	2200	3	1500	2	2
1979	2300	3	1400	3	2
1980	2000	0	1000	0	0
1981	2100	0	1100	0	0
1982	2200	1	1300	1	0
1983	2400	7	1400	1	0
1984	Not known	1	1344	1	0
1985	2362	0	1398	0	0
1986		Not known	1065 4)	0	0
1987		Not known	1013	0	0
1988		Not known	1026	0	0
1989		Not known	927	0	0
1990		Not known	896	0	0
1991		Not known	921 5)	0	0
1992		Not known	951	0	0
1993		Not known	884	0	0
1994		Not known	799	0	0
1995		Not known	714	1	1
1996		Not known	629	1	1
1997		Not known	544	0	0
1998		Not known	430	0	0
1999		Not known	307	1	1
2000	519+270 1)	Not known	400 3)	0	0
2001		Not known	393 7)	1	0 6)
2002		Not known	390 7)	0	0
2003			380 7)	0 8)	0 8)

1) The number of divers for 2000 (519 sat., 270 surface) was taken from IMCA, Ref. /22/
2) Surface-oriented diving fatalities were subtracted from the total based on Ref. /20/ and /23/. The figures up to 1975 are mostly bounce diving
3) UK number of divers assumed to be ½ of Northern Europe divers, see ratio for 1980 to1985
4) Numbers for 1986 - 1990 obtained from Ref. /21/
5) Numbers for 1991 and later obtained from 1990 number, and assuming similar decrease as in Norway, see Table 4.1
6) There was one fatality in 2001 due to cerebral hemorrhage after 6 days of unconsciousness, following an 80 m dive. Not considered diving related and therefore omitted
7) Number of divers for 2001, 2002 and 2003 based on number for 2000, assuming slight decrease
8) Zero fatalities in 2003, Ref. /24/

As one can see, many of the exposure figures had to be obtained by assumptions and extrapolations. They are therefore rather uncertain.

For the UK sector and the period 1976 to 2003 (1971-1975 excluded because of bounce diving) the number of fatalities from saturation diving was 15, and the number of diver years 24,010. Of the diver years 2/3 or 16,007 (same ratio as for 2000) are assumed to be saturation divers. This gives a yearly fatality risk for saturation divers of

$$15/16{,}007 = 9.4 \cdot 10^{-4} \text{ per year}$$

From the IMCA report, Ref. /22/, we know that, for year 2000, the average number of days in saturation for the saturation divers was 69.3 days. If we assume that each saturation diver spends on the average 70 days per year in saturation we can calculate the number of man-hours in saturation from the number of diver years. With all these - uncertain - assumptions we can obtain the 10-year moving average of FAR as shown in Figure 4.13.

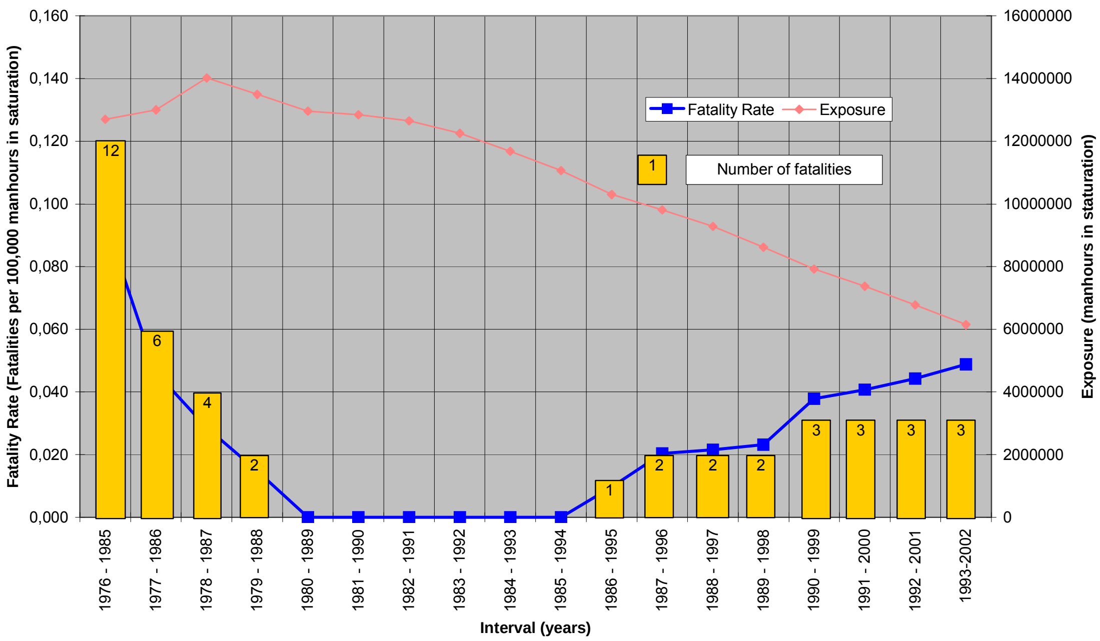


Figure 4.13: Fatality Frequencies for Saturation Diving, UK Sector, 10-Year Moving Averages

The reason for the relatively low FAR for the time period 1980 -1990 is at present not fully understood. New regulations and increased focus on safety matters after the poor performance in the years up to the mid-eighties may be a contributing factor, Ref. /25/.

On the basis of the data in Table 4.7 and the assumptions concerning man-hours in saturation one can again make a prediction on the present, expected risk level by using the χ^2-distribution method. The results are shown in Table 4.8.

Table 4.8: Risk Predictions for Saturation Diving, UK Sector, Based on Different Averaging Intervals, Last Available Time Period

Incident type	Averaging interval		FAR (fatalities per 100 million man-hours in saturation)		
	No. of years	From - to	Lower 90 %	Mean	Upper 90 %
Fatalities	1	2003	-	-	541
	5	1999-2003	2	48	227
	10	1994-2003	15	54	139

For understanding the historical development of diving risk it is also useful to look at the non-overlapping 5 year averages, see Table 4.9.

Table 4.9: Historically Observed Fatal Accident Rate for Saturation Diving, UK Sector (Non-overlapping 5 Year Periods)

Time period	Observed fatal accident rate [1)]
1974 - 1978	0.51
1979 - 1983	0.03
1984 - 1988	0
1989 - 1993	0
1994 - 1998	0.06
1999 - 2003	0.05

1) Number per 100,000 man-hours in saturation

As mentioned before, there is considerable uncertainty concerning the exposure (man-hours in saturation) for the UK sector. As a sensitivity test, the FAR values were also calculated for exposures which are 25 % lower and 25 % higher than the "best estimates" used above. For the 10-year average this results in the following lower/mean/ upper values:

25 % lower:	20	-	72	-	185
25 % higher:	12	-	43	-	111

Taking into account also this uncertainty the overall uncertainty interval increases roughly to

12 - 54 - 185

(No 90 % uncertainty interval can be given without knowing the probability distribution of the exposure estimate)

There are two known cases of fatalities directly related to diving accidents which are not included in Table 4.7. In both cases the divers were paralyzed (Ref. /26/). One died 18 months after the accident as a direct consequence of being paralyzed from the neck down, the other committed suicide.

Other fatalities which are not included are cases where a diver fell ill while under decompression and died due to the fact that medical assistance could not be given to the same extent which would have been possible under normal circumstances. These cases are defined as non-diving related illness and are not included in the statistics, therefore.

4.5 Discussion and Summary of Immediate Diving Risk

4.5.1 Fatal Accident Rate (FAR)

Traditionally, focus in diving risk analysis has been on Fatal Accident Rate (FAR). FAR has the advantage that the incident is clearly defined (a person is dead), and that underreporting is rarely a problem. This is not the case for other risk indicators such as number of injuries or number of near misses where the definition of the incident to be reported is not so clear and may vary, depending on the practice in the reporting company.

The disadvantage of FAR as a risk measure is, from a statistician's point of view, that the number of incidents per year is so small. This leads to large uncertainties which make it necessary to calculate averages over large time intervals (5, 10 or 15 years). This tends to "smear out" variations in time and to make it difficult to see historical developments and trends.

Even with large averaging periods of 10 or 15 years there will be periods with zero fatalities. Statistically, this problem can be tackled in two ways:

- Calculating a 90 % upper limit value: one can only state that FAR is less than this upper limit value with a probability of 90 %, or
- Assuming that one fatality would have occurred in a time interval twice as long. In this case a lower and upper limit of the 90 % interval can be calculated, together with a mean FAR.

Obviously, the uncertainties become very large and it can be discussed how the resulting FAR-values are to be interpreted and used in risk management.

Due to the much higher diving activity in the UK sector as compared to Norway (a factor of 6-10 higher) the data from the UK are statistically much more reliable. It should be noted that the zero FAR-value for Norway in the later years would jump to 170 (10-year average) if just one fatal accident occurred, given the low activity in the last 10-year period.

We believe that the most appropriate FAR estimate should be based on a combination of UK and Norwegian data for 1990 - 2003 for saturation diving. This was judged appropriate since the new Norwegian diving regulations were issued in June 1990 and the "Pioneer Period" came to an end. Also, operations in the British Sector and the Norwegian Sector are comparable and the way of operation has not changed considerably in this time period. Although some people claim there are stricter requirements and closer follow up by clients and authorities of diving operations in the Norwegian Sector compared to the British Sector, it was not found appropriate to give credit for this in terms of a lower fatality rate estimate. More detailed evaluations are required to substantiate such a difference. On this basis we obtain for the period 1990 to 2003:

Exposure:	9,673,669 + 1,266,710 =	10,940,379 man-hours in saturation
Fatalities:	3 + 0 =	3
FAR:	$3/10,940,379)\cdot 10^8$ =	27 (90 % conf. interval: 7 - 71)

A FAR-value of 27 might be considered unreasonable when looking at the period 1990 to 2003 on the Norwegian sector, without a single fatality. On the other hand one can calculate the probability for not having a single fatality in this period, given FAR = 27. The diving exposure for the period is 1,266,710 hours in saturation and the probability to survive this exposure without fatality is

$$P = (1 - 27\cdot 10^{-8})^{1,266,710} = 0.71 = 71\ \%$$

This shows that the actual outcome of zero fatalities has a reasonably high probability with FAR = 27. In fact, the outcome of zero fatalities has a higher probability than the outcome of one or more fatalities (29 %).

The exposure of 9,673,669 man-hours in saturation for diving in the British Sector was obtained from Table 4.7 and the rather uncertain assumptions listed in Chapter 4.4. The British exposure is a factor 7.6 higher than the Norwegian exposure in the same time period (1,266,710 man-hours in saturation). Comments were received from the diving industry (Ref. /27/) that the British exposure is more than a factor 7.6 higher than the Norwegian exposure. A higher British exposure, for example a factor 10, would result in a lower FAR value.

For inshore diving the best available FAR estimate was based on unofficial statistics for the period 1990 - 2003, see Chapter 4.3. A FAR value of 400 has been estimated. It must be noted that this value is relevant for the number of hours in water and, as such, should not be compared to the FAR value for saturation diving which is per hour in saturation.

For surface oriented offshore diving no FAR value can be predicted on the basis of the available data, only a 90 % upper limit estimate, see Table 4.4.

4.5.2 Individual Risk per Annum (IRPA)

The individual fatal risk per annum can be obtained from the hourly risk (FAR) by making assumptions on the number of hours in saturation (saturation diving) and the number of hours in the water (inshore diving) for the average, full-time professional diver. The following assumptions are considered reasonable:

- Saturation diving: 24 hours for 80 days = 1,920 hours
- Inshore diving: 150 dives for 2.5 hours = 375 hours

With this the following IRPA-values are obtained for fatalities:

- Saturation diving: $1920 \times 27\cdot 10^{-8} = 0.0005$ per year
- Inshore diving: $375 \times 400\cdot 10^{-8} = 0.0015$ per year

4.5.3 Other Fatal Risk Indicators

Other risk indicators than FAR might be more suitable for day-to-day risk control because of their higher frequency of occurrence and - hence - their lower statistical uncertainty. In the Norwegian system of incident reporting to the NPD three other risk indicators are available:

- Cases of decompression illnesses per 100,000 hours in saturation
- Non-DCI injuries per 100,000 hours in saturation
- Near misses per 100,000 hours in saturation.

The number of cases of decompression illness is also so low that it is not very suitable for risk control. For non-DCI injuries and near misses 5-year averages are statistically best suited. The latest available 5-year averages (rounded) are:

- Non-DCI injuries: 22.5 per 100,000 hours in saturation
- Near misses: 6.7 per 100,000 hours in saturation

These values should be monitored continuously and compared to established risk acceptance criteria. When values are close to or exceeding the acceptance criteria, risk-reducing measures should be implemented. It should be remembered that non-DCI injuries also include any first aid treatment and ear infections. The latter constitute approximately 50 % of all non-DCI injuries.

4.6 Serious Long-Term Effects

4.6.1 Introduction

Until now we have summarized and analyzed effects which occur during diving or immediately thereafter, and for which the cause is quite obvious. The question of causation i.e. whether diving really is the cause of the observed effect or not, was therefore not a matter of discussion. This is quite different for long-term effects. There is an ongoing controversy in the diving community and among the scientific experts about whether, and to which degree, diving is the cause of detrimental health effects such as:

- Damage of the central nervous system (CNS)
- Mental disturbances
- Post-traumatic stress disorder (PTSD)
- Lung damage
- Toxic/chemical effects from pollution.

The symptoms can occur many years after the end of the diving activity. Such long-term effects can be very serious and lead to the loss of the diving license, to partial or complete disablement and, as a consequence, to loss of the possibility to compete for diving tasks, which in turn may lead to financial problems and possibly to depressions, suicide or other.

There is a vast amount of literature on the subject, but many of the studies performed have weaknesses which make the results uncertain. A good survey over the subject is given in the book "Bennett and Elliot's Physiology and Medicine of Diving" see Ref. /4/. Later in this chapter we summarize results from three of the latest reports on the subject:

- Report from the Lossius' Commission
- Haukeland Investigation
- HSE ELTHI Diving Study.

4.6.2 Causation Testing

Much of the discussion has been triggered by the question of whether divers with certain long-term symptoms should receive financial compensation. This type of discussion is not unique for divers. A similar problem exists for workers in nuclear facilities who have received high radiation doses and who later have developed cancer. In court cases in the United States claims for financial compensation have to be supported by evidence that "…it is more likely than not" that the observed cancer has been caused by the received radiation dose. A causation test has been developed for that purpose, Ref. /28/. If re-formulated for diving, it would be:

1. Confirm the diagnosis. If not confirmed, stop at this point
2. Check recent scientific literature to confirm that diving can cause the illness in question. If not confirmed, stop at this point
3. Check minimum latency period. If time between received dose and occurrence of illness is shorter, stop at this point
4. Determine the causation dose
5. Determine the baseline risk for the illness in question, i.e. the risk to develop the illness in question without diving. (For cancer among male Americans 50 % during lifetime)
6. Determine any other factors in the persons life which could contribute to the occurrence of the illness
7. Check if the dose received has ever been observed to cause the illness. If not, this indicates that the dose is below the threshold. Stop at this point
8. Check the dose received against the dose response table or curve. If the dose is higher than the dose required to produce the baseline risk - and only then - is it "more likely than not" that the illness is caused by diving.

The most difficult point in the test is point no. 8 since it requires a dose-response curve or table of the form shown in Figure 4.14. Curves like the one in Figure 4.14 are available for many effects (toxic impact, thermal impact).

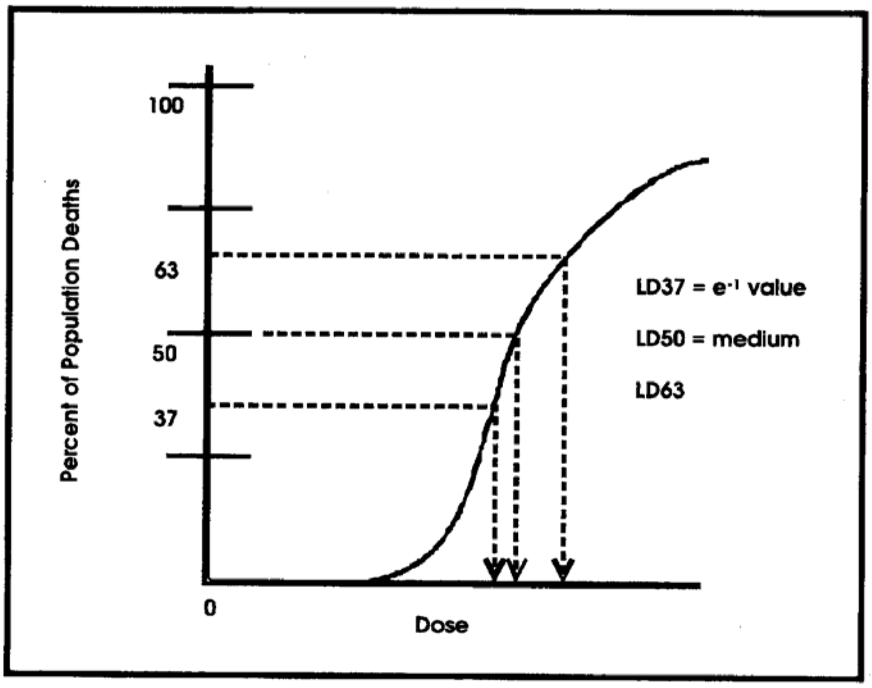


Figure 4.14: Typical Dose - Response Curve (Page 598 of Ref. /29/)

For radiation dose and cancer a simple linear relationship is proposed by the International Radiation Protection Commission (IRPC) in the form of "probability coefficients" or dose response factors. For non-fatal cancer a probability coefficient of

0.008 per Sv (Sv = Sievert, measure for radiation dose)

is recommended by the IRPC, meaning that the probability to develop non-fatal cancer after receiving a radiation dose of 1 Sv is 0.008. What would be desirable for the diving discussion are factors for each of the known - or suspected - long term effects such as damage of the lungs, damage of the central nervous system (CNS), post-traumatic stress disorder (PTSD). These factors should predict the probability of developing the different effects, given a certain diving "dose". Possible diving doses are, for example, according to Ref. /30/:

- Number of years with diving experience
- Number of years with Norwegian Sector diving experience
- Number of surface-oriented dives with air as breathing gas
- Number of bounce dives with mixed gas
- Number of days in saturation
- Maximum diving depth.

4.6.3 Data from National Insurance Administration

The Norwegian National Insurance Administration (Rikstrygdeverket, RTV) has provided data on professional divers who either receive disablement pension, or disablement pension in combination with occupational disease compensation (Ref. /31/). They also give the number of divers who are retired due to old age or who have died, but previously have received disablement pension. The number of divers in the different categories is:

- Disabled: 52
- Disabled, with occupational disease: 45
- Retired (previously disabled): 3
- Deceased (previously disabled): 5
- Other: 6

The total of 111 divers comprises both offshore and inshore divers, but fire brigade divers are excluded. It should be noted that the occupational classification in the RTV register can be misleading since some divers can be classified as construction workers, platform workers, welders, etc. and, thus, will not be included in the number of 111.

The reporting period covers a time span from before 1990 up till now. The distribution over different time periods is given in Table 4.10 and the distribution over age at time of disablement in Table 4.11.

Table 4.10: Number of Disabled Divers in Different Time Periods (Ref. /31/)

Year	Number of divers disabled
1990 and before	9
1991 - 1995	34
1996 - 2000	29
2001 and later	30
Not given	9
Total	111

Table 4.11: Age of Divers when Disabled (Ref. /31/)

Age when disabled	Number of divers
25-39	25
40-49	32
50-59	37
60 or more	9
Not given	9
Total	111

The rate of disablement per year can be estimated from the numbers for the 5-year intervals 1991 - 1995 and 1996 - 2000:

1991 - 1995: 34 disablements
1996 - 2000: 29 disablements

This gives an average of 6.3 disablements per year. The number of active divers in the time interval 1991 - 2000 is not known.

A disablement rate per year can be calculated when the relevant number of active divers is known. The number of Norwegian offshore divers in the time period 1991 -

2000 is not known, but figures of typically 20-25 active divers each year are mentioned. The relevant number of inshore divers in this period is very uncertain and, hence, a disablement rate has yet not been calculated. It is, however, recommended to improve follow-up and statistics on disablement rate for divers as a tool in risk management for diving.

The disablement rate of the general public which can be obtained from Table 9.20 of the Statistical yearbook published by the Norwegian National Insurance Administration, RTV (Ref. /32 /). There the number of newly disabled persons per 1,000 non-disabled persons per year is given for the year 2002, for males of different age:

< 40 years old: 2.51 per 1,000 non-disabled per year
40 - 49 years old: 6.48 per 1,000 non-disabled per year
50 - 59 years old: 18.90 per 1,000 non-disabled per year

If one subtracts from these numbers the contributions from accidents, poisoning and violence (0.17 for < 40 years old, 0.45 for 40-49 years old, 0.84 for 50-59 years old) one obtains the following figures for newly disabled persons:

< 40 years old: 2.34 per 1,000 non-disabled per year
40 - 49 years old: 6.03 per 1,000 non-disabled per year
50 - 59 years old: 18.06 per 1,000 non-disabled per year

One group of people which divers can be compared with is male professional pilots. Both, divers and pilots, need certificates in order to perform in their work. The checks necessary to obtain and renew the certificates are of course different, but "good health" is necessary in both cases. Another similarity between the two professions is that the "starting health" in both professions will be better than for the general public. This has to do with the type of persons choosing these professions and the health requirements which must be fulfilled when starting their education.

An investigation into the rate of pilot certificates loss has been conducted by the Norwegian Civil Aviation Authority and the Institute of Aviation Medicine, Ref. /33 /. For the 20 year time period from 1982 to 2001 a total of 275 cases of disqualification were observed, for a population of 48,229 male pilot years. The data were analyzed with respect to pilot age and diagnosis. Some results are shown in Table 4.12.

Table 4.12: Rate of Disqualification of Male Professional Pilots 1982 - 2001 Ref. /33/

Pilot age	Disqualifications per 1,000 pilots per year
20 - 29	0.96
30 - 39	2.4
40 - 49	6.8
50 - 59	13
60 - 69	5.74
Aver. all ages	5.7

The low rate of disqualification for the 60 - 69 years old is explained by the fact that the number of pilots in this group with valid certificates is small (≈ 120) and that it is a very selected group with the "healthiest and most enthusiastic" pilots.

4.6.4 Report from Lossius' Commission

The Norwegian government appointed a commission under the leadership of judge Petter A. Lossius in June 2000 in order to investigate all circumstances related to diving in the Norwegian Sector in the pioneer period (1965-1990). The work was completed and the report published on 31.12.2002, see Ref. /3 /.

The commission tried to identify as many pioneer divers with relationship to Norway as possible, i.e. Norwegian and foreign divers living in Norway, and Norwegian divers living abroad. Using information collected from different sources the names of 378 divers were identified. This number appears to be low considering that the number of Norwegian divers with a bell diving certificate registered at the Petroleum Safety Directorate (PSD) until 1990 is 327, and the number of Norwegian divers with surface certificate 336 (Ref. /9/). The numbers with foreign nationality are 1838 with a bell diving certificate and 15 with a surface certificate. How many of these live in Norway is not known.

The commission sent out questionnaires to 365 of the identified divers and received a response from 235 of them.

It has been argued that the total number of pioneer divers which should have been included in the analysis was much higher than 365. This means that the 365 registered divers are a sub-group of the total population and that the results determined for the sub-group may not be representative for the pioneer divers as a whole. We cannot confirm that the investigated sub-group is representative since there is a lack of information on the selection principles for the sub-group and a lack of information on the divers not included in the investigation.

Information concerning their social security status was obtained from 335 divers. 63 (19 %) received a disability pension. The age distribution for the disabled divers and for the public in general is shown in Table 4.13.

Table 4.13: Percentage of Disabled Divers and the General Public (Ref. /3/)

Age group	No. of divers in age group	Disabled divers		Percentage disabled in General public
		Number	Percentage	
36 - 40	21	3	14.3	3.8
41 - 45	60	14	23.3	5.5
46 - 50	98	16	16.2	7.8
51 - 55	83	19	22.9	11.5
55 - 60	62	10	16.1	17.2
61 - 65	9	0	0.0	31.7
66 - 70	2	1	50.0	40.3
Total	335	63	19	

The two highest age groups contain too few divers to be statistically very relevant. The differences are largest for the lowest age groups. The commission has not carried out any statistical tests on these data. This has been done, however, on the initiative of the Alliance of North Sea Divers (NSDA), by statisticians at the Norwegian Agricultural University (Norges Landbrukshøgskole Aas), Ref. /34/. They show that the observed differences are significant at the 0.01 level, which means that the probability that the samples were taken from the same population is extremely small, less than 0.01 (1 %). Or in other words: The differences are real, not just the result of statistical sampling from the same population.

In Ref. /34/ some weaknesses in the data interpretation of the Lossius report were pointed out, for example the way how scores were attributed to the answers:

- Excellent score 1
- Good score 2
- Satisfactory score 3
- Poor score 4
- Very poor score 5

when asking for an assessment of the divers state of health. From the received answers an average score of 3.14 (SD = 1.25) was calculated and compared to an average score of 3.0 for the general population. Such a comparison is only meaningful if there is a linear relationship between the categories and they are equally spaced. This is by no means certain. No justification is given for the selection of the average score of 3 for the general public.

The questionnaire also asked for the frequency of certain health disorders. The results are shown in Table 4.14.

Table 4.14: Reported Frequency of Disorders (Ref. /3/)

Occurrence frequency	Joint pains		Back pains		Memory problems		Mental difficulties		Hearing problems	
	No.	Perc.	No.	Perc.	No.	Perc.	No.	Perc.	No.	Perc.
Never	34	16 %	140	67 %	28	13 %	28	16 %	57	29 %
Occasionally	67	32 %	68	33 %	68	32 %	59	34 %	55	27 %
Fairly often	48	23 %	-	-	40	19 %	29	16 %	22	11 %
Often	61	29 %	-	-	75	36 %	59	34 %	66	33 %
	210	100 %	208	100 %	211	100 %	175	100 %	200	100 %

The percentages in Table 4.14 are not the same as in Table 7.3 of Ref. /3/ where there were some obvious errors in the calculation of percentages. Percentages in Table 4.14 were recalculated using the numbers of divers with the different disorders. No comparison has been made to a corresponding test among the general public.

The Lossius Commission tried to establish if there is any correlation (covariance) between the number of dives/depth of dives on the one hand, and state of health as given by the divers in the questionnaire on the other hand. Both for bounce dives and saturation dives the degree of covariance was between r = 0.13 and 0.14. (Values below r = 0.5 indicate low covariance). Also this statistical analysis and the conclusion drawn from it (no correlation) were criticized in Ref. /34/.

4.6.5 Haukeland Examination

4.6.5.1 Introductory Remark

In parallel with the work of the Lossius Commission, Haukeland University Hospital carried out health examinations of selected divers (Ref. /30/). Divers who complained about health effects which they thought were due to diving were asked to contact Haukeland University Hospital. A total of 115 divers responded, and at the time the report was published 81 of these had been examined. The 81 examined divers are not representative for the total diver population of an estimated 350 pioneer divers since they were those who themselves believed to suffer from permanent health deficiencies due to their diving activity. None of the 81 divers were active professional divers according to Ref. /35/. When calculating frequencies of certain health effects, the number of occurrences was related both to 81 and 350 divers. The latter method should give the lowest possible estimate since it assumes that there are no further occurrences among the 269 divers (i.e. 350 - 81) not examined.

Even when relating occurrences to 350 divers the resulting frequencies may become too high if the correct size of the population is higher than 350. For a discussion of the diver population size, see Chapter 4.6.4, paragraph 2.

The 81 selected divers underwent a number of examinations:

- Health status and life quality, as perceived by the divers (Chapter 2, K. Troland, E. Thorsen)
- Lung performance (Chapter 3, E. Thorsen)
- Decompression sickness and high pressure nervous syndrome (HPNS) (Chapter 4, E. Sundal, H. Nyland, M. Grønning)
- Clinical neurological examination (Chapter 5, E. Sundal, H. Nyland, M. Grønning)
- Clinical neurophysiologic examination (Chapter 6, H. Skeidsvoll)
- Hearing and balance examination (Chapter 7, F. Goplen, S. H. Glad Nordahl)
- Neuropsychologic examination (Chapter 8, K. Troland, J. T. Nicholas)
- Post-traumatic stress disorder (PTSD) (Chapter 9, K. Troland, E. Thorsen).

Some of the main results are summarized in the following chapters.

It should be noted that the investigations at Haukeland will continue and that Ref. /30/ is a preliminary report. The Haukeland team will send questionnaires to all divers, not only to those who contacted Haukeland themselves, complaining about health effects. Also a control group matching in age will be selected from the general publication and analyzed in the same way.

4.6.5.2 Health Status and Life Quality as perceived by the Divers (Questionnaires)

This investigation was carried out using questionnaires. Some of the questions related to the present status with respect to permanent or temporary disablement. The divers were categorized with respect to their age into four age categories. The percentages of disablement were calculated by relating the numbers to both the 81 divers which were interviewed, and to the 350 divers which were assumed to constitute the total population of pioneer divers (cohort). Table 4.15 shows the results in relation to the 350 total population.

Table 4.15: Percentage Disablement among Pioneer Divers

Age Group	Number of divers in age group	Permanently disabled		Temporarily **or** permanently disabled		General public Percentage disabled
		Number	Percent [1)]	Number	Percent [1)]	
30 - 39	5	1	4.5	1	4.5	3.1
40 - 49	23	5	5.0	9	9.1	6.1
50 - 59	44	17	8.9	28	14.7	14.4
60 - 66	9	6	15.4	6	15.4	36.0
Total	81	29		44		

1) Percentages are based on an assumed total population of 350 divers, instead of 81

The investigators conclude that the percentage of disabled divers is approximately the same as one expects for the general public. They also point out that the results obtained by the Lossius Commission show a much higher prevalence of disablement among divers, a factor 2 - 4 higher than in the general public, see Table 4.13. The reason for this difference is explained by the higher number of divers (238) for whom information was available in case of the Lossius Commission, as compared to 81 in case of the Haukeland investigation. Haukeland bases the percentages on the total population of 350 divers assuming that those not asked are not disabled. In this way the Haukeland prevalence is to be considered a minimum figure and the figures obtained by the Lossius Commission is judged to be most relevant.

When asking for specific sicknesses and symptoms, the results in Table 4.16 were obtained.

Table 4.16: Most Frequently Reported Sicknesses

Sickness	Number of divers	Percentage (%) [1)]
Mental problems	31	8.9
Fractures	29	8.3
Sinusitis	24	6.9
High blood pressure	21	6.0
Head damage, concussion	20	5.7

1) Percentages are based on an assumed total population of 350 divers, instead of 81

As noted, the percentages are calculated in relation to 350 divers (assumed total cohort size). In relation to the 81 divers examined the percentages would be a factor 350/81 = 4.3 higher. Even when relating the numbers to 350 divers, the percentages given (prevalence) are higher than the corresponding percentages in the general public. For mental problems, for example, the percentages in the general public are 4 % for the age group 25 - 44 years, and 6 % for the age group 45 - 66 years.

Table 4.17: Most Frequently Reported Symptoms

Symptom	Number of divers	Percentage (%) 1)
Difficulty to remember things	74	21.1
Difficulty to concentrate	61	17.4
Pain in joints	60	17.1
Tired	58	16.5
Irritated	55	15.7
Numbness in hands/feet	55	15.7
Depressed	51	14.6
Back pains	51	14.6
Sleeplessness	49	14.0
Reduced hearing	48	13.7
Pain in hands/feet	48	13.7
Tinnitus	47	13.4

1) Percentages are referred to an assumed total population of 350 divers, instead of 81

Also here the percentages are larger than those expected for the general public, but comparisons are difficult to make due to differences in the formulation of questions and the way results are presented.

A number of questions concerning their general health status revealed that 19 % (of the 350) divers considered their health status as bad, while the corresponding number for the general public is 9 % (45 - 66 years old).

The investigators conclude that most of the 81 examined divers report reduced health status which hinders them in their work and leisure activities, and which reduces their possibility for social contacts. As a consequence, the percentage of divers with reduced life quality is higher than the corresponding percentage in the general public, even when the numbers are related to the total cohort size of 350 divers.

The investigators point out the possibility for over-reporting of illnesses and symptoms due the focus in the media, the discussion about responsibilities, the possibility for financial compensations, etc. But results from similar examinations in the UK where these factors were eliminated by anonymisation and where control group results were available point in the same direction.

4.6.5.3 Lung Performance and Respiratory Symptoms

This investigation combined self-reported respiratory symptoms and objectively measured pulmonary function data.

30 of the examined divers (8.5 % of 350) reported persistent coughing, heavy breathing under physical activity, or whistling noises from the chest. The expected prevalence for a comparable group of non-divers (adjusted for age, smoking habit, dust from welding) is 4.5 %. The difference is statistical significant at a level $p < 0.01$. (The probability that the symptoms occurred equally frequent in divers and the reference population is less than 1 %.)

The subjects were examined by static spirometry (measurement of lung volumes), dynamic spirometry (measurement maximum expiratory flow rates), pulmonary gas diffusion capacity and work capacity. A number of spirometric indices (FVC, FEV1, FEV1/FVC, FEEF25-75 %) as well as the pulmonary diffusion capacity were statistically less (indicating deteriorated lung function), while the RV/TLC ratio was statistically higher than compared to relevant age- and sex matched reference populations.

The investigators conclude that respiratory obstructions measured by spirometry are more severe among the pioneer divers than in the general Norwegian population. No association was observed between diving dose and pulmonary function, though the authors warn that the number of subjects examined might be too small to reveal this. The effects cannot be explained by smoking habits, allergies or exposure to other working environments than diving.

4.6.5.4 Decompression Sickness and High Pressure Nervous Syndrome (HPNS)

This chapter of the report is mostly concerned with symptoms which occur during diving or shortly thereafter, like those related to decompression sickness (DCS) and serious gas cut. But some divers reported "persistent" symptoms such as joint pain, headache, tinnitus, etc. following specific dives. In most cases these symptoms followed in cases where decompression sickness, gas cuts, and/or physical damage was experienced during the dive. Only 7 of the 81 divers reported that they never have experienced DCS. Table 4.18 below shows how many of the divers have experienced the different forms of DCS, and how many times.

Table 4.18: Self-reported Incidents of DCS

Type of decompression sickness	Number of divers	Average number of occurrences, per diver
Joint DCS	53	6.6
Skin DCS	42	6.2
Spinal/cerebral DCS	18	1.3
Other types of DCS	7	2.8
None experienced	7	

HPNS causes certain deficiencies in the central nervous system (CNS) which start to occur when the depth of compression is more than 180 msw, but which normally disappear within 6-8 hours after stabilizing the depth.

The investigators draw no conclusions concerning the frequency of persistent symptoms or long-term effects or their correlation with reported DCS.

4.6.5.5 Clinical Neurological Examination

This examination consisted of semi-structured interviews and clinical neurological tests, see Table 4.19. The first ten symptoms were also recorded in the Health Status and Life Quality Test (Chapter 4.6.5.2 Table 4.17), but the results were slightly different.

Table 4.19: Neurological Symptoms

Symptom	Number of divers	Percentage (%) [1]	Percentage (%) [2]	Percentage (%) [3]
Difficulty to remember things	67	82.7	19.1	21.1
Difficulty to concentrate	59	72.8	16.8	17.4
Sleeplessness	50	61.7	14.3	14.0
Tired	47	58.0	13.4	16.5
Pain in joints	44	54.3	12.6	17.1
Irritated	41	50.6	11.7	15.7
Depressed	36	44.4	10.3	14.6
Numbness	35	43.2	10.0	15.7
Back pains	35	43.2	10.0	14.6
Tinnitus	32	39.5	9.1	13.4
Anxiety	19	23.5	5.4	
Clumsiness	14	17.3	4.0	
Shifting mood	14	17.3	4.0	
Tendency for social isolation	12	14.8	3.4	
Respiratory difficulties	12	14.8	3.4	
Trembling	10	12.3	2.8	
Stumbling	6	7.4	1.7	

1 Percentages calculated on the basis of a cohort size of 81 divers
2 Percentages calculated on the basis of a cohort size of 350 divers
3 Percentages taken from Table 4.17, for comparison

The last seven symptoms are new, i.e. they were not included in the health status and life quality examination, Chapter 4.6.5.2 and Table 4.17.

The results were tested for statistical relationships between the symptoms and findings on the one hand, and certain risk factors like cardiovascular diseases, head injuries and unconsciousness, alcohol consumption, and age on the other hand. Odds' ratio (OR) was calculated, but without finding a significant statistical relationship.

The investigators concluded that the clinical neurological examinations reveal the same general picture as the one obtained by using questionnaires and asking for the divers own opinion on the health status, see Chapter 4.6.5.2. Symptoms and findings were more frequent/severe than expected.

4.6.5.6 Clinical Neurophysiology

This examination tried to give objective and quantifiable results showing the performance of the central nervous system (CNS) as well as peripheral nerves and muscles. The methods used were electroencephalography (EEG), cognitive response (P 300), and somato-sensoric induced response (SER).

The EEG results showed that 40 % of the examined divers showed drowsiness: after a few minutes rest with closed eyes the EEG showed signs of beginning sleep. This is a much higher percentage than expected in a normal population. 20 % of the divers had an EEG which was considered slightly pathological, and one diver had a marked pathological EEG. The other tests (P 300 and SER) showed only minor effects and the results were not compared to expected results from normal populations.

4.6.5.7 Hearing and Balance

Hearing tests showed a marked loss of hearing capacity in the frequency region 3-6 kHz, as compared to the normal hearing capacity for the corresponding sex and age group. The loss in this frequency range can be explained by damage from experienced noise. There was also some loss in the lower frequency ranges which is probably due to other factors.

For the balance tests no comparison to the normal population was possible. Compared to a test group of 8 younger, still active divers the examined pioneer divers showed clear signs of reduced balance capability. But for a more reliable analysis a larger reference group needs to be examined.

4.6.5.8 Neuropsychological Examination

The 81 pioneer divers underwent a standardized series of tests (Halstead Reitan test battery) in order to test neuropsychological symptoms such as problems with memory, with awareness, with psycho-motoric functions. The scores achieved in each test were compared to expected scores (average values and SD) for comparable reference groups.

The authors summed up their results by concluding that the pioneer divers have reduced awareness, concentration, memory, psycho-motoric speed and mental flexibility. For some of the divers the observed results must be characterized as pathologic findings. Altogether, these results indicate a reduced life quality.

Results were tested by multiple regression analysis for signs of correlation to known risk factors such as age, alcohol consumption, head injuries, cerebrovascular illness. No significant correlations were found. There were no clear correlations to diving doses either, such as number of dives, number of days in saturation, diving depth, and not even to self-reported decompression sickness (DCS), treated or untreated. The design of the test (pre-selected group of divers with symptoms, large diving dose, high percentage of DCS or suspected DCS) makes it impossible to derive valid dose - response relationships.

4.6.5.9 Post-traumatic Stress Disorder (PTSD)

Many of the examined divers have experienced or been witness to incidents which can lead to post-traumatic stress disorder (PTSD). Only 3 out of 74 participating divers reported that they had never experienced life-threatening incidents. The others had experienced

- gas cuts
- getting caught/jammed
- dropped objects
- drifting due to water currents
- under cooling
- loss of mask/helmet
- uncontrolled ascent
- nearness of ship screw
- being sucked in/out
- loss of communication
- water in diving bell
- loss of diving bell.

23 stated that they had been witness to incidents which resulted in the death of a diver. (This number seems to be very high, taking into account the number of fatalities which have occurred. But several divers can have witnessed the same accident) 14 divers had been witness to incidents where divers lost consciousness.

Traumatic stress and psychological symptoms were examined by using a questionnaire called Minnesota Multiphase Personality Inventory (MMPI-2) and a method called "Impact of Event Scale" (IES). The latter method results in three scores which describe different aspects of PTSD. Results of the IES test are summarized in Table 4.20.

Table 4.20: Results of "Impact of Event Scale" Testing (74 Participants)

Type of test	Average score and SD	Cut off score	No. of participants with elevated scores
IES Intrusion (7 parts)	19.57 +/- 5.75		
IES Avoidance (8 parts)	18.52 +/- 5.35		
IES-R Hyper arousal (6 parts)	13.14 +/- 3.89		
Total score	38.10 +/- 10.55	35	48 (65 %)

The difference between the average total score and the limit score was found to be significant at the $p < 0.01$ level when tested by one-sample t-test.

63 of the divers reported that they had participated in the search for, and rescue of, persons. In 12 cases these persons were friends or colleagues. Several of the divers participated in the rescue operations following the Alexander Kielland accident. 22 of the divers reported suicidal thoughts, and several had attempted to commit suicide once or several times.

65 of the divers had never been followed up or debriefed after a psychological stressing incident. It was not usual, either, to discuss and talk about such incidents with colleagues, superiors, wives and friends.

The investigators conclude that the examined pioneer divers suffer under substantial psychic stresses due to the incidents to which they were exposed during their diving career. A large fraction of them fulfill the criteria for post-traumatic stress syndrome (PTSD), accompanied by increased suicidal tendencies.

4.6.6 HSE ELTHI Diving Study

4.6.6.1 Introduction

The ELTHI Diving Study (Examination of Long-Term Health Impact of Diving) was carried out by the University of Aberdeen for the HSE, Ref. /36/. In contrast to the Norwegian studies presented in Chapters 4.6.4 and 4.6.5, the ELTHI Study did not focus on a selection of pioneer divers with a high percentage of self-reported complaints. Instead, all 2,958 divers with a traceable address (out of 8,000 registered with the HSE who obtained their professional diving certificate before 1991), were contacted. Of these 1,754 responded and returned the questionnaire. Some of these were excluded for different reasons and some were added from the group of offshore workers, ending up with 1,540 divers in the group to be analyzed.

Some of the responders responded first after the 2nd and 3rd mailing of the questionnaire. There were no large differences in the results between 1st, 2nd and 3rd responders. From this the investigators conclude that there are no large differences between responders and non-responders and that the sample is representative for the total population.

Another major difference between the ELTHI Study and the Norwegian studies is that a comparison group consisting of 1,035 offshore workers was examined in the same way as the divers. The offshore workers were selected among those who had a medical certificate of fitness for offshore work between 1990 and 1992, who had a current UK address, and who had never dived. The selection was done in such a way that the two groups - divers and offshore workers - had comparable demographic characteristics with respect to age, sex (all male), economic status (Carstair score) and body mass index. There were, however, significant differences in smoking, drinking habits, and educational qualifications. These differences were adjusted for in the results.

The investigation consisted of three phases:

- Phase 1a: Questionnaire evaluation of 1,540 divers and 1,035 offshore workers
- Phase 1b: More detailed questionnaire and clinical comparison of 151 divers and 102 offshore workers (10 % sample); reliability testing of questionnaire
- Phase 2: Case control study of "forgetfulness and loss of concentration" among 102 "forgetful" divers, 99 "non-forgetful" divers, and 100 "non-forgetful" offshore workers.

For understanding the results it is important to note that the divers in ELTHI Study were younger (average age 45) and still more active (87.7 % still employed, 55 % currently diving) than the divers in the Norwegian studies where the average age was 51 years and only 59 % were still permanently employed (Lossius Report). The percentage of divers still diving is probably much lower than 55 %, in both Norwegian studies. Additional information received from the University of Aberdeen (Ref. /37/) gave the following distribution for the 12.3 % divers not employed:

- Unemployed: 5.5 % (84), may contain a number of self-employed divers between jobs
- On sickness benefit or retired due to ill health: 3.3 % (50)
- Retired: 3.5 % (54).

The divers in the ELTHI Study had not only dived in the offshore industry, but also in the police force, as diving instructors, as scientific- or media-employed divers, etc. They had used different diving techniques in their professional activities:

- 93 % had experience with SCUBA diving
- 77 % had experience with surface decompression diving (air or nitrox)
- 62 % had experience with other air or nitrox diving (surface demand)
- 42 % had experience with mixed gas bounce diving
- 42 % had experience with saturation diving.

In addition, 75 % of the divers were also engaged in recreational diving activities.

4.6.6.2 Results Phase 1a

The frequency of occurrence of 11 self-reported **symptoms** was compared for divers and offshore workers. The differences in frequencies were expressed as Odds Ratio (OR). An OR > 1 indicates a higher frequency among divers, an OR < 1 a lower frequency among divers. After adjustment of the results for age, drinking, smoking, head injury and body mass index (BMI), only three symptoms were significantly different, see Adjustment 1 results in Table 4.21.

Table 4.21: Odds Ratio for Symptom Frequencies which Differed Significantly between Divers and Offshore Workers (Adjusted, see Text)

Symptom	Adjustment 1		Adjustment 2	
	OR (95 % CI)	p	OR (95 % CI)	p
Joint pain	1.5 (1.3 - 1.9)	< 0.001	1.1 (0.9 - 1.4)	0.2
Forgetfulness	3.7 (2.7 - 5.0)	< 0.001	3.1 (2.2 - 4.3)	< 0.001
Impaired hearing	1.5 (1.2 - 2.0)	< 0.002	1.2 (0.9 - 1.6)	0.3

Adjustment 2 consisted of the addition of welding and lost time accidents to the regression model. After this adjustment only the frequency of "forgetfulness or loss of concentration" showed a significant difference.

For this symptom also a relationship was established between the percentage of divers reporting it and their diving exposure. A clear increase with exposure was found for saturation diving (number of days in saturation), mixed gas bounce diving (number of dives), and surface oxygen decompression diving (number of dives), but not for the other diving techniques.

The frequency of occurrence of 15 self-reported diagnosed **medical conditions** was also compared. Only asthma, high blood pressure and stroke were significantly different, after adjustment for lifestyle and demographic attributers. These conditions were all significantly less frequent in the diver group than in the control group.

Health related **quality of life** (HRQOL) was analyzed using the SF-12 questionnaire. Depending on the answers in the questionnaire two different summary scores are determined:

- - PCS = Physical Component Summary Score
- MCS = Mental Health Component Summary Score.

Table 4.22 shows the results.

Table 4.22: PCS and MCS Scores, Means ± 1 SD

Test	Divers	Offshore workers	Adjusted p*	OHLS** (men)	Standard population
PCS	52.1 ± 7.9	52.0 ± 7.6	0.9	51.2 ± 9.2	50 ± 10
MCS	51.6 ± 9.1	50.7 ± 9.4	0.09	51.4 ± 8.9	50 ± 10

* Adjusted for age, smoking, drinking, head injury
** Oxford Healthy Lifestyle Survey

A large score indicates high quality of life. Differences are in favor of divers, but they are hardly significant. It was found that both PCS and MCS are influenced by welding and accidents (3-day-lost-time-accidents), both for divers and offshore workers.

4.6.6.3 Results Phase 1b

The **first part** of Phase 1b was designed to test the reliability of the large questionnaire analysis (Phase 1a) by subjecting a 10 % subgroup to a more detailed questionnaire examination. Good agreement was found between the two examinations strengthening the confidence into these methods.

The **second part** of Phase 1b consisted of objective, clinical measurements and comparison of these with the self-reported symptoms and medical conditions in the questionnaires. The following clinical measurements were performed:

- **Noise induced hearing loss:** Both divers and offshore workers have noise induced hearing losses of varying degree, but differences between the two groups were insignificant
- **Lung function:** 11 different parameters were measured. Two measures of forced expiratory flow (FEF25% and FEF50%) were significantly lower for divers than for offshore workers ($p < 0.01$, adjusted for smoking). No relationship was found between diving method/diving dose and reduction of FEF
- **Stabilometry:** No significant differences were found.

The second part of Phase 1b also contained a personality test developed for the US Air Force. This so-called ALAPS test (Armstrong Laboratories Aviation Personality Survey) gave the results in Table 4.23.

Table 4.23: Results of ALAPS Personality Test

Characteristics	Divers Mean (95 % CI)	Offshore workers Mean (95 % CI)	p	Trainee Air Force personnel Mean (95 % ± SD)
Risk taking	9.8 (9.3 - 10.4)	7.1 (6.4 - 7.7)	< 0.001	12.2 ± 2.9
Impulsivity	8.6 (7.9 - 9.3)	6.7 (6.0 - 7.4)	< 0.001	7.3 ± 3.6
Organization	11.4 (10.9 - 11.9)	12.6 (12.0 - 13.2)	0.002	12.4 ± 3.4
Dogmatism	6.0 (5.6 - 6.4)	5.6 (5.2 - 6.1)	0.2	6.0 ± 3.0
Team orientation	10.8 (10.2 - 11.5)	11.5 (10.8 - 12.2)	0.2	11.9 ± 3.8
Deference	5.8 (5.2 - 6.3)	5.8 (5.1 - 6.4)	1.0	6.3 ± 2.8

Divers and offshore workers differed significantly in risk taking, impulsiveness and organization.

4.6.6.4 Results Phase 2

Phase 2 was a case control study concerned with the symptom "forgetfulness and loss of concentration" which was found to be the most significant difference between divers and offshore workers found in Phase 1a. The following groups were compared:

- 102 forgetful divers (F-divers)
- 100 not-forgetful divers (NF-divers)
- 100 not-forgetful offshore workers (NF-OSWs).

Among others, the case study revealed the following facts:

- A higher proportion of F-divers reported medical complains than NF-divers and NF-OSWs. (15 different types of complains were included in the test)
- More F-divers (43 %) had high blood pressure as compared to NF-divers (30 %) and OSWs (32 %)
- Several neuropsychological tests (logical memory, verbal memory and learning, reaction time, sustained attention, spatial memory, etc.) showed significant differences between F-divers and the two control groups
- A statistically significant relationship was found between memory function and diving dose (number of dives) in case of mixed gas bounce diving. The relationship was not statistically significant for the number of days in saturation or the amount of SCUBA diving
- Magnetic Resonance Imaging (MRI) of the brain revealed a mild degree of organic brain damage. The observed white matter lesions were most common in divers who performed mixed gas bounce diving.

Comparing the diving exposure (dose) of F-divers and NF-divers it was found that F-divers had, on the average, experienced 1,610 dives, NF-divers 1,033 dives ($p = 0.03$). Of the F-divers, 47 % had experienced DCI as compared to 21 % of the NF-divers ($p < 0.001$).

4.6.6.5 Conclusions of the ELTHI Study

The investigators from the University of Aberdeen draw the following main conclusions from their study:

- The factor with the strongest influence on the reduction of Health Related Quality of Life (HRQOL) is the occurrence of work related accidents (accidents leading to absence from work in more than 3 days)
- A significantly higher percentage of divers as compared to offshore workers complain about "forgetfulness and loss of concentration". This percentage increases significantly with increasing diving dose, i.e. number of days in saturation in case of saturation diving, or number of dives in case of mixed gas bounce diving
- The symptom "forgetfulness and loss of concentration" is significantly related to reduced HRQOL and reduced performance in objective tests of cognitive function and memory
- Welding, exposure to drill mud or petrochemicals, and contaminated breathing gas have an amplifying effect on the symptoms experienced by divers.

4.6.7 Comparison of the three Studies on Long-Term Effects

There are some important differences between the three studies summarized in the preceding Chapters 4.6.4, 4.6.5 and 4.6.6 which one has to keep in mind:

- The Lossius Report aimed at investigating a limited, special group of divers, namely pioneer offshore divers with a relationship to Norway (foreign and Norwegian divers living in Norway, and Norwegian divers living abroad). Results were obtained from 235 divers. The size of the total population is not known

- The Haukeland Investigation focused on an even more limited group, namely Norwegian pioneer divers who complained about negative health effects which they believed were due to their diving activity. Results were obtained from 81 divers. Most of these were included in the 235 divers of the Lossius Report

- The ELTHI Study had a much broader approach, trying to include as many as possible of the 8,000 divers registered with the HSE as having professional diving certificates before 1991. Results were obtained from 1,540 divers. The ELTHI researchers could demonstrate that they were a representative sample of the total population.

The much broader approach of the ELTHI Study led to a much "healthier" diver population since it included a higher percentage of still active and younger divers than the two Norwegian studies.

For further discussion of the differences and results of the three studies, see Chapter 9.2, Long-Term Risk, in Chapter 9, Conclusions and Recommendations.

4.7 Suicides

4.7.1 Introduction

The subject of suicides among divers has been discussed following a study presented by McCallum at the Godøysund Conference in 1993, Ref. /38/. Later the subject has been commented in the mass media indicating an alarming high rate of suicides among former divers.

As part of the present study available sources have been examined to achieve an indication of the magnitude of the problem of suicides among divers. Suicide rates may be an indicator of the state of health and quality of life in general. However, it has not been possible or intended as part of this study to investigate individual cases of suicide and clarify their causes and relationship to the diving activity performed. Such investigations require special competence.

4.7.2 General Statistics

Suicides are regarded as a tragic and potentially preventable public health problem worldwide. Suicides are (with 800.000 cases per year) also ranked by the World Health Organization as the second most major cause of death for the world as a whole. Only the figure for fatalities in connection with road accidents is higher according to Ref. /39/.

The rate of suicides is normally reported as number of cases per year for 100,000 people. The suicide rate is found to differ considerably depending on time period, country, sex and age group. According to Ref. /40/ there is also an underreporting of suicide as a cause of death of approximately 25 %.

In Table 4.24 some suicide rates are summarized to illustrate the differences.

Table 4.24: Suicide Rates in the General Public

Population	Typical suicide rate (cases per year for 100,000 people)	Comments	Reference
Norway, male all ages, 1994	17.4		Ref. /41/
Norway, female all ages, 1994	6.9		Ref. /41/
Norway, male age 20 - 59 years, period 1976 to 1995	25	Suicide rate varies between 19 and 36 for different age groups and time periods	Ref. /42/
Norway, female age 20 - 59 years, period 1976 to 1995	12	Suicide rate varies between 5 and 15 for different age groups and time periods	Ref. /42/
UK, male all ages, 1996	11		Ref. /41/
UK, female all ages, 1996	3.3		Ref. /41/
UK, male age 25-44, period 1976-1995	20	Suicide rate varies between 15 in 1976 and 24 in 1995. Increasing trend in this period	Ref. /41/
UK, female age 25-44, period 1976-1995	7	Suicide rate varies between 6 and 9. Decreasing trend in this time period	Ref. /41/
Russia, male all ages, 1994	74		Ref. /41/
Finland, male all ages, 1995	43		Ref. /41/
United states, male all ages, 1995	20		Ref. /41/
Sweden, male all ages, 1996	20		Ref. /41/
Denmark, male all ages, 1995	24		Ref. /41/
Spain, male all ages, 1992	11		Ref. /41/

The suicide rate shows considerable differences internationally. The suicide rates in the Nordic countries are relatively high compared to other countries, especially some south European countries. In the Baltic countries and member states of the former Soviet Union the suicide rates are among the highest in the world. In all countries except China the suicide rate is higher among men than women (Ref. /44/).

4.7.3 General Risk Factors

Based on Ref. /43/ and /44/ the following general description related to suicides is established.

Suicidal behavior is complex. Some risk factors vary with age, sex and ethnic group and may even vary considerably over time. The risk factors for suicide frequently occur in combination.

Research has shown that more than 90 percent of people who kill themselves have depression or another diagnosable mental or drug abuse disorder, often in combination with other mental disorders. Adverse life events in combination with other risk factors such as depression may lead to suicide.

The suicidal rates are reported to be largely dependent on pattern of society and cultural and religious subjects. Suicide rates have traditionally decreased in times of war and increased in times of economic crises (Ref. /45/). In the US the reported suicide rates among white people are approximately twice those of non-whites. In addition, factors such as unemployment, alcohol consumption and availability of fire arms are reported to be important.

4.7.4 Diving Statistics

The Lossius Commission, Ref. /3/, have evaluated suicide rates among Norwegian divers while the suicide rates among UK divers where investigated in Ref. /21/. The resulting fatality rates are largely dependent on the total number of divers the fatalities should be related to and the time period to consider. On the basis of information gathered in Ref. /3/ and /21/ and after discussions with the authors of the reports, suicide rates are estimated and presented in Table 4.25 below. It should be noted that, as discussed in Chapter 4.6.4, there is uncertainty concerning the population size to be used for Norwegian commercial divers. Action has been taken to clarify this aspect further, but at present the figure of 378 divers is considered the best available basis.

The suicide rates are calculated as case per year for 100,000 people. For comparison the typical suicide rate in Norway for men age 29 to 59 years is also shown.

Table 4.25: Suicide Rates among Divers (Cases per Year per 100,000 People)

Time period	Population	Number of suicides reported	Calculated suicide rate	Typical suicide rate for men in Norway	Comments
1970 - 2000 (30 years)	Norway - 378 commercial divers	11	97	25	Both population and time period adjusted compared to Ref. /3/. The population is taken as the total number of commercial divers registered by the Lossius Commission and the time period is taken total period judged to be covered by reported incidents
1986 - 1996 (10 years)	Norway - 378 commercial divers	11	291	25	All known suicides occurred in the period 1986 to 1996
1976 -1993 (18 years)	UK - 2,111 commercial divers	13	34	25	Based on the McCallum study, Ref. /38/
1971 - 1994 (23 years)	UK - 2,111 commercial divers	22	45	25	Time period adjusted compared to Ref. /21/
1983 -1990 (8 years)	UK - 2,111 commercial divers	14	82	25	Population adjusted compared to Ref. /21/

4.7.5 Evaluation

The suicide rate among divers, in particular in Norway, but also in the UK, has been reported to be considerably higher than what is expected among the general population of the same sex and age in Norway. The majority of known suicide case has occurred over a relatively concentrated time period. In Norway this period extended from 1986 to 1996 while it extended from 1983 to 1990 in the UK.

In Norway the suicide rate among divers is reported to be up to 12 times higher than that expected for the general population of the same sex and age. In the UK the suicide rate is reported to be up to 3 times higher than expected.

There is reason to believe that there are considerable differences in suicide rates among different professions. Diving is a much specialized profession and it can be argued that divers are not "average" in personality and that this could affect the expected suicide rate.

The reported suicide rates for divers are historical values and illustrate the life situation for previous divers. As such the interesting part for the present diving activity is to understand possible causes in order to evaluate the necessity of changes to avoid similar situations in the future. With the high suicide rate reported for divers in Norway it is recommended to pursue this subject further. Based on a preliminary evaluation possible influencing factors for the high reported suicide rate among divers in Norway may be:

- Unemployment due to reduced diving activity and low ability to find other relevant work
- Reduced physical health due to the diving experience and experienced incidents/ accidents
- Reduced mental health due to insufficient handling of Post Traumatic Stress Disorder
- Low recognition of their health problems due to lack of knowledge in the public health service.

Some characteristic differences in personality (risk taking, impulsivity) have been reported between divers and the general population. This may be an influencing factor on suicide rates. However, no data have been found to support or eliminate a correlation between risk taking and impulsivity on the one hand, and a tendency towards suicide on the other hand.

The way diving is carried out today, the risk of both life-threatening incidents and decompression illness is considerably reduced and the activity level is relatively stable. It is, hence, expected that the suicide risk is reduced for the presently active divers.

The organization of the diving industry will influence the risk for suicides and it is recommended to consider this aspect further. Important issues in this respect are considered to be:

- Better screening/selection of divers
- Better medical follow-up
- Better debriefing after incidents
- Better employment conditions
- Better planning for ending diving career and re-education.

5. COMPARISON OF RISK AND RISK ACCEPTANCE CRITERIA

5.1 Risk in other Areas

5.1.1 Work in Norway

In order to establish a basis for comparison and to discuss the acceptability of diving risk it is useful to look at the historical risk as experienced in other professions and other activities.

Statistical data on fatalities and injuries during work are recorded, analyzed and published by labor authorities in almost all countries, as well as by international organizations. These data are not always comparable due to different definitions of injuries, reporting routines, industry categories, etc. Not all published data contain information on the exposure levels such as number of employees or number of hours worked which makes it impossible to derive frequencies.

The annual reports published by the Norwegian Labor Directorate contain information on number of fatalities, number of injuries, and number of work-related illnesses for different branches of industry (NACE code), see Ref. /46/. It does, however, not give the exposure in terms of man-hours spent within the different branches of industry. This information has to be obtained from other sources like the branch organizations or the Official Statistics of Norway (SSB, Statistisk Sentralbyrå). Only for the years 1998 and 1999 did the annual reports of the Labor Directorate give frequencies as number per 10 million work hours (1989) and number per 10,000 work years (1999). Looking at the latest frequencies available (1999 Ref. /47/) one finds values in the range zero to 2.50 per 10,000 work years. Results are shown in Table 5.1.

Table 5.1: Fatality Rates for 1999 in Norway (Ref. /47/)

Industry branch	NACE no.[1)]	Fatalities per 10,000 work years	Fatalities per 100 mill. work hours[2)]
Mining	10, 12-14	2.50	15.2
Other service activities	90, 93, 99	1.58	9.6
Oil refining, chemicals, plastic	23-25	1.36	8.2
Land transportation	60	1.23	7.5
Agriculture, forestry	01-02	1.14	6.9
Construction	45	1.03	6.2
Metals and metal products	27, 28	0.69	4.2
Food	15, 16	0.68	4.1
Power and water supply	40, 41	0.63	3.8

1) NACE = Nomenclature général des activités économiques dans la Communauté européenne, corresponds to SIC = Standard Industrial Classification at the 2-digit level
2) Assuming 44 x 33.5 = 1,650 work hours per work year

The Norwegian Petroleum Directorate (NPD) regularly analyzes fatality rates for work offshore. In a major project concerning the risk level on the Norwegian Continental Shelf the long-term trend (1967 - 2000) as shown in Figure 5.1 was found, Ref. /48/. The trend for the last ten years is shown in a different scale in Figure 5.2.

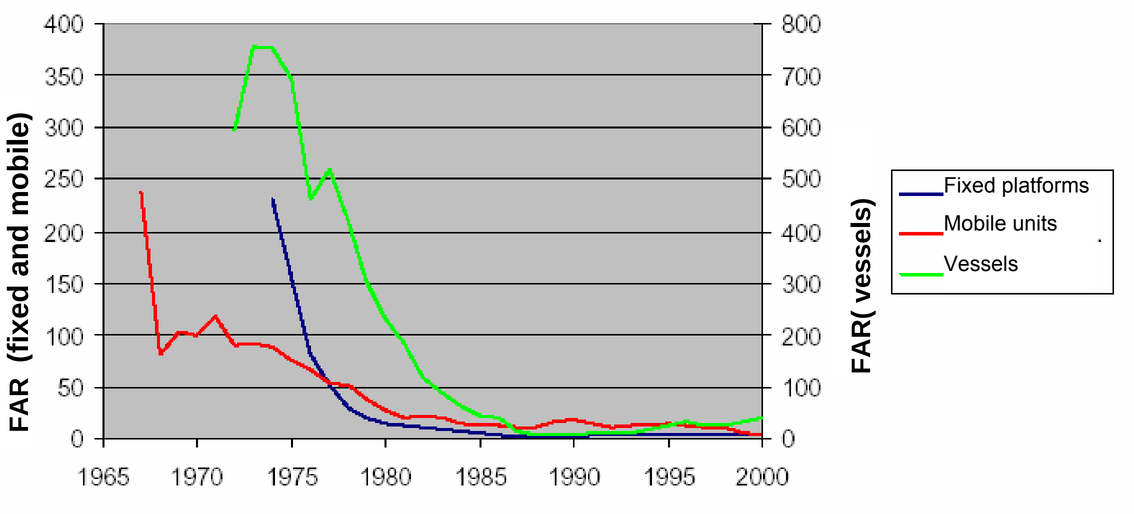


Figure 5.1: Development of Fatality Rate (FAR) for Production Installation, Mobile Installations and Vessels, 10-year Floating Averages, FAR = Number of Fatalities per 100 million Work Hours, 12 working Hours per Day (Ref. /48/)

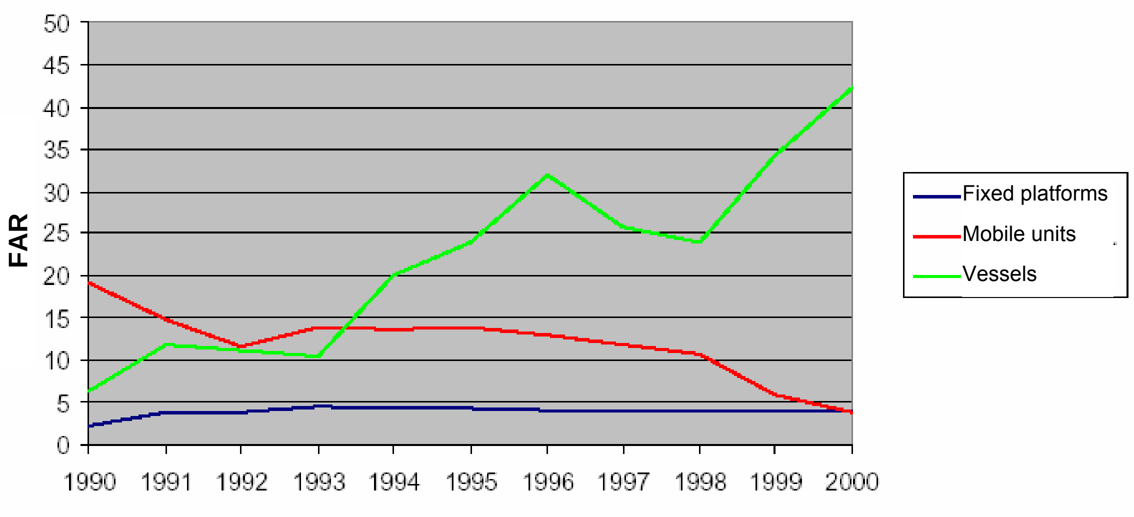


Figure 5.2: Development of Fatality Rate (FAR) for Production Installation, Mobile Installations and Vessels, FAR = Number of Fatalities per 100 Million Work Hours (Ref. /48/)

As one can see the FAR for fixed production installations has fallen strongly from 1973 to 1985 and it has been stable from 1990 to 2000 in the range 3 to 4. With 1,600 work hours per year a FAR of 3.5 corresponds to an individual risk per annum (IRPA) of $5.6 \cdot 10^{-5}$ per year.

The values shown in Figure 5.1 and Figure 5.2 are averages for all types of personnel on the offshore installations. The values will vary between different groups of personnel. NPD publishes injury rates for different groups of personnel, see Ref. /15/. An injury, in this context, is defined as an incident which requires medical treatment or which results in absence from work into the next 12-hour shift. (Note that this definition does not include first aid treatment as in the case for diving - see Chapter 4.2). For 1999 the following injury rates were recorded:

- Administrative and production personnel: 14 injuries per million work hours
- Drilling and well operation personnel: 26 injuries per million work hours
- Catering personnel 23 injuries per million work hours
- Construction and maintenance personnel: 33 injuries per million work hours
- Weighted average for all: 25 injuries per million work hours

Looking at these numbers it is of interest to compare them with the number of non-DCI injuries found for saturation diving in Chapter 4.5.3. There a figure of 22,500 injuries per 100 million hours in saturation was found, or 225 injuries per million hours in saturation. This is a much higher figure than those given above for personnel on fixed offshore installations. Partly this can be explained by the fact that diving actually is more likely to cause injuries than normal platform work, partly by the more stringent injury reporting criteria in the diving community, as compared to platform practice. It should also be noted that outer ear infections constitutes 50 % of the reported diving injuries and that these problems are specific and typical for divers.

Fatality rates for the different groups of personnel are not given due to the low number of fatalities experienced. But the variation of injury rates may be used as an indicator for how the fatality rates would vary between different groups of personnel. For the group of construction and maintenance workers a fatality rate a factor 32.7/24.5 = 1.33 higher than the average FAR must be expected, i.e. a FAR in the range 4 - 6.

Another group of persons exposed to risk are helicopter pilots flying regularly to offshore installations. A study by SINTEF (Ref. /49/) has evaluated the risk for helicopter passengers and crew based on 29 fatalities which were recorded between 1990 and 1998 in the Norwegian and UK sectors. The traffic volume was almost 16 million person flight hours resulting in a FAR-value of 180. Assuming that crew and passengers are equally exposed per flight hour this number can be used to calculate the individual risk per annum (IRPA) for pilots. According to information from CHC Helicopter Service the maximum number of flight hours for pilots is 800 per years, Ref. /50/. Using 600 as an average one obtains an IRPA of 0.001.

For offshore workers working on fixed platforms with a 2 weeks on/4 weeks off work cycle the number of flights will be 18 per year. With 1.5 hours flight duration this gives 27 hours of helicopter flight per year. The contribution to the yearly average FAR from helicopter transportation becomes $180 \cdot (27/3{,}200) = 1.5$, and to IRPA $180 \cdot 10^{-8} \cdot 27 = 4.9 \cdot 10^{-5}$ per year.

5.1.2 Work in the UK

In the United Kingdom (UK) the Health and Safety Executive (HSE) publishes yearly statistics of fatal injuries. In the latest edition for 2002/03, Ref. /51/, the rates of fatal injury to employees are presented for the industries with the highest rates. For the three time periods 2000/01, 2001/02 and 2002/03p (p = data are preliminary) the averages were as shown in Table 5.2.

Table 5.2: Average Fatality Rates for 2000/01, 2001/02, 2002/03 in the UK (Page 4, Ref. /51/)

Industry branch	SIC no.[1)]	Fatalities per 100,000 work years	Fatalities per 100 mill. work hours[2)]
Recycling of waste and scrap	37	19.9	12.1
Quarrying of stone	14	9.8	5.9
Extraction of crude oil and gas	11	8.5	5.2
Sewage and refuse disposal	90	7.2	4.4
Agriculture	01, 02, 05	6.6	4.0
Construction	45	5.7	3.5
Mining and extraction of coal	10	5.4	3.3
Manufacturing basic metals	27	4.8	2.8
Land transportation	60	4.1	2.5

1) SIC = Standard Industrial Classification
2) Assuming 44 x 33.5 = 1,650 work hours per work year

5.1.3 Work in the US

Data for the **United States** are published by the US Department of Labor, Bureau of Labor Statistics in their yearly Census of Fatal Occupational Injuries, Ref. /52/. For year 2001 (last available, at present) the following fatality rates in Table 5.3 were given for the most exposed industries.

Table 5.3: Fatality Rates for 2002 in the USA (Ref. /52/)

Industry branch	SIC no.[1)]	Fatalities per 100,000 work years	Fatalities per 100 mill. work hours[2)]
Agricultural production - crops	01	37.0	22.4
Oil and gas extraction	13	28.7	17.4
Coal mining	12	23.5	14.2
Trucking and warehouse	42	21.0	12.7
Lumber and wood products	24	20.1	12.2
Agricultural services	07	13.8	8.4
Agricultural - livestock	02	12.5	7.6
Construction	15/16/17	12.2	7.4
Local and interurban transport	41	8.8	5.3

1) SIC = Standard Industrial Classification
2) Assuming 44 x 33.5 = 1,650 work hours per work year

Instead of looking at different industry branches it is of great interest to look at different professions. The Bureau of Labor Statistics has published an article entitled "Dangerous Jobs" which makes such a comparison, Ref. /53/. The article gives the data shown in Table 5.4.

Table 5.4: Fatality Rates for Different Occupations (from Ref. /53/)

Occupation	Fatality count	Employment (in 1000's)	Fatality rate (per 100,000 workers)	Fatality rate (per 100 mill. work hours)[2)]
Fishers	48	45	106.7	64.6
Timber cutters	98	97	101.0	61.2
Airplane pilots	111	114	97.4	59.0
Structural metal workers	38	59	64.4	39.0
Taxicab drivers	99	213	46.5	28.2
Construction laborers	309	780	39.5	24.0
Roofers	60	205	29.3	17.7
Electric power install./repairs	35	126	27.8	16.8
Truck driver	749	2861	26.2	15.9
Farm occupations	579	2282	25.3	15.4
Police, detectives etc,	174	1051	16.6	10.0
Electricians	117	736	15.9	9.6
Nonconstruction laborers	212	1337	15.8	9.6
Welders, cutters	72	604	12.0	7.2
Guards	101	899	11.2	6.8
Groundskeepers, gardeners	77	832	9.3	5.6
Carpenters	96	1255	7.6	4.6
Auto mechanics	47	819	5.7	3.5
Supervisors, proprietors, sales	212	4480	4.7	2.9
Cashiers	116	2727	4.3	2.6
Total [1)]	6210	126248	4.9	3.0

1) The total does contain **all occupations**, not only those selected for the table. Therefore columns do not add up to total
2) Assuming 44 x 33.5 = 1,650 work hours per work year

A graphical representation of these results is shown in Figure 5.3.

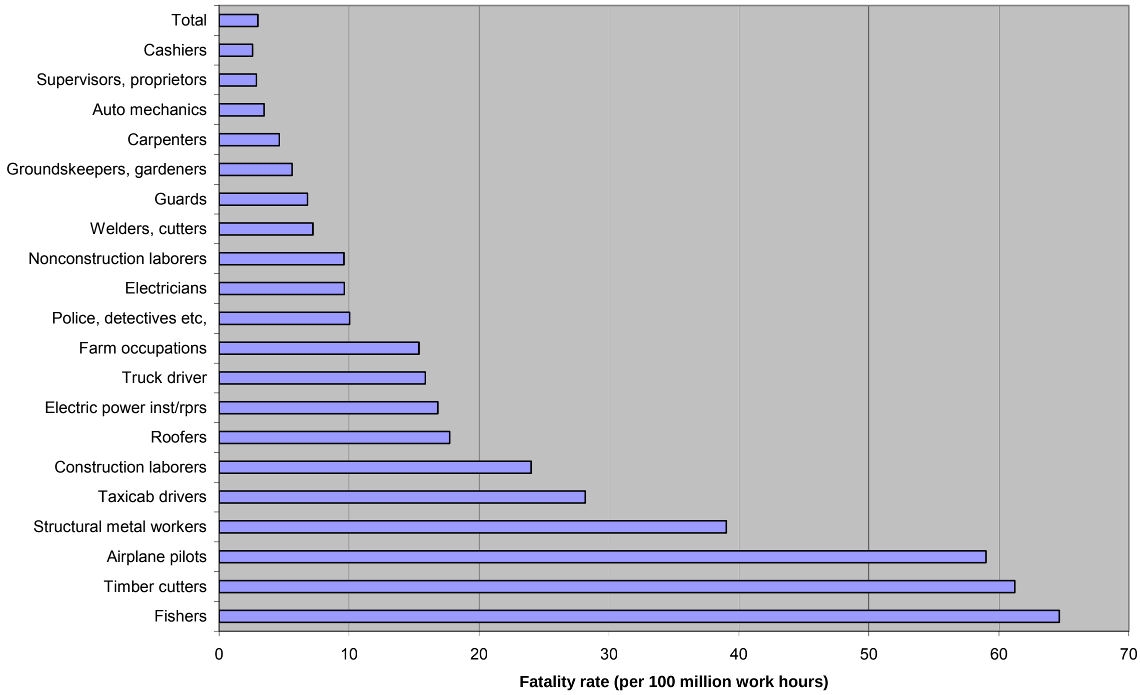


Figure 5.3: Fatality Rates for Different Occupations (from Ref. /53/)

5.1.4 Risk during Certain Activities

It should be clearly understood that also the fatality rates given per 100 million work hours are averages over all (normally) 1,650 hours which comprise a normal working year. They must not be confused with fatality rates per activity hour. For example, airplane pilots in the US have a fatality rate of 59 per 100 mill. work hours. But their normal work year will be composed of x flying hours and 1,650 - x non-flying hours. If we assume x = 500 flying hours and neglect the fatality risk during non-flying hours, the actual risk during flying is

$$59 \cdot \frac{1650}{500} = 195 \quad \text{per 100 million flight hours}$$

Fatality rates per activity hour have been calculated for persons in traffic in Norway, Ref. /54/. They apply to the actual hours while traveling, see Table 5.5.

Table 5.5: Fatality Rates for Norwegian Traffic Participants in Period 1988 - 1993 (from Table G.3.5 of Ref. /54/)

Type of transport	Number of people killed	Number of activity hours (100 mill)	Fatality rate (fatalities per 100 mill activity hours)
Pedestrian	348	17.6	19.7
Cyclist	123	7.1	17.3
Driver or passenger moped	71	1.2	60.5
Driver or passenger light motorcycle	12	0.1	125.8
Driver or passenger heavy motorcycle	129	0.3	425.7
Car driver	682	29.9	22.8
Car passenger	417	23.3	17.9
Taxi passenger	4	0.9	4.5
Bus passenger	23	6.9	3.3
Passenger on commercial domestic airplane	44	0.4	120.5
Passenger on train	13	2.1	6.2
Passenger on ship	10	1.9	5.2
User of leisure boat	295	1.6	189.4
While at home (15-74 years old)	1514	942.3	1.6
While at home (75 years and older)	4846	129.3	37.5

A graphical presentation of the results is shown in Figure 5.4.

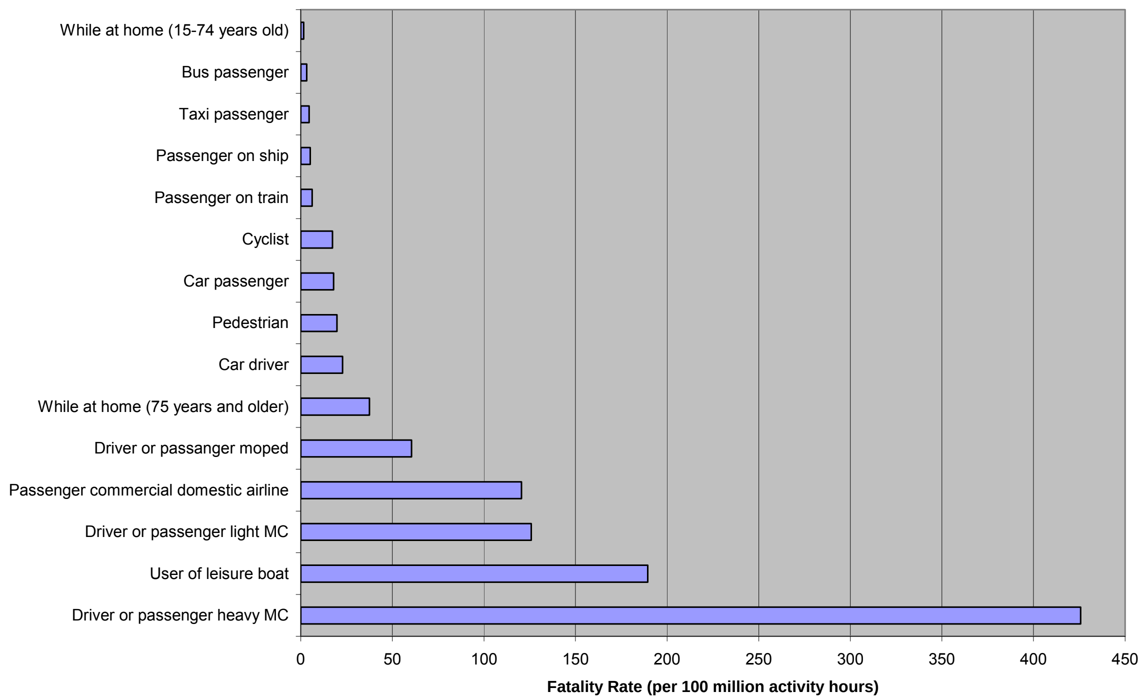


Figure 5.4: Fatality Rates for Norwegian Traffic Participants 1988 - 1993 (Ref. /54/)

A study performed by SINTEF on the risk of helicopter transportation in the North Sea concluded with a fatality rate of 190 per 100 million flight hours. This is an average for the time period 1990 to 1998 for both Norway and the UK, see p. 42 of Ref. /49/.

5.2 Acceptance Criteria in Use

5.2.1 Statoil

Statoil has adopted risk acceptance criteria for use in the whole Statoil Group, both for onshore and offshore activities, Ref. /55/. For individual risk to 1st party persons (employees and other personnel working regularly on an installation) the following upper limits are specified:

FAR < 5 for onshore installations
FAR < 10 for offshore installations

The following definitions are given:

- FAR = fatalities by accidents, per 100 million exposed hours
- The criterion is valid for the operational phase of the installation. For the construction phase the projects are requested to establish their own criterion
- The criterion is valid for the period during which personnel is inside/on the installation. Ordinary travel to/from the installation is not included
- The criterion is to be regarded as average for all personnel groups
- The criterion is to be regarded as average for each 12 month period.

It should be noted that FAR in Statoil's criterion is expressed per **exposed hour**. For personnel on an offshore installation the number of exposed hours per day is 24, while the number of **work hours** per day is 12. The historical FAR values presented in Chapter 5.1.1 were given per work hour. The values would be halved if given per exposed hour.

With respect to special work operations it is stated in Statoil's document, Ref. /55/, that such operations, if they are considered to represent a high risk, should be subject to risk analysis. It is not necessary to quantify the risk in terms of FAR or other risk measures, but it is necessary that the group of people carrying out the risk analysis is composed of people with the necessary qualifications and practical experience, with participation of the person(s) responsible for the operation.

The fact that FAR < 5 (or FAR < 10) is the average for all personnel on an installation implies that certain groups will be exposed to higher values, and other groups to lower values. This fact raises the question of whether it is necessary to define an upper limit of FAR for high-risk groups. Discussions have been going on in Statoil and other companies and a value of FAR < 25 has been mentioned (Ref. /56/) as a possible criterion for a highly exposed group of 1st party persons. Also this value is considered as average over a 12 month period and it covers the total time spent offshore, including ordinary transportation to/from the installation and transportation within the offshore field.

5.2.2 Hydro

Hydro also has adopted risk acceptance criteria for use in Hydro, in their Handbook of Safety Risk Assessment, Ref. /57/. For on-site individual risk it is specified that

- the average probability for loss of life of any person employed or hired by Norsk Hydro when he/she is at work should not exceed 10^{-3} per year.

In Hydro's definition of risk the value of $1 \cdot 10^{-3}$ per year is to be considered as average over all 8760 hours per calendar year. Converting the figure to an hourly rate one obtains a FAR-value of

$1 \cdot 10^{-3}$ / 8760 = $1.14 \cdot 10^{-7}$ per hour = 11.4 per 100 million hours

It should be noted that Hydro's criterion is not an average for all people, but an absolute upper limit for the most exposed group of individuals on the installation. But it is still a time average over the period while at work, meaning that the most exposed individual will experience certain time periods with a risk higher than 11.4 per 100 million hours.

5.3 Proposed Criterion for Immediate Effects

5.3.1 Fatalities

Based on the presented risk figures for other comparable activities and the acceptance criteria in use in the Norwegian petroleum industry it is, for the purpose of this study, applied to use the criterion of

FAR < 25 for the most exposed group of offshore workers

used by Statoil also for diving activities. Since this is a yearly average and the number of hours spent on the installation by an average offshore worker is 3,200 the individual risk per annum (IRPA) is

$25 \cdot 10^{-8} \cdot 3200 = 8 \cdot 10^{-4}$ per year

This figure includes ordinary helicopter transportation to and from the installation and transportation within the field (contributing $5 \cdot 10^{-5}$ per year to IRPA, see Chapter 5.1.1) but no other forms of transportation from home to work, or contributions from home accidents and recreational activities. For a diver a yearly exposure of 80 days = 1,920 hours in saturation is rather normal. If we allow that ¼ of the $8 \cdot 10^{-4}$ per year is due to risk from other causes than saturation diving, this will result in a saturation diving FAR of

$6 \cdot 10^{-4}$/1920 = 31 per 100 million hours

Instead of using the exact value of 31 we propose to use the already well established value in the Statoil system for the group of most exposed persons on a platform, that is

FAR = 25 per 100 million hours in saturation

In order to achieve the goal of limiting the yearly risk to

IRPA = $6 \cdot 10^{-4}$ per year for a full time activity

it might be necessary to limit the number of days per year in saturation or, better, to introduce risk-reducing measures which lower the FAR value.

For surface-oriented offshore diving it is not reasonable to define a FAR criterion per hour in the water. The results in Chapter 4.2.6 show that the frequencies for decompression illness, non-DCI injuries, and near misses are much higher than those for saturation diving. Even though fatalities have not been recorded for surface-oriented diving one must expect that a rather high frequency for fatalities would apply. It is therefore recommended to use only the yearly criterion of

IRPA = $6 \cdot 10^{-4}$ per year for a full time activity

5.3.2 Risk Indicator "Non-DCI Injuries"

It is not common practice to define acceptance criteria for injuries, but for risk management purposes the injury rate can be useful as an indicator. For offshore workers an injury rate of 1,400 to 3,300 per 100 million work hours was recorded in 1999, see Chapter 5.1.1. Per work hour, this rate is a factor 1000 higher than the fatality rate. For saturation diving the ratio is lower, 22,500/27 = 830, see Chapters 4.5.1 and 4.5.3. Note that the reporting criteria for diving injuries differ from those for offshore workers in general. With the present reporting routines for diving injuries a value of

$830 \cdot 25 \cdot 10^{-8} \approx 20{,}000$ non-DCI injuries per 100 million hours in saturation

seems to be a reasonable "alarm level" since it is expected to result in a FAR-value near the acceptance criterion of 25. When exceeding 20,000 non-DCI injuries per 100 million hours in saturation, extra safety measures should be implemented.

20,000 non-DCI injuries per 100 million hours in saturation might be considered a high number compared to the number of injuries recorded on platforms, but it must be remembered that this also includes first aid treatment and that almost half the non-DCI injuries reported from divers are outer ear infections, see Figure 5 in Ref. /13/.

With a goal of FAR < 10 the alarm level should be:

$830 \times 10 \cdot 10^{-8} \sim 8{,}000$ non-DCI injuries per 100 million hours in saturation.

5.3.3 Risk Indicator "Near Misses"

Another possible risk indicator is the number of reported near misses. At present the rate of reporting is 6,700 near misses per 100 million hours in saturation (last available 5-year average, see Chapter 4.5.3). With a present FAR = 27 and a goal of FAR = < 25 the criterion or "alarm level" for near misses should be

6700 x (25/27) = 6,200 near misses per 100 million hours in saturation.

With a goal of FAR < 10 the alarm level should be:

> 6700 x (10/27) = 2,500 near misses per 100 million hours in saturation.

5.4 Long-term Non-Fatal Effects

Until now Chapter 5 has been concerned with the immediate effects of diving, i.e. with cases of death or injury while diving, while being in decompression, or immediately thereafter. But it is known that diving can have long-term effects a long time after the actual diving event, in many cases several years later. The long-term effects can be damage of the lung, damage of the central nervous system (CNS), post-traumatic stress disorder (PTSD), and others. Some of these may lead to permanent disablement, some, directly or indirectly, to death.
When approaching the question of the acceptability of risk one has to make sure that

- there is a causal relation between diving and the long-term health effects
- there is a comparable base risk (without diving) with which the risk increase due to diving can be compared.

The first point is still being discussed in the scientific community but there are strong indications that diving, in some cases, will lead to long-term health effects.

The second point can be approached by consulting statistical data on the occurrence of certain sicknesses and reasons for death, for comparable groups of the population. The acceptance criterion can then be formulated by stating:

> Diving should not lead to an increase of risk by more than a certain percentage above the base risk.

In Chapter 4.6.3 disablement rates were presented for the general public and for pilots. For the age group 50-59 years the following rates were found:

- General public: 18 per 1,000 non-disabled per year
- Pilots: 13 per 1,000 non-disabled per year.

For divers an overall average, regardless of age, was estimated:

- Divers: 32 per 1,000 non-disabled per year.

This figure is based on the uncertain assumption of 200 active divers, see Chapter 4.6.3.

5.5 Proposed Criterion for Long-term Non-fatal Disablement

Table 5.6 summarizes "disabling" rates for the general public and professional pilots.

Table 5.6: Disabling Rates, General Public and Pilots

Age group (males)	Disabled per 1,000 non-disabled per year (Ref. /32)	Disqualifications per 1,000 pilots per year (Ref. /33)
40 - 49	6	7
50 - 59	18	13

For divers the corresponding figures should not be much higher (max. 50 % higher) than the figures in Table 5.6. The figure of 50 % is proposed to reflect that the risk of being disabled due to diving-related causes should be small compared to the average risk in the general population. In order to determine the actual disabling rate for divers one has to establish a better system for recording this rate.

5.6 Long-Term Fatal Effects

5.6.1 Example from Radioactive Exposure of Workers

Even though there may be no direct evidence for fatal long-term effects it is of interest to discuss the acceptability of such effects in the light of other industrial experience.

For professionals exposed to radioactive radiation in their daily work the national and international authorities have adopted a maximum yearly dose of 20 mSv (mSv = milli Sievert). (This dose has been gradually reduced over the years, from 50 mSv in 1970 to 20 mSv now). The relationship between radiation dose and the probability to develop cancer is known from a great deal of research. The International Commission on Radiological Protection (ICRP) publishes recommended dose-risk conversion factors, Ref. /58/. For fatal cancer this factor is

0.04 per Sv

For a dose of 20 mSv/year the probability to develop fatal cancer is therefore

$20 \cdot 10^{-3} \cdot 0.04 = 8 \cdot 10^{-4}$ per year

This probability can be compared with the probability to develop fatal cancer in unexposed people. For men the following death rates from malignant neoplasms are given in Table 112 of Norway's Statistics Year Book 2003 (Ref. /59/) for the years 1996 to 2000:

- 30 - 39 years old: 14 per 100,000 inhabitants
- 40 - 49 years old: 57 per 100,000 inhabitants
- 50 - 59 years old: 207 per 100,000 inhabitants

If one looks at the youngest group and uses the figure of 14 per 100,000 inhabitants one can say that the base probability to die of this sort of cancer is

$14/100,000 = 1.4 \cdot 10^{-4}$ per year

The additional probability of $8 \cdot 10^{-4}$ per year from radiation exposure represents therefore an almost six-fold increase of the cancer risk. If one uses as the base risk the probability to die due to any sickness (not due to accidents) one can use the fatality tables from Norwegian Official Statistics (NOS), Ref. /60/ which give for the year 2001 the following numbers for men:

- 35 - 44 years old: 117.8 per 100,000 inhabitants per year
- 45 - 54 years old: 305.8 per 100,000 inhabitants per year

Using 200 per 100,000 inhabitants per year as an average the base probability to die from any sickness becomes

$200/100,000 = 2 \cdot 10^{-3}$ per year

The additional probability of $8 \cdot 10^{-4}$ per year from radiation exposure represents in this case a 40 % increase.

5.6.2 Example from Radioactive Exposure of the Public

Another example of acceptable risk from radiation exposure can be found in a report by the Swedish Nuclear Inspectorate (SKI), Ref. /61/. In this case it is an acceptance criterion for 3rd party persons, i.e. not workers at the installation in question, but members of the public. For a planned radioactive waste disposal facility the US Environmental Protection Agency (EPA) has set a limit of 8.5 additional fatal cancer cases per million members of the population per year. Assuming approximately the same cancer fatality rate in the US as in Norway we find in Ref. /59/ average values for 1996 to 2000 for all ages:

- Men: 257 fatal cancer cases per 100,000 inhabitants per year
- Women: 217 fatal cancer cases per 100,000 inhabitants per year

Using 237 fatal cancer cases per 100,000 inhabitants per year as an average this corresponds to 2,370 fatal cancer cases per million inhabitants per year. The acceptable 8.5 additional cases correspond therefore to an increase of

$(8.5/2370) \times 100 = 0.36$ %

One has to keep in mind that acceptance criteria for 3rd party persons are always much more stringent than those for 1st party persons. In case of divers we are of course talking about 1st party persons.

5.7 Proposed Criterion for Delayed Fatalities

If one follows the same philosophy for establishing risk criteria as for long-term non fatal diving risk one can argue that it is reasonable to allow a 10 % increase of the fatality rate due to any other sickness. For men 35 - 44 years old this fatality rate is 118 per 100,000 inhabitants, Ref. /60/. This means an additional fatality risk of

$0.1 \cdot 118/100,000 = 1.2 \cdot 10^{-4}$ per year is considered acceptable. It is of interest to compare this to the acceptance criteria proposed for immediate risk and to see how they would sum up to a total lifetime risk for a diver with, for example, 15 years of diving activity and 40 years of post-diving life. His accumulated life time risk due to diving would be

$$25 \cdot 10^{-8} \cdot 15 \cdot 1920 + 40 \cdot 1.2 \cdot 10^{-4} = 0.0072 + 0.0048 = 0.012 = 1.2\ \%$$

Figure 5.5 shows this graphically.

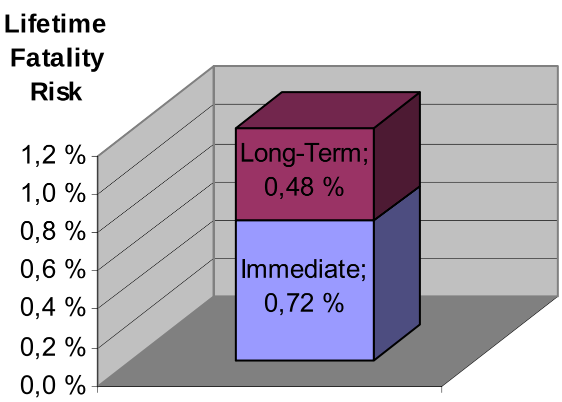


Figure 5.5: Maximum Possible Contributions from Immediate and Long-term Fatalities to Lifetime Accumulated Risk, with Proposed Acceptance Criteria

The fact that the two contributions are approximately equal shows that there is a reasonable balance between the two acceptance criteria for immediate and delayed fatality risk.

It should be noted that at present there is no indication that there are any delayed fatalities due to diving other than suicides, which must be treated separately. It is therefore not possible to calculate any risk figure for this type of consequence. Nevertheless it is useful to establish an acceptance criterion for the case that a risk measure can be established in the future.

6. INCIDENT INVESTIGATION

6.1 Introduction

Incident investigations are increasingly seen as pertinent to organizational learning from past failures and to avoid similar incidents happening in the future. Traditionally an incident report will provide an organization with a description of events which principally focus on the status of the system at discrete moments along a timeline. Reports usually place the emphasis on developing a description of consequences rather than causes of the incident, explaining what happened but not why it happened. Such analyses are invariably technically oriented involving detailed descriptions of plant, equipment, reactions and their governing logic systems. It is only by adopting investigation techniques which explicitly identify root causes, i.e. the reasons why an incident occurred, that organizations may learn from past failures and avoid similar incidents happening in the future.

6.2 Root Cause Analysis

The principles of root cause investigations have long been recognized in fields such as engineering, quality control and environmental management, as well as in safety management. Root cause investigation techniques have been successfully borrowed from other disciplines and adapted to meet the requirements of the safety field. To put it simply, root cause analysis is a tool designed to help incident investigators describe what happened during a particular incident, to determine how it happened and to understand why it happened. Differences arise however, in the particular emphasis of the techniques. Some focus on management and organizational oversights and omissions while others consider human performance/error problems in more depth. Each has its strengthes and weaknesses. Typical root cause methodologies include:

- MTO (Man[1], Technology and Organization) Ref. /62/
- CREAM (Cognitive Reliability and Error Analysis Method) Ref. /63/
- HPIP (Human Performance Investigation Process) Ref. /64/.

Root cause analyses are based on a systems approach to incident causation, Ref. /65/, i.e. most incidents are caused by complex chains of events in which human, technology and organization reciprocally affect each other. However, the definition of a root cause varies between authors and root cause methodologies, with different levels of causation being adopted by different organizations. Comparisons between different methods are therefore not always straight forward.

Generally most systems distinguish between three levels:

1. The operator or technical system at the sharp end
2. Latent conditions in the organization
3. Risk controls imposed by external organizations.

The operator or technical system at the sharp end refers to the direct cause or causes of an incident. These include the factors directly involving the human and technical resources, e.g. attention slips or memory lapses in relation to task performance, lack of

[1] *MTO is a direct translation from Swedish Människa, Teknik och Organisation (Human, Technology and Organisation). The use of Man instead of Human reflects ease of recognition as the method is frequently used and referred to in both English and Scandinavian languages simultaneously*

situation awareness, erroneous communication, violation of procedures, as well as technical faults, poor ergonomic design and equipment damage.

The direct causes of an incident will often happen as a result of the latent conditions in the organization. The latent conditions are root causes that impact on the operators or the ability of technical systems to perform the task at hand. Latent conditions include factors such as maintenance, planning, leadership, supervision, competency, procedures, safety culture and other organizational issues relating indirectly or directly to task performance.

Risk controls imposed by external organizations consist of the international and national laws and regulations the organization must or should adhere to, as well as factors such as the market conditions, new research and development, audits of the safety management system and customer requirements. The external controls play an important role in defining how an organization manages risks.

6.3 Incidents investigated

The incidents investigated were selected to see if different types of severity in relation to reporting requirements would impact on the categorization of the direct and root causes. Three levels of investigation were selected from in-depth analysis of severe incidents, via incidents reported to the NPD, to all incidents reported in the companies' internal incident databases. The goal was to gain a comprehensive picture of the direct and root causes and to identify if any were conspicuous when the consequences of the incidents were more severe.

Due to the quality and quantity of the data available the analysis employed different methods to achieve the best result. The investigations conducted were:

1. In-depth analysis of three "Near-Miss" incidents:
   - Accidental exposure to pressure reduction, 2000
   - Diver hit on helmet by frame structure, 1997
   - Clamp tilting and falling on diver, 1997

2. Incidents reported to the NPD
   - Report from the dive database - DSYS 2002

3. Synergi reports (short version):
   - Statoil,1996-2003
   - Stolt Offshore, 1999-2003
   - Subsea 7, 1999-2003

For each investigation a brief description of the method employed and the results will be described.

6.4 In-depth Analysis of Three "Near-Miss" Incidents

6.4.1 Method

The in-depth analysis of three "Near-Miss" incidents was based on the MTO (Man, Technology and Organization) perspective, Ref. /66/. MTO is a systems perspective which has developed over the years as different industries have been engaged in addressing the influence of organizational and human factors on safety. The MTO perspective has been used in the aviation, nuclear power generation, railway transportation and offshore petroleum industries since the 80's in both small and large scale accident and incident investigations.

In the last few years the Norwegian petroleum industry has had increased focus on the development of investigation methods based on the MTO perspective. This focus was also enhanced when the supervisory authorities outlined requirements in the new petroleum regulations for the use of a MTO perspective during investigation of situations of hazard and accident.

The MTO perspective is derived from accident investigations and research which specify that most accidents are caused by complex chains of events in which human, technology and organization reciprocally affect each other. In order to prevent accidents one has to identify underlying human, organizational and technological causes. These root causes have historically proven to be a combination of deficiencies in organizational systems, lack of competence and training, safety culture, ergonomics and technology.

MTO is a perspective where knowledge from areas such as human factors, psychology, safety engineering and organizational theory are used in order to identify the way humans, technology and organizations interact and affect each other. Consequently, MTO is a collection of methods developed to systematically identify and analyze underlying causes for accidents and related technical and organizational barriers that need to be in place to prevent the reoccurrence of the accidents.

The usual steps in a MTO analysis are:

1. To document what has happened; step by step in an event diagram
2. To identify direct and root causes
3. To analyze which organizational and technical barriers failed and which functioned
4. To suggest actions based on the previous steps.

This is done using the following methods: a) an event and cause analysis, Ref. /67/, b) a barrier and root cause analysis, Ref. /68/ and c) a non-conformity analysis, Ref. /69/. These three analyses are documented in a chart which shows the flow of events.

The three incidents selected for analysis were chosen due to the high quality and rich detail available in the companies' incident reports. They were not selected on the basis of severity or causes. The goal of the in-depth analysis was to illustrate the direct and root causes found in diving operations.

6.4.2 Accidental Exposure to Pressure Reduction

The incident happened on the 5th and 6th October 2000, Ref. /70/. According to the incident report by operating company, six divers were accidentally exposed to pressure reduction from a depth of 14 msw to the surface in a time period of 4 hours and 10 minutes. This process should under normal circumstances take 24 hours.

None of the divers were injured but the diving MD who assessed the incident stated that a worst case scenario would have caused neurological damage and potentially resulted in loss of license or physical disability. The diving MD thought it unlikely that the incident could have caused any fatalities.

The direct cause of the incident was malfunctioning equipment, but there were many root causes such as poor supervision, violation of procedures, inadequate planning and competency deficiencies. These are all related to inadequate work practices. A graphic description of the incident is shown in Appendix C.

6.4.3 Diver Hit on Helmet by Frame Structure

The diving incident happened 3rd November 1997, Ref. /71/. The incident as described in a company report happened as follows. The pipelay/trenching vessel was removing buoyancy elements at KP 546 in the Dutch Sector. The diving work was carried out by surface-oriented diving using a wet bell at a water depth of approximately 30 metres.

The incident happened when a 7.5 ton suppressor frame was lowered to the seabed from the diving vessel to pick up a buoyancy tank on the pipeline. Just before the frame arrived at the buoyancy tank one of the two divers involved in the task went partly inside the frame to catch a strap. This was done without asking the permission to do so. He was subsequently hit on his helmet by part of the frame structure causing damage to the helmet and the video camera fixed to it. The diver did not sustain any injuries.

The direct cause of the incident was incorrect work execution. Root cause identified was insufficient risk assessment in relation to task performance. A graphic description of the incident is shown in Appendix C.

6.4.4 Clamp Tilting and Falling on Diver

The incident happened 31st July 1997, Ref. /72/. According to the company report the incident happened as follows. The diving vessel was installing a 16" riser from Visund at the Dome top of Gullfaks A. The working depth was 70 metres. Two divers were working on the dome top installing a clamp for the horizontal riser. A lift bag was used to make the final installation. The clamp was lowered on its foundation beam and the closing of the clamp was about to start. Diver 1 descended down to the dome top while diver 2 was working on the side of the clamp. Diver 1 planned to go up to the clamp area again and used the lift bag dump line for climbing, causing air to dump from the bag. This resulted in the clamp tilting and falling on diver 2, temporarily trapping him, and causing severe damage to the diving helmet and SLS unit. The main supply of air was still OK and diver 2 returned to the bell on his own after being freed and assisted by diver 1. The diver received no injuries.

The direct cause of the incident was inadequate work planning and incorrect work execution. The direct causes related to equipment design and markings. A graphic description of the incident is shown in Appendix C.

6.4.5 In-Depth Analyses - Conclusions

The conclusions derived from the in-depth analyses illustrate how human, technical and organizational factors all play a role in causing diving incidents. Direct causes linked to work execution as well as technical errors were identifiable. Root causes related to amongst others things planning, procedures, competency, and safety culture. The quality of the incident description and original analysis was critical to perform further in-depth analysis and it was clear that the more effort that was put into the original analysis the better the quality and, hence, the identification of direct and root causes.

The selection of incidents, however, did not provide a comprehensive picture of typical causes as the sample size was too small. It would be desirable to conduct further in-depth investigations, but the quality of the incident reports available does not permit such investigations. To develop a better picture of incident causes, there was a need to enlarge the sample size. This was done using incident reports submitted to the NPD and Synergi reports from companies involved in the project.

6.5 Incidents reported to the NPD

The NPD Report from the dive database - DSYS 2001, Ref. /13/ consists of statistics and analyses based on data from the period 1985-2002. The NPD states that there still is some uncertainty connected to the data, in particular to the aspects of the level and the form of reporting. The report was used to help identify direct and root causes based on the statistics. No further analysis was performed.

The report focuses primarily on the consequences of diving incidents and accidents and says little about the direct and the root causes related to Man and Organization. It does illustrate the incidents related to system failure, i.e. Technological failures. The value of the analysis, however, is affected by the categories "unknown" and "other" comprising 45 % of all the data. The major contributors identified were:

- Gas supply system (12 %)
- Personal diving equipment (11 %)
- The vessel (8 %)

with the diving bell (5 %), tools (4 %), the chamber system (4 %), the handling system (4 %), the hot water system (2 %), the habitat (1) and the DP-system (2 %), the life support system (1 %) contributing the remaining 24 %.

Given the time span of the statistics, 17 years, no analysis was made to identify trends over time. For example, personal diving equipment has improved significantly in the last decade, yet the analysis fails to confirm or reject an expected reduction in technical failures relating to personal diving equipment. A greater focus on trends would have been desirable.

The lack of identification in relation to incident causation relating to Man and Organization makes the report of limited value for the investigations conducted in this chapter. At the same time the deeper analysis of the technical failures may be deceptive as the large number of "unknown" or "other" technical failures will interfere with the result and potentially be a misleading. The report has therefore primarily been used as a support document.

6.6 Synergi Reports (short Version)

6.6.1 Introduction

Synergi is an incident investigation database used frequently in the offshore petroleum industry by individual operators. The way the database is used varies according to the goals and means of the organization and the competence of the user. The database provides a means of categorizing and quantifying information gathered in investigations and also allows the investigator to specify corrective actions.

The database is not perfect as it fails to take into account all relevant factors. The accident database controls what information can be registered and by definition limits the ability to discover trends, or make correct interventions outside the boundaries of the database categories. This restriction can have a considerable impact on an investigation. Equally, the incident descriptions are only as good as the data entered. Limited or insufficient data will inevitably lead to reports of reduced quality.

The reports analyzed were of varying quality and it was not always easy to identify direct and root causes. In cases where the direct or root causes were not identifiable, no recording was made. In the reports analyzed there was no indication of the estimated risk of the incidents and the long term consequences of injuries to involved personnel. These factors would be of interest to establish actual risks associated with task performance.

The analysis of the short Synergi reports included the following:

- Statoil (1996-2003)
  * 162 incidents, saturated diving from the Norwegian sector
  * 89 incidents, offshore surface diving from the Norwegian sector

- Subsea 7 (1999-2003)
  * 26 incidents from around the world

- Stolt Offshore (1999-2003)
  * 115 incidents from around the world.

This gives a total number of 392 Synergi reports. The reports from Stolt Subsea 7 JV did not distinguish between saturation and offshore surface-oriented diving. However, it was assumed that Stolt Offshore and Subsea 7's diving activities were in saturation.

6.6.2 Method

6.6.2.1 Root Cause Analysis

The method used for the analysis of the Synergi registered incidents reflected the type of data available. Initially a preliminary analysis was conducted to identify relevant categories. These were derived from typical root cause analysis methods, e.g. MTO, CREAM and HPIP. The categories encompassed two levels: direct causes and root causes. In adherence to the MTO methodology, the categorization differentiates between three distinctive cause types; defining causes relating to human and technology as primarily direct and causes relating to the organization as root causes.

The categories were tested to see if all causes registered in the involved companies' Synergi databases were included. This was done on a sample size of 30 cases. The categories were then adjusted to include new relevant items and remove categories seen as irrelevant. Finally, the 392 cases were analyzed and categorized according to the categories described below, see Appendix B for a complete listing. To ensure that the categorization based on the short version of the Synergi databases was reliable and valid, 10 % of the incidents were further analyzed based on the long version of the Synergi reports.

The following categorization was found to be reliable and valid. The direct causes relating to man and technology are described first, followed by the root causes.

6.6.2.2 Man

Physical state refers to human error caused by the following and also includes illness or sickness caused by working under decompression:

- Fatigue
- Cold, hot, noise, etc.
- Fitness to dive
- Health
- Work environment (physical and psycho-social).

Mental state refers to human error caused by

- Attention slips
- Memory lapses
- Complexity
- Workload/stress.

Work execution refers to human error caused by the way the task is performed:

- Decision making (rule and knowledge-based mistakes)
- Situation awareness (rule and knowledge-based mistakes)
- Work routines (informal).

Communication refers to human error caused by communication errors in terms of:

- Quality
- Quantity
- Existence.

Violation refers to human error caused by:

- Deliberate breaches of procedures, rules, regulations, etc.

6.6.2.3 Technology

Ergonomics refers to failures in overall design and layout such as:

- Design of work place
- Design of sleeping quarters
- Access to equipment.

Equipment design refers to the quality of equipment design in terms of:

- Functional requirements
- Markings
- Construction complexity
- User friendliness
- Components.

Malfunctioning equipment refers to technical errors caused by malfunctioning equipment:

- Reliability
- Breakdowns
- Leakage.

Equipment damage refers to technical errors cased by equipment damage in relation to:

- Functional requirements
- Markings
- Construction complexity
- User friendliness
- Components.

6.6.2.4 Organization

Supervision refers to the impact of line management in terms of:

- Quality
- Quantity
- Leadership style.

Competence refers to the systems for development and maintenance of competence:

- Worker
- Colleagues
- Trust in each others competence
- Training: quality and quantity
- Certification control.

Safety culture refers to interaction between risk controls, attitudes and behaviors in relation to task performance:

- Confidence in organization
- Control over own work

- Quality of emergency procedures
- Acceptance criteria for risks
- Communication of priorities
- Time/financial pressure
- Deviations from regulations
- Productivity vs. safety
- Risk management.

Employment issues refer to the impact the organization has on:

- Job insecurity
- Multi-skilling
- Company support for contractors
- Contract.

Procedures refer to the prescribed actions diving personnel has to follow incl. directives, rules and regulations:

- Quality
- Quantity
- Existence.

Planning refers to the planning activities in relation to task performance:

- Quality
- Quantity
- Existence.

Maintenance refers to the activities performed to maintain technical systems at a safe level according to company, national or international standards:

- Quality
- Quantity.

6.6.3 Results

6.6.3.1 Overview

A total number of 392 incidents were analyzed, see Table 6.1. Looking at the direct causes (man and technology) a split of 62 % for Man and 38 % for technological errors was found. This ranged from 70 % man and 30 % technology at one company to 58 % man to 42 % technology at another. It was only possible to identify root causes for 193 of the 392 incidents. These were primarily related to errors caused by man.

Table 6.1: Percentage Distribution of direct Causes and Root Causes

Direct causes	Man (M)	Percentage
391 cases	Physical state	17
	Mental state	7
	Work execution	24
	Communication	4
	Violation	10
	Sum Man	**62**
	Technology (T)	
	Ergonomics	3
	Equipment design	13
	Malfunctioning equipment	20
	Equipment damage	2
	Sum Technology	**38**
Root causes	Organization (O)	
193 cases	Supervision	10
	Competence	7
	Safety culture	12
	Employment issues	11
	Procedures	22
	Planning	21
	Maintenance	17
	Sum Organization	**100**

Of the total 392 **Synergi** reports 21 have no M/T entry, only O. On the other hand, 20 reports have an entry for both M and T. This results in a number of "cases" of

392 - 21 - 20 = 391 (see 1st column of table)

to which the M/T counts are to be related when calculating percentages. 193 is the number of reports which give a root cause.

6.6.3.2 Direct causes: Saturation Diving vs. Surface

A comparison analysis of the direct causes between saturation and surface diving was conducted. There appears to be some distinct differences between saturation and surface diving. The results indicate that divers in saturation commit more errors due to their physical and mental state and have more problems with malfunctioning equipment than surface divers. This probably reflects the unique working environment, where divers live in and work from a bell for considerable time periods. Violations and problems relating to equipment design were greater issues for surface diving. Figure 6.1 shows the percentage distribution of the direct causes divided into saturation and surface diving.

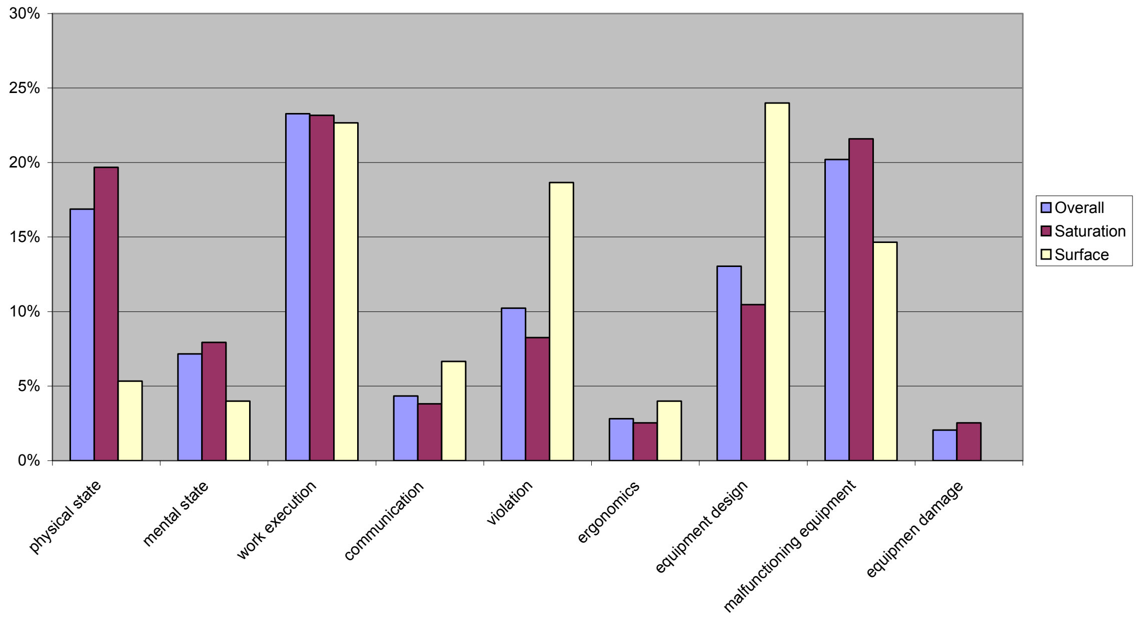


Figure 6.1: Percentage Distribution of Direct Causes (M&T), Saturation and Surface

6.6.3.3 Root Causes: Saturation vs. Surface

The analysis of the root causes comparing saturation with surface diving activities identified some interesting differences. The most extreme differences were found for supervision were many incidents for saturation diving were identified and comparatively few for surface diving. This may reflect the different roles the supervisors have in relation to the diving activities. Planning was also identified to a lesser extent as a root cause for surface diving. Employment issues were in contrast not identified as a root cause in any of the saturation diving incidents but played a significant role in 30 % of the surface dives. Figure 6.5 shows the root causes divided into saturation and surface diving activities.

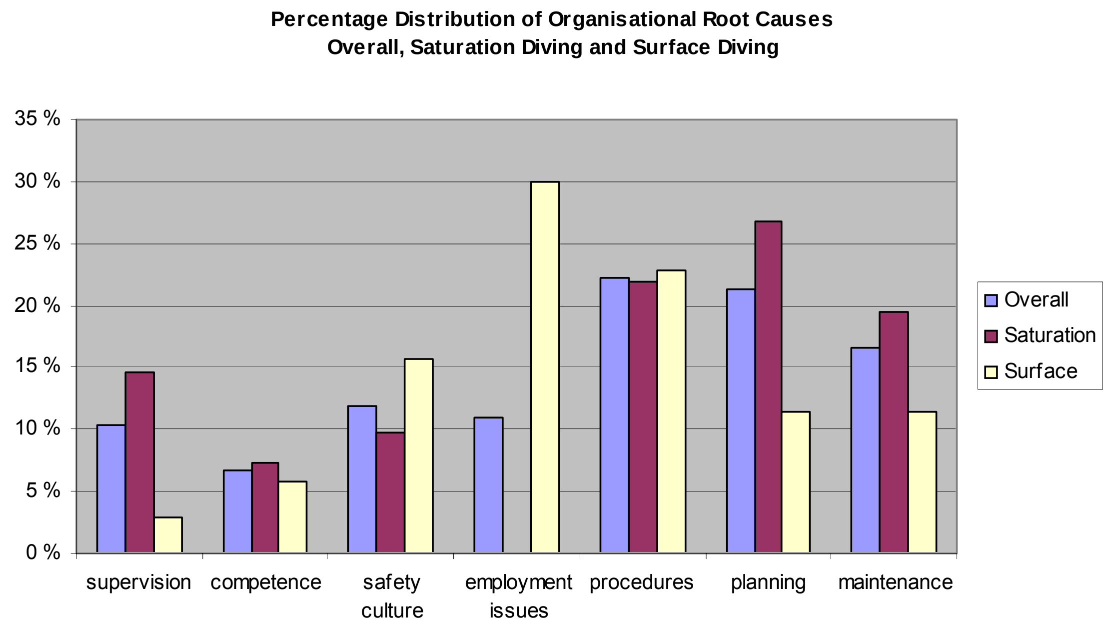


Figure 6.5: Percentage Distribution of Root Causes (Organizational), Saturation and Surface Diving

6.6.3.4 Conclusions Synergi Reports

The results from the analysis of the **Synergi** reports deviate from the general picture often found in other industries. Based on accident statistics from other industries, one would expect an 80-90 % man and 10-20 % technology distribution. The average rate of 62 % for man and 38 % for technology can be explained in several ways. Diving is a unique industry where the reliance on well designed, maintained and functioning equipment is critical for safe operations. Equipment faults can rapidly have severe consequences. The divers, thus, have an increased focus on the equipment and may report faults more rapidly than, e.g. platform personnel.

An alternative explanation is associated with potential underreporting of incidents relating to human error. The divers are more dependent on good working relationships internally in the team and with the crew on the vessel. Reporting on each other may be frowned upon, especially if work is stopped as a result. However, whether the first, the second, or both explanations are correct is unclear.

Figure 6.2 shows the distribution of man, technology and organizational factors. The dominating organizational causes identified are linked to the work practices in the sea and on the diving vessel. These factors are associated with the diving contractor. The factors that the operating company has a greater influence on are less dominating. The figure was shown to experts from diving contractors, operating companies, NPD and union representatives. The few comments received were related to the relatively low level of man-caused errors.

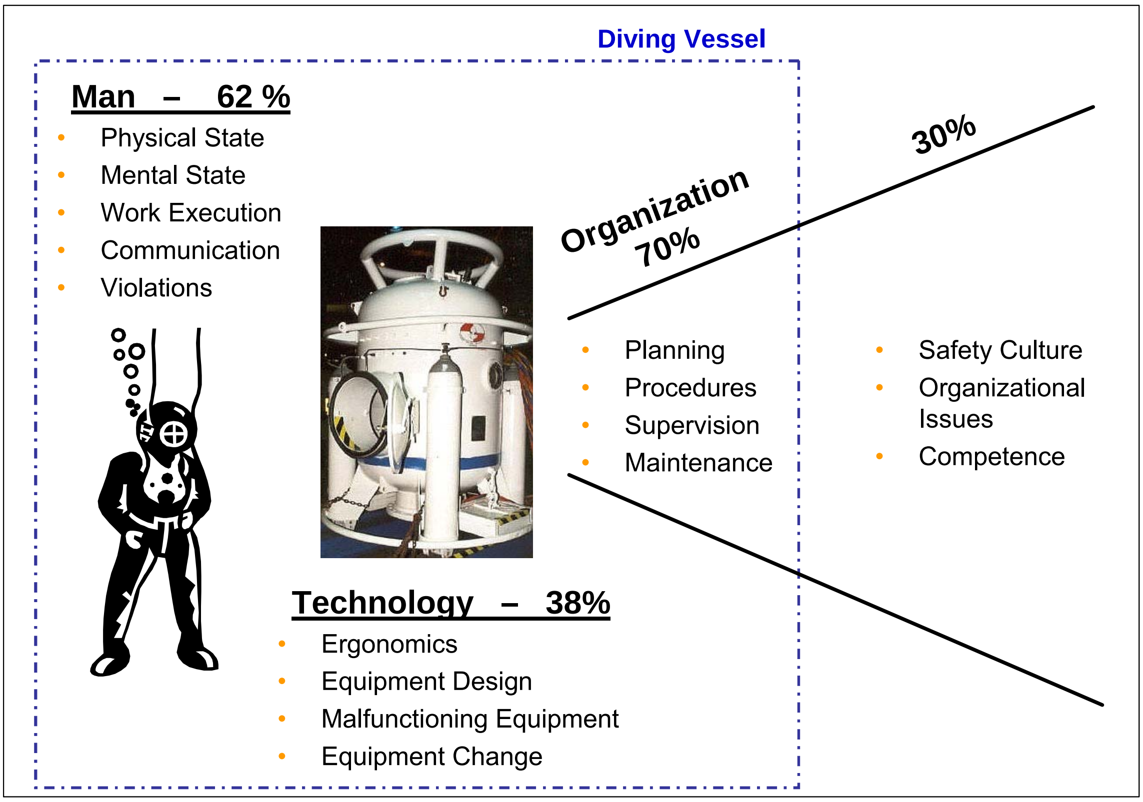


Figure 6.2: Man-Technology-Organization Diagram

Further analysis of the data has identified some root causes quite strongly linked to direct causes. However, this was only possible for a few root causes. There appears to be a strong connection between malfunctioning equipment and maintenance. 75 % of the root causes identified for malfunctioning equipment were related to maintenance. A connection between work execution and procedures was also found. 55 % of the root causes identified for work execution were related to procedures. A relationship between mental state and planning was also evident. 59 % of the root causes identified for mental state were planning. No clear results were established for the remaining categories.

6.7 Conclusions from Incident Investigations

The results obtained from the three levels of incident investigation paint a coherent and relatively clear picture of the causal factors involved in diving incidents. The impact of work execution, physical state and malfunctioning equipment are the major contributors (comprising 60 % of direct causes), highlighting the importance of the interaction between man, technology and the immediate environment. The dominant root causes: procedures, planning, maintenance and supervision (comprising 70 % of the root causes identified) are strongly linked to local work execution and management, whereas further removed issues such as safety culture and organizational issues (comprising 23 % of the root causes) were seen as less pertinent. Thus, the main contributors to diving incidents are reported to be work practices predominantly found locally in the sea, on and around the diving vessel.

The factors identified as frequent contributors to incidents correspond well with the findings of a HSE Research Report into the attitudes to safety culture among professional divers and offshore workers, Ref. /73/. In the study involving 233 professional divers and 120 non-diving age-matched offshore workers, divers in particular emphasized immediate surroundings as critical to safe operations, e.g. supervision, working environment and the competency of the team. This was seen as a reflection of the task and the fact that the divers mainly work for contractor companies. The safety culture of the operator companies seldom has a significant impact on the diving operations. Indeed, safety culture was given a lower than expected weighting by divers than by offshore workers in general as a root cause of incidents.

7. RISK MODELING

7.1 Purpose

The purpose of the risk model is to describe and to analyze the correlation between the various factors influencing risk and the overall risk outcome. Understanding this correlation makes it possible to understand changes in risk as they are revealed by historical, statistical trends, and to identify measures for reducing risk in a cost-effective way.

7.2 Influence Diagram

One way to visualize the correlation between the factors influencing risk and the overall risk level is by means of influence diagrams. This method has been successfully used in other studies and the method used here follows closely the one used by SINTEF in a safety study of helicopter transportation, Ref. /49/.

Figure 7.1 (next page) shows the influence diagram for diving. The diagram was structured in four levels:

- 1st level: risk for incidents/accidents
- 2nd level: the operational or direct causes leading to incidents/accidents
- 3rd level: the indirect or root causes, mainly related to organizational issues
- 4th level: external causes.

At the second level, the direct causes are categorized as either related to "Man" or "Technology", while all the indirect causes are mainly related to "Organization". In this way, all three elements of MTO (Man, Technology, Organization) are clearly distinguished and visualized.

The direct causes at the 2nd level are called Risk Influencing Factors or RIFs[2] in Ref. /49/. There, a distinction was made between frequency influencing RIFs and consequence influencing RIFs. In principle, this is an important distinction, but in our case many RIFs have an effect on both frequency (probability) and consequence. A separation into two categories is therefore complicating and not considered necessary.

For an explanation of the direct causes and the root causes it is referred to Chapter 6.6.2. The 9 direct causes and 7 root causes are shown with arrows in Figure 7.1. Each arrow has a percentage corresponding to the percentages found in the analysis of the incident reports, see Table 6.1.

[2] *RIFs at the 2nd level are called "Operational Rifs" in Ref. /49/. The root causes at the 3rd level are called "Organizational RIFs", but we reserve the expression RIF to the factors at the 2nd level only. Ref. /49/ uses the notion "Regulatory and customer related RIFs" at the 4th level, but we prefer "External Causes"*

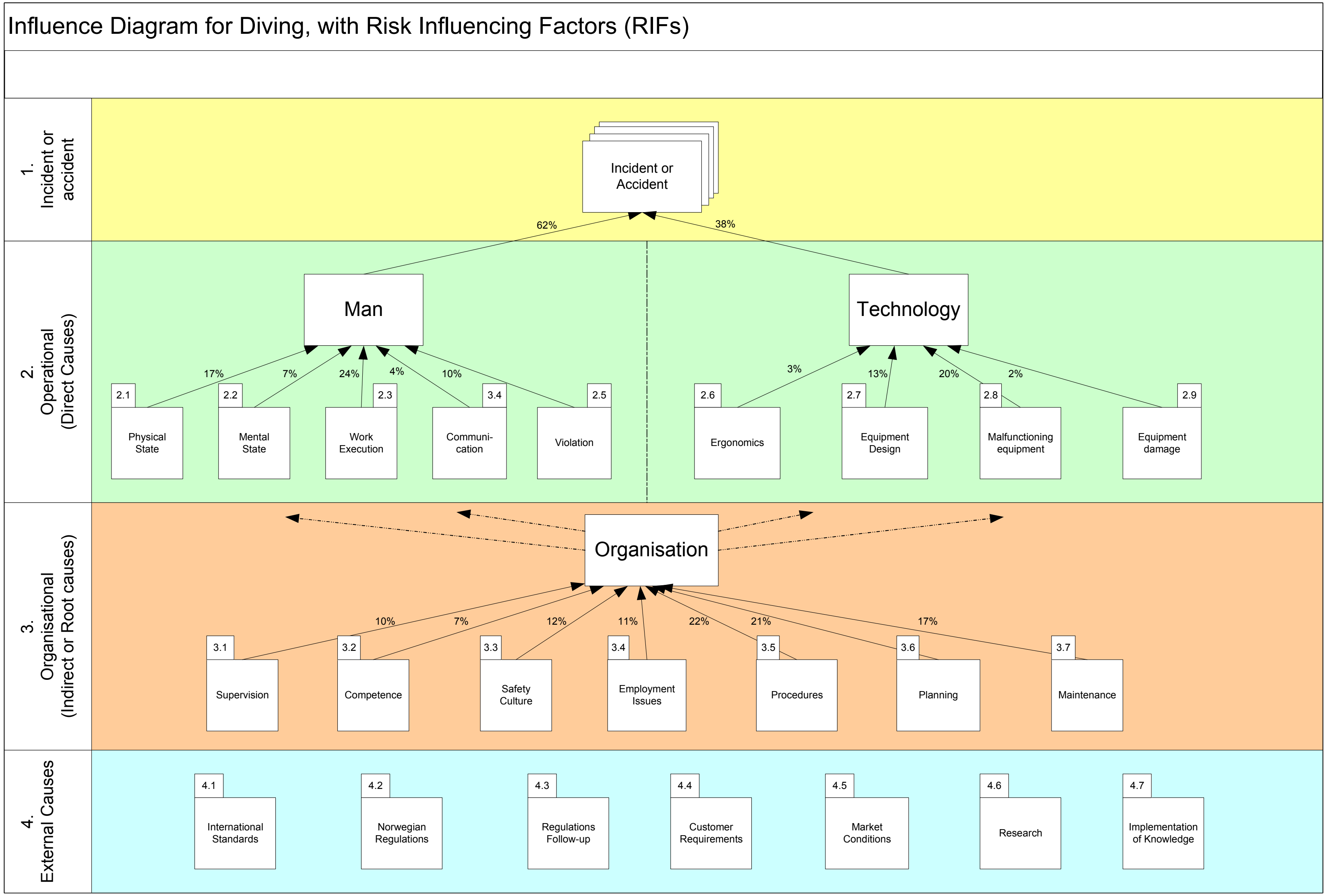


Figure 7.1: Structure of Diving Risk Influence Diagram

7.3 Quantification by Means of a Risk Influence Diagram

The 9 different RIFs in Figure 7.1 are not all equally important in determining the risk level. In order to describe the differences in importance each RIF can be assigned a "weight factor" expressed as, for example, a percentage (the sum of all weight factors should be 100 %). Assigning the weights is done by "expert judgment", taking into account

- statistically observed causes for incidents/accidents
- results of interviews of experienced divers and diving superintendents
- literature on diving
- influence of root causes.

In addition to the weight each RIF can be characterized by a quality or status indicator. While weight factors are considered constant in time, the status factors will change as a function of time. For example, one might assign the RIF "Work Execution" a weight factor of 22 %. If we assume that the quality of work execution can be improved from the 1997/2003 level to a much higher quality status in 2004/2008 we can express this by assigning the 1997/2003 status the value 1, and the 2004/2008 status the value 0.5. By this we mean that the risk contribution from the RIF "Work Execution" has been halved. A RIF which has improved so much that the risk contribution is completely eliminated would get a status value of zero. The weight factor would not be changed since it is still considered an important RIF.

For the quantitative estimation of the risk level one can select a suitable point in time for which a quantitative risk value - for example a FAR-value - is available. For this point in time (snap shot) one can put all status values equal to one, using this as a reference case. Mathematically we can express the risk for this case as

$$R_{ref} = \sum_{i=1}^{N} w_i \cdot s_i$$

where

N = total number of all RIFs
w_i = weight of RIF_i
s_i = status of RIF_i

At the reference time, since all $s_i = 1$ and $\Sigma w_i = 100$, the risk level will be

$R_{ref} = 100$

Improvements in one or several RIF status values (making $s_i < 1$) will result in

$R_{ref} < 100$

Correspondingly, quality deteriorations give $s_i > 1$ and

$R_{ref} > 100$

Given that a risk measure is known for the reference state the risk measure for any other state can be estimated. For example in case of the fatality accident rate:

$$FAR = FAR_{ref} \cdot (R/R_{ref})$$

Risk reduction measures can - and should - start at the organizational level, with the root causes. Also here one can define weight and status values in order to describe changes in time. But the functional relationships between the weight/status of the different root causes and the direct cause are not simple. For example, improvement of organizational issues will result in reduced risk contributions from several direct causes. Other root causes can be more directly related to direct causes, such as:

Maintenance to equipment damage
Procedures to work execution
Planning to mental state.

See Chapter 6.6.3.4 for more details. For a more quantitative description of the influence of root causes on direct causes one can use the matrix presentation in Table 7.1.

Table 7.1: Effect of Root Causes (O) on Direct Causes (M and T)

Organization (O)	Man (M)					Technology (T)			
	Physical State	Mental state	Work execution	Communication	Violation	Ergonomics	Equipment design	Malfunctioning equ.	Equipment damage
Supervision	1	2	1	1	2	1	1	2	1
Competence	0	1	1	0	2	0	0	0	0
Safety culture	1	1	1	1	2	1	1	1	1
Employment	1	1	1	1	2	1	1	1	1
Procedures	2	1	3	1	2	0	1	1	0
Planning	2	3	1	1	0	0	1	1	0
Maintenance	1	0	1	0	0	0	0	3	1

Effect scale:
0: no effect of O on M/T
1: weak effect of O on M/T
2: medium effect of O on M/T
3: strong effect of O on M/T

7.4 Influence Diagrams for Different Diving Techniques and Phases

In principle, different influence diagrams need to be developed and analyzed for each diving technique (saturation, surface supplied, bounce) and even for each operational phase of a dive. In case of saturation diving the operational phases would be compression, bell run down, work in the water, bell run up, decompression. The structure of the influence diagram shown in Figure 7.1 is, however, so general that it can be applied to any diving technique and operational phase. But the weight factors and status factors of each RIF must be determined separately, at least for each diving technique. Separation into different operational phases is difficult and possibly not very useful since the risk measures, for example the FAR values, are not known for the different operational phases, only for the dive as a whole.

One distinction which has to be made is between

- immediate risk
- long-term risk.

Quite obviously, some of the RIFs are more important for immediate effects, but not so important for long-term health effects. An example would be the diving suit heating system which certainly is important for avoiding overheating or undercooling, but not so important for the occurrence of delayed health effects. On the other hand, wrong oxygen partial pressure can lead to long-term lung damage.

Not taking into account the different operational phases of a dive we need four different influence diagrams with different RIF weight factors:

- Saturation dive immediate risk
- Saturation dive long-term risk
- Surface supplied dive immediate risk
- Surface supplied dive long-term risk.

For the time being the available information from surface supplied diving incidents is too scarce to justify an attempt to establish the corresponding influence diagrams.

7.5 Change of Risk Level with Time

An attempt was made to analyze the change of risk level with time. For this, an early analysis of the causes for 39 fatal incidents has been used, Ref. /17/. The cause distribution as given in Ref. /17/ is shown in Table 7.2, together with an adaptation of this distribution to the same set of causes as used in Chapter 6.6. The percentages in the last column were normalized so that the sums of the M + T cases equals 100, and the sum of the O cases also equal 100. (The total sum equals 200).

Table 7.2: Cause Distribution for Fatal Accidents UK, 1971 - 1977, Ref. /17/

Original distribution		Adapted distribution		
Cause	Percent	Cat.	Nearest cause	Percent
Human	33	M	Work execution	54
Medical supervision	2	O	Supervision	8
Diving supervision	7	O	Supervision	27
Equipment	17	T	Malfunctioning equipment	27
Inadequate training	10	O	Competence	38
Unsuited/lack of equipment	7	T	Equipment design	11
Unknown	5			
Physical condition	5	M	Physical state	8
Maintenance	7	O	Maintenance	27
Sum	93			200

There are significant differences in the cause distributions shown in Table 6.1 (1996-2003) and those in Table 7.2 (1971-1977). However, the distribution between man (M) and technology (T) is exactly the same, namely 62 % vs 38 %. Reasons for the differences in cause distribution can be:

- Only severe-consequence incidents (fatalities) are included in the 1971-1977 analysis
- Pioneer period: regulations and procedures are non-existent or insufficient.

If we assume that small-consequence incidents can develop into severe incidents and that the cause distributions for small and severe consequence incidents are approximately the same we can disregard the first reason. Differences in the cause distributions are therefore mainly due to historical differences in the MTO risk factors.

We have seen that the risk level as measured by, for example, the FAR values for saturation diving has decreased strongly from 1976/85 to the present. From the data presented in Chapter 4 we see a decrease by a factor 4 - 5 for the 10-year averages, both in the UK and Norway. In Table 7.3 we show a possible historical development of the risk influencing factors.

Table 7.3: Historical Development of Risk Influencing Factors (RIFs)

Cat	Cause	Past		Present		Future	
		1971-1977		1997-2003		2005-2011	
		Weight	Status	Weight	Status	Weight	Status
M	Physical state	8	5	20	1		
	Mental state			8	1		
	Work Execution	54	5	23	1		
	Communication			4	1		
	Violation			8	1		
T	Ergonomics			3	1		
	Equipment design	11	5	10	1		
	Malfunctioning equ.	27	5	22	1		
	Equipment damage			3	1		
O	Supervision	35		15	1		
	Competence	38		7	1		
	Safety culture			10	1		
	Employment issues			0	1		
	Procedures			22	1		
	Planning			27	1		
	Maintenance	27		20	1		

The weight factors for the "Present" are identical with those shown in Figure 6.1, the weight factors for the "Past" with those shown in Table 7.2. The status values of all RIFs for the present are arbitrarily chosen as 1, i.e. the present risk level is chosen as reference for past and future risk levels. In the table the status values of the past are all put equal to 5 to reflect the observed FAR-value for 1976/85. This results in a risk sum of

$$\sum_{i=1}^{9} w_i \cdot s_i = 500$$

which is a factor 5 higher than the corresponding risk sum of 100 for the present. A risk sum of 500 for the past could also have been achieved by assigning different weight factors (but their sum must be 100), and/or by estimating different status values.

Estimates for the future, i.e. quantitative estimates of the risk reducing potential, are also possible by means of Table 7.3. By conducting formal expert judgment sessions (Delphi Method) it will be possible to estimate both the future weight distribution of the direct causes and the change - hopefully reduction - of their status values. By calculating again the risk sum R one can obtain an estimate for

$$FAR_{future} = FAR_{present} \cdot (R_{future}/R_{present})$$

If it was possible, for example, to reduce all status values to 0.7 (keeping the weight distribution constant) the present FAR-value of 27 might get reduced to 19. In practice one would of course concentrate the efforts on those RIFs which have the highest weight, but cost benefit considerations will also be of importance.

8. IMPACT OF EXTERNAL RISK FACTORS

8.1 Introduction

Organizations are influenced by external risk factors; i.e. acts, regulations, national and international standards, market conditions, new research and development, management system audits and customer requirements, etc. These external risk influencing factors are of importance to the organization's management of risk.

To assess what impact these external risk factors have had, expert input from the Reference group was used. The goal was to identify and clarify which risk influencing factors were pertinent and which had less impact to the total risk picture.

8.2 Norwegian Regulations

The Norwegian Petroleum Directorate (NPD) and Petroleum Safety Authority (PSA) administer the regulations related to the Norwegian Continental Shelf.

The acts and regulations relating to manned underwater operations are:

- Act 4 February 1977 relating to worker protection and working environment
- Act of 22 March 1985 relating to petroleum activities
- Regulations relating to safety in the petroleum activities
- Regulations relating to management systems for compliance with statutory requirements in relation to safety, working environment and protection of the external environment in the petroleum activities
- Regulations relating to worker protection and working environment in the petroleum activities.

Common regulations by the NPD, the Ministry of Environment and the Directorate of Health were issued relating to manned underwater operations in the petroleum activities 11 June 1990. The NPD is responsible for supervising the compliance of the provisions, with the exemption of Chapter V, for which the Norwegian Board of Health (NBH) is the supervisory authorities.

In addition a number of guidelines were issued relating to

- manned underwater operations (1990)
- qualifications for personnel (1990)
- dynamically positioned diving support vessels (1983)
- evaluation of breathing apparatus for use in manned underwater operations (1991).

To a large extent the legislation contains functional requirements which among other things refer to safety related qualities in relation to a given solution, without specifying any particular solutions to be adopted. The regulations have been supplemented by guidelines which indicate possible solutions complying with the required qualities. Documentation showing that the solutions selected fulfill the functional requirements of the legislation shall exist at all times. This entails that the enterprise itself must define requirements and provide a description of the solutions. For manned underwater operations the regulations from this period were to a large degree influenced by deterministic requirements.

On 31 August and 3 September 2001 new regulations were issued. These are also common regulations between NPD, the Norwegian Pollution Control (SFT) and NBH:

- The Framework Regulation
- The Management Regulation
- The Information Duty regulation
- The Facilities Regulation
- The Activities Regulation.

In these regulations functional requirements are further developed. Guidelines to these five regulations are also issued and supported by national and international standards. The guidelines must be viewed in context with the regulations to obtain the best possible understanding of what the authorities wish to achieve through the regulations. An important principle of risk reduction is also further emphasized.

The Framework Regulation states that "The party responsible shall encourage and promote a favorable health, environment and safety culture comprising all activity areas ….".

This provision is new, but expresses principles already present in the regulations.

For manned underwater operations the functional requirements are stated in the Activities Regulation Chapter XVII and a guideline that states that NORSOK U-100N should be used and where the specific requirements are stated.

Accident and incident investigation has functional requirements in the Management Regulation (Section 19). It is, however, supported by specific requirements in the guidelines (Section 19). The requirement for reporting diving-related incidents and accidents is stricter than for other incidents. The definition of what is to be reported is:

"An undesired event (that) covers fatal accidents, accidents/incidents with personal injuries requiring medical treatment, first aid or which entails absence from work into the next 12 hour shift. Near misses are also included". (DSYS).

It is the general view of the expert input that even though the requirements have been changed the same level of strictness is maintained in the Norwegian sector.

This is also confirmed by the economic and administrative evaluation of the new regulations made by the NPD.

The fact that there are differences between Norwegian regulations and the British regulations in some areas is said to be a challenge for those operating on both sectors. In particular, provisions concerning hyperbaric evacuation and working environment are stricter in the Norwegian regulations than in the UK regulations.

In the Norwegian Sector the operator is responsible for ensuring that requirements are complied with. While in the UK Sector more responsibility is put on contractors.

8.3 The Norwegian Model of Three-Party Cooperation

The model of cooperation between the authorities, employers and employees is the basis of the Norwegian regulations. In fact it is one of the stated objectives of the Working Environment act; "to provide a basis whereby the enterprises themselves can solve their working environment problems in co-operation with the organizations of employers and employees and with control and guidance from public authorities" (Section 1.3 Objectives).

The two legitimate systems of employee participation are the Safety Delegate system (Working Environment act) and the unions (Petroleum act). The Safety Delegate System is operational through the Working Environment Committee, where safety delegates together with the employer work to safeguard the working environment, health and safety. The unions work through representation of members to safeguard working conditions and wages.

According to NOPEF who organize most of the Norwegian divers on the Norwegian Sector, this is made very difficult if not impossible due to the short term contracts and short term employment of personnel. The supervisory activities of the NPD also confirm that the Safety Delegates occasionally are not given the courses required in the regulations and that their involvement in HSE matters could be improved. Leading personnels' knowledge of Norwegian regulations has also been identified as not good enough, at times. It is argued that that these shortcomings have been eliminated after 1995. This can however not be supported by the results of the NPD supervisory activities.

8.4 Regulation Follow-up and Supervisory Activity

8.4.1 Introduction

The system of regulatory supervision is based on mutual confidence between the authorities, the operators, and the other parties engaged in the activities. As the operator is responsible for its own activities, the supervisory activities conducted by NPD are additional to the activities performed by the operator.

The regulations require that the authorities shall be notified if a situation of serious hazard or accident occurs. Depending on the criticality of the situation, the authorities will decide what supervision is to be carried out. In connection with serious situations the authorities may carry out continuous supervision of the operator's handling and normalization of the situation, and make the necessary decisions. The supervisory authorities may visit the scene of an accident. As a rule this will not take place before the situation has been brought under control. The purpose is to carry out an independent examination of the sequence of events, the root causes, any deviations and the status of existing barriers and to carry out supervision of the measures initiated by the operator to prevent recurrence. The development of emergency preparedness is also part of this investigation.

The authorities' supervisory activities include:

- Dealing with applications for consent
- Meetings
- System audits
- Verifications
- Dealing with applications for exemption
- Participation in meetings between the licensees in the production license
- Follow-up of the operator's handling of situations of hazard and accident.

For the manned underwater operations the audits and the consents represent a major part of NPD's follow up. It is therefore interesting to examine the extent and content, including orders issued in the process, to identify if risk reduction goals are achieved. NPD has not performed accident investigations of their own in this period, but requested the investigation reports performed by the operators and contractors. From 1990 to 2003 this includes 31 reports from the different operators. Early reports lack the quality required for such investigations, but in the late nineties the reports have improved in investigation methods and results.

8.4.2 Enforcement Measures in Supervision

The authorities have a number of enforcement measures within their control. The relevant measures are chosen after an assessment of the seriousness of the case in question, and the operators' abilities and willingness to correct any deviation themselves. In many cases the operator will correct deviations as requested by the authorities, without the need for more formal measures. Available enforcement measures are consents, orders, enforcement damages, suspensions, reporting to the police and reporting and giving advice to the Ministries.

8.4.3 Supervisory Activities from 1990 - 2003

This project has closely examined the supervisory activities performed by NPD in this period in order to be able to see how the goal of risk reduction is achieved. NPD has performed in total 43 audits in the period from 1990 - 2001, see Table 8.1. No audits have been performed later than 2001 due to reorganization within the NPD.

Table 8.1: Audits Performed by NPD

Company	No. of audits	Time period
Norsk Hydro	7	1990 - 2000
Statoil	14	1990 - 2000
Amoco	1	1990
Saga	2	1990 - 1995
Elf	7	1991 - 2001
Norske Shell	3	1993 - 1995
PPCoN	9	1992 - 1999

The audits have focused on all the main aspects of manned underwater operations, from operation management (organization, responsibilities and reporting, including familiarization, planning and implementation) to technical verification of equipment and personnel competence (especially leaders and Safety Delegates), and also training and contractual aspects. The activities have addressed all the responsible parties, such as the operating companies, the contractors and sub contractors. NBH have participated in audit teams with NPD and looked into working environment issues and health requirements.

The observations and findings from supervisory activities reflect the project's observations from the MTO analysis. The most important direct and indirect causes to incidents are followed up in supervisory activities. In this period the focus has more or less been constant and the findings likewise.

A possible explanation for this is that due to the organization of manned underwater operations with short term contracts and personnel hired from project to project, the same risk factors (and findings) will remain.

A total of nine orders were issued during this period.

8.4.4 Consents relating to Manned Underwater Operations 1990 - 2003

The operator is required to obtain consent from the authorities at important milestones, to be able to continue his activities. This includes obtaining consent prior to the start up of manned underwater operations. An application for consent represents a binding document with regard to the operator's duty of compliance with regulatory requirements falling within the area of responsibility of the NPD, the SFT and the NBH.

The term deviation in this connection refers to a discrepancy between chosen solutions and specified requirements, including both own requirements as well as legislation requirements. The term exemption refers to a decision by the authorities to accept a deviation from a legislative requirement with significance to safety.

8.5 International Standards and Cooperation

8.5.1 Cooperation across different Sectors

The rules and regulations vary across the different Sectors. Harmonization is advantageous but what standards should be the goal of the harmonization is a pertinent question.

The diving vessels operate in the Danish, Dutch, German and UK sectors adhering to the national regulations for each sector. There are differences between the regulations and in some areas the Norwegian regulations are perceived to be stricter while in other areas it is the other way around. The flexibility for the diving contractors to operate in the Norwegian Sector is therefore reduced.

Examples of areas where the Norwegian regulations and standards are perceived to imply favorable conditions w.r.t. safety are:

- Diving tables which are reported to be less strenuous for the divers
- Reporting routines for diving activities which include quarterly reports and annual/ final experience reports. This causes high focus on occurred incidents and possibilities to follow-up incident frequencies on different levels
- The responsibility put on the operator which implies a closer follow-up of diving operations by the operator
- The model of cooperation between the authorities, employers and employees which implies Working Environment Committee and Safety Delegates working together with employer to safeguard the working environment, health and safety.

One problem associated with different requirements in different sectors is that diving operations have to be carried out with different standards, equipment, rules and culture when crossing a line which only exists on paper. The fact that two different sets of regulations are in use in different sectors may be challenge with the present low activity level. Since no one wishes to compromize at the lowest common denominator it may be of value to look at the reasons why the differences exist and to develop a system for smoother transition across the different sectors. Such work has been started.

8.5.2 Development of a Guideline to manage Regulatory Differences

The "Norway/UK Regulatory Guidance for Offshore Diving" (NURGOD) and guidelines published by the International Marine Contractors Association (IMCA D 034 December 2003) have been developed to provide standardization of procedures and approaches for managing the regulatory differences between the two nations. This is an attempt to ease the operational process for offshore diving across the different sectors.

When crews and equipment from either UK or Norway are to operate in each others waters, it is necessary that the operation is carried out in accordance with the national laws of the respective offshore sector. That is, if a vessel crosses from UK to Norwegian waters it needs to satisfy Norwegian regulations in order to operate in the Norwegian sector. Likewise, if Norwegian crews or equipment cross from Norwegian to UK waters it is necessary that they operate according to UK regulations while in the UK sector.

The main objective of the guidance document is to facilitate the use of diving vessels and resources between the two jurisdictions (UK and Norway) and to ensure safety and efficiency to offshore diving operations by developing a common approach via the use of this document. The document is based on the assumption that the body of laws in the two countries are compatible in this context. However, where differences have been identified the guidance highlights those differences. The process for revision of legislation is not treated in this guidance.

It is assumed that UK operators and diving contractors satisfy the UK laws and regulations for offshore diving operations. In the same manner, it is assumed that Norwegian operators and diving contractors satisfy the Norwegian body of laws.

The guidance has been prepared jointly by the industries in UK and Norway. In this work OLF (Oljeindustriens Landsforening - The Norwegian Oil Industry Association) and IMCA (International Marine Contractors Association) represented their respective members from these industries.

In the document (IMCA D 034) it is stated (quote):

> *This document has been developed by IMCA members and reviewed by interested parties including OLF, the Norwegian Petroleum Directorate (NPD) and the UK Health & Safety Executive (HSE).*
>
> *The basis for the content of the document is a gap analysis which has been undertaken to review and document the differences between the UK and Norwegian sector legislation and regulations. This gap analysis is available upon request from IMCA.*
>
> *The guidance offers examples of good practice in the management of the transfer of diving operations between the above named sectors.*

8.5.3 European Diving Technology Committee (EDTC)

The EDTC aims to make professional diving safer. Its seeks to reach its aim by providing an independent forum which may make recommendations relating to diving safety, technology and medicine, providing a place for discussion of matters related to manned underwater operations, techniques of diving, types of equipment and their use, together with medical aspects, examinations and arrangements for monitoring the fitness of divers (wherever possible). A number of common documents have been issued attempting to harmonize standards throughout the member states.

In 2003 the organization has published a revised standard on "Personnel Competence Standards" and a standard for examination of diving personnel. This standard aims to be the basis of a common European reference document.

The EDTC admits members from European countries where representation will be one each of the following categories: Government, the Diving Industry, Medical and Union. The EDTC also co-operates with the sport diving industry and has, thus, admitted representatives from this (large) population, as well as representatives from professional diver training schools.

8.5.4 The International Marine Contractors Association (IMCA)

The International Marine Contractors Association (IMCA) is an international trade association representing offshore, marine and underwater engineering companies. The three companies offering diving services on the Norwegian side are all represented in this organization as well as other affiliated organizations such as NUI A/S.

IMCA promotes improvements in quality, health, safety, environmental and technical standards through the publication of information notes, codes of practice and by other appropriate means. Members are self-regulating through the adoption of IMCA guidelines as appropriate. They are committed to act as responsible members by following relevant guidelines and by being willing to be audited.

Some of its most important objectives are to strive for the highest possible standards of health, safety and environment with a balance of risk and cost and to ease the free movement of equipment and personnel globally.

8.6 Market Conditions

8.6.1 Contracts

In the eighties and up until 1990/92, long term contracts dominated the manned underwater operations on the Norwegian continental shelf. In the beginning of the 1990's activity-levels decreased dramatically. As a result, all of the operators abandoned their long-term contract philosophies and started hiring diving services from project to project. The operators, Hydro, Saga and Statoil, decided to attempt to stop using divers/diving altogether within the year 2000, due to the increasing media focus on assumed long-term injuries among the diving population. Efforts were made to replace divers with remotely-operated technologies with some success. However, the need for divers could not be removed all together.

This also resulted in two of the contractors forming Joint Ventures. Today there are two such Joint Ventures operating on the Norwegian continental shelf.

These efforts have been successful in the sense that several of the tasks previously done by divers, today can be performed with remotely-controlled vehicles or tools. On the other hand, this has also lead to a natural deterioration of the resources required for safe and efficient diving. Diving vessels and systems are aging. Although investments are made to maintain and upgrade vessels and systems it is judged that improvements and technological development are hampered by the reduced activity level. There has been a very limited recruitment of new diving personnel in all positions as well as personnel with diving medical/technological competence.

The decision to abandon diving altogether has now been reversed and the operators realize the necessity to achieve a sustainable activity level within manned underwater operations to ensure the availability of qualified resources to perform diving if and when the need arises.

8.6.2 Forms of Employment

The dominating form of employment for divers today is the British practice of self-employment combined with day rate contracts resulting in that the actual employment only lasts for the duration of the divers offshore period. This is a development that has followed the reduction in diving activity on the Norwegian side, and the consequent need for the diving vessels and companies to operate internationally. Divers are chosen for the jobs by the superintendent and is dependent on his acceptance to keep working.

It is claimed that this implies that it is less likely that they will report unsafe acts and behaviour or try to improve things as they easily can be "run off the ship". Others claim that reluctance to report unsafe acts is no longer the case.

One should also consider that symptoms that are reported and treated automatically lead to three months exclusion from diving. For regularly employed divers this usually means three months of alternative work or, if required, a sick leave with pay. For the vast majority of divers without regular employment exclusion from diving means three months without work and pay.

The employment tradition is perhaps the most important explanation for the differences in safety culture that have existed between the two sectors. The different traditions of employment and also the differences in how the three-party cooperation is expected to work, gives important input to understanding some of the challenges met in the diving industry.

Long term or permanent contracts and employment are seen as attractive by many in the industry, but the low level of activity on the Norwegian sector makes this difficult or impossible as not enough work would be available for the divers employed.

Due to the self-employed status of many of the divers, it is difficult to maintain any control over the diving logs, involvement in incidents and long term health records. This would be easier if divers were permanent employees of the diving contractors.

8.6.3 Health Issues

The type of employment found in the diving industry, predominantly self-employment, makes it difficult for the diving contractors to monitor the exposure to and involvement individual divers have in incidents taking place in other places. The confidentiality rules regarding medical records also prevents good control as the diving contractors cannot see how many different doctors the diver has visited before the health certificate has been issued.

The fact that most divers are self-employed increases the risk of them trying to get through the health check even if the diver is aware that something may be wrong. This is due to the potential financial consequences associated with losing the health certificate.

8.6.4 Status Personnel

8.6.4.1 Divers Education

The State Diving School (SDS) in Bergen has educated professional divers in Norway for a long time, but has not offered bell diving education since 1996.

The development strategy since the early 1990's aiming to reduce diving activities in the Norwegian Sector has had a strong impact on recruitment and training of new divers. The low activity level combined with the uncertain future led to a low demand for bell diver education and thereby to a stoppage of the education of bell divers in Norway. Currently INPP in Marseilles, France is the only provider of internationally accepted "Closed Bell Diver" courses in Europe.

There has been ongoing work for a couple of years looking into an alternative administrative structure for the education of divers in Norway, as compared to the present school directly owned by the Ministry of Education. This process is progressing towards a solution where Bergen University College (HiB) will have the educational and financial responsibility for diver education (including bell diving). The practical diving activities will be performed in close cooperation with "Centre of Diving Competence", a new company to be established by the Government through "Bergen University College" and Statoil and Hydro, by including the activities, production facilities, employees and contracts currently in NUI AS. The "Diving Competence Centre" will acquire a Bell Diving System for educational purposes and the bell diving education will then be resumed.

Concerning supplementary education which is essential for a transition into some other employment after ending the diving career, the Kromberg report stated the following:

"The committee has discussed the need for additional training prior to being accepted to a diving education, but will not further promote this".

Instead the committee proposes:

*"The committee will instead recommend that the training Institutions encourage and help the students to plan their career based on a maximum time span of 15 - 20 years as active divers and stimulate them to further educate themselves in their free time". (*Page 108*).*

8.6.4.2 Diving Superintendent

The diving superintendent is seen as playing a major role with regards to both how work is performed and with regards to safety. The diving superintendent selects personnel for the job and has a free hand to pick and choose according to his/her best knowledge and will. This gives the diving superintendent a unique and powerful role that defines how work is performed and what safety levels are accepted. Divers who perform according to the desired standards will be asked back on the next trip, divers who don't won't. The diving superintendent can, thus, be perceived as the defining character of the local safety culture.

The role of the diving superintendent is especially strong when contracts are based on lump sum payments. The desire to make as much money as possible will ensure that the same people with the "right" attitude will be in work most of the time and that it will be difficult for newcomers to break into the workplace. It is questionable whether the industry is best served by managers with such power. Alternative means of organizing diving activity should be investigated.

8.7 Conclusions regarding External Risk Factors

The risk involved in diving operations is influenced by external risk factors like acts, regulations, national and international standards, market conditions, research and development, customer's requirements, etc. These aspects have been looked into and the conclusions summarized below.

The drop in the activity level and the efforts by some of the operators involved in the Norwegian offshore petroleum industry to replace divers by diverless technologies has lead to a reduced ability to maintain and improve the resources required for safe and efficient diving. Diving vessels and systems are ageing and technological development is limited. Further there has been very limited recruitment of new diving personnel in all positions as well as personnel with diving medical/technological specialist competence. These concerns must be met if the industry is to maintain the appropriate safety level in future diving operations.

Future diving will be needed as a contingency to handle incidents with large economical or environmental consequences both in connection with accidents in the oil and gas industry, but also in connection with ship, aircraft or submarine accidents in or near Norwegian waters.

Optimizing areas into efficient oil and gas producers will lead to more or less marginal fields being developed and tied in to the already existing infrastructure. Such work can often be cost effectively performed by divers, and in some cases diving might be the only possible method to perform such work.

Abandonment of "empty" fields and wells, including removal of installations, subsea wells and pipelines is another area where diving in many cases will be an easier, cheaper and more secure way to perform the work necessary.

The Norwegian regulations have been under constant development in this period. Some new concepts and principles have been introduced. Some of the intentions of developing functional requirements are to place the responsibility for the operation with the industry and to give the industry a better chance to implement solutions that are "fit for purpose". It should also give ample possibility to work through international organizations to agree on standards and norms. This is work with a long term perspective and a critical question is of course to decide on the basis for standardization.

Norwegian Authorities continue to focus on diving activities as having a high incident potential. The supervisory activities represent an important aspect of maintaining the appropriate safety level. It also contributes to common understanding of problems and possible solutions.

The investigation reports had a varying quality. This could indicate that the potential for learning from experience is not fully employed.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Immediate Fatality Risk

9.1.1 Risk Level

The historical fatality rate for saturation diving has been determined. The results are shown in Table 9.1.

Table 9.1: Historically Observed Fatal Accident Rate for Saturation Diving (Non-overlapping 5 Year Periods)

Time period	Observed fatal accident rate [1)]	
	Norway	UK
1974 - 1978	0.46	0.51
1979 - 1983	0.43	0.03
1984 - 1988	0.09	0
1989 - 1993	0	0
1994 - 1998	0	0.06
1999 - 2003	0	0.05

1) Number per 100,000 man-hours in saturation

In order to reduce the uncertainty and to obtain the best possible predicted present day risk level, an overall average FAR value for the Norwegian and UK Sectors together was also calculated, see Table 9.2. FAR is defined as the number of fatalities per 100 million man-hours in saturation.

Table 9.2: Predicted Present-day Fatal Accident Rate (FAR) for Saturation Diving, UK and Norwegian Sector Combined, Based on Period 1990-2003

Fatal Accident Rate (FAR) for saturation diving		
Lower limit	Mean	Upper limit
7	**27**	71

The individual risk per annum (IRPA) for a full time saturation diver can be calculated from the FAR value by assuming an average of 1920 hours per year in saturation. This results in

$$\text{IRPA} = 27 \cdot 10^{-8} \times 1920 = 0.0005 \text{ per year of full activity}$$

Data for inshore diving are scarce. Data from unofficial statistics for inshore diving indicate:

FAR = 400 (per 100 million hours in the water)
IRPA = $400 \cdot 10^{-8}$ x 375 = 0.0015 per year of full activity

The IRPA value is based on the assumption of 150 dives per year with an average duration of 2.5 hours, for a fully active diver.

In later years saturation diving has been the dominating diving method in the Norwegian Sector. The amount of surface-oriented diving today is low and bounce diving is no longer employed in the Norwegian Sector. This contributes to an improved safety level since saturation diving is considered the safest diving method.

9.1.2 Acceptance Criteria

For the purpose of this study an "upper acceptability limit" has been introduced for the yearly individual fatality risk, IRPA. This risk should be less than 0.0006 per year. In addition an hourly criterion of FAR less than 25 per 100 million hours in saturation is introduced for saturation diving.

9.1.3 Comparison of Risk

The acceptance criteria introduced were established mainly on the basis of practice in the offshore industry, for the most (risk) exposed personnel group.

Figure 9.1 shows a comparison of fatality rates for different professions.

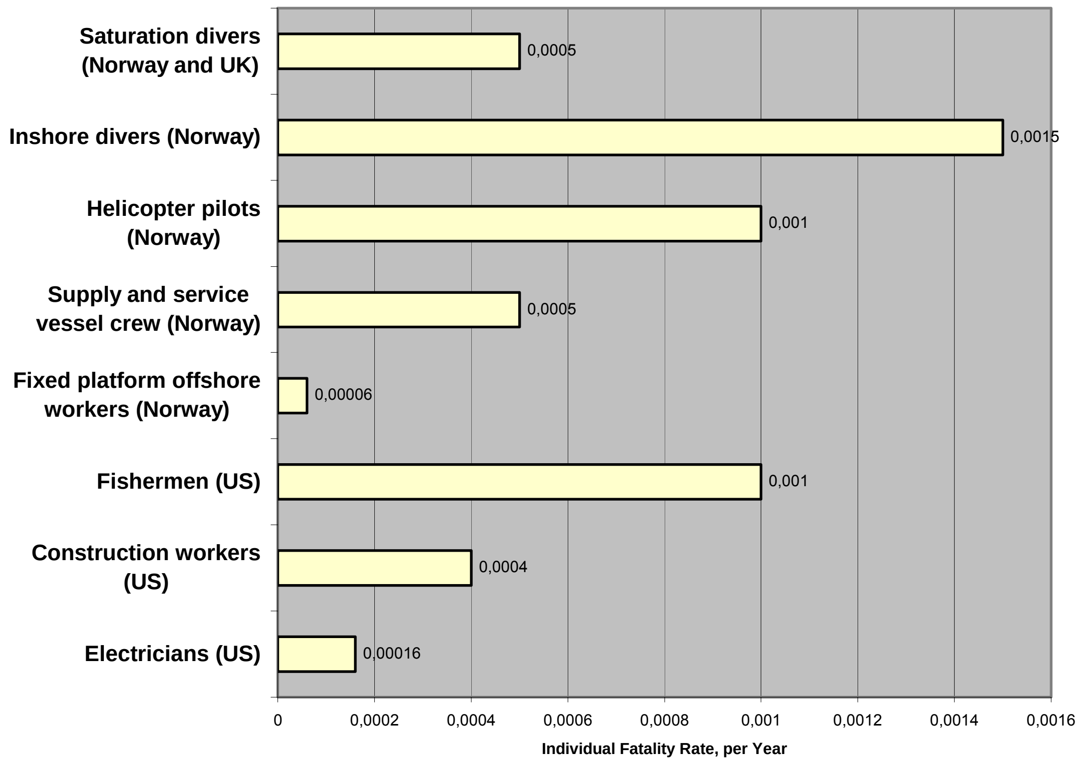


Figure 9.1: Comparison of Fatality Rates for Different Professions

9.1.4 Risk-Influencing Factors

Risk-influencing factors for fatality risk are judged to be correlated with risk factors for less severe incidents. Approximately 400 incidents have been investigated and the results imply that both the complexity of the work performed and the failure of technical equipment are important risk influencing factors. The low activity level with a natural deterioration of the resources required for safe and efficient diving is found to be a challenge in this respect. There has been very limited recruitment of new diving personnel in all positions as well as personnel with diving medical/technological specialist competence. The extensive use of short term contracts makes it difficult to achieve improvements in work performance and safety culture.

It is recommended to perform work sessions according to a proposed methodology to identify cost effective risk reducing measures. For saturation diving, potential areas for improvement (direct causes) seem to be:

- Physical state of diver
- Work execution
- Equipment failure
- Work supervision
- Quality of procedures
- Work planning and identification of risk aspects (HAZOP and SJA)
- Maintenance of equipment.

The improvement areas are also illustrated by the recorded distribution of causes found in the incident investigations where also root causes can be seen. Aspects such as the ageing of divers, selection of divers (physical and psychological screening), short term contracts and local safety culture are seen as important issues when trying to achieve improvements.

9.1.5 Risk Indicators

For year-to-year risk monitoring and control FAR and IRPA values are not well suited due to large statistical uncertainties. Other risk indicators such as the number of reported injuries and near misses are better suited for this purpose. For the latest 5-year averages (1999-2003) the following values for risk indicators were found for saturation diving in the Norwegian sector:

Risk indicator	Incidents per 100,000 hours in saturation		
	Lower limit	Mean	Upper limit
Non-DCI injuries	17.7	**22.5**	28.2
Near misses	4.2	**6.7**	10.1

The risk indicators "Non-DCI injuries" and "Near misses" can be applied as an indicator of the actual fatality risk. For risk monitoring and control purposes the following criteria are proposed as an indication of obtaining a FAR less than 10 for saturation diving:

- Less than 8 non-DCI injuries per 100,000 hours in saturation
- Less than 2.5 near misses per 100,000 hours in saturation.

9.2 Long-Term Risk

9.2.1 Methodological Difficulties

Investigations into long-term health effects are difficult for several reasons:

- Some of the studies of long-term effects are concerned with retired divers and reflect, therefore, historical rather than present day diving conditions
- The divers examined are not a representative sample from the total diver population
- Divers to start with, are not an average sample of the general population. A comparison of the prevalence of certain symptoms among divers with prevalence in the general population is therefore difficult
- Many of the examinations are based on self-reported effects and can be influenced by the diver's economical interests
- When establishing statistics for long-term health effects, it is necessary to assure that the investigated divers are representative for the diver population. At present it has not been possible for Scandpower to confirm that the health effects identified by the Lossius Commission and Haukeland scientists are representative for the average population of divers in the Norwegian sector
- Long-term health effects may take many years before they are fully developed and there may be several contributing factors to the effect. This implies considerable uncertainty w.r.t. applicability to current diving. Diving conditions have changed over time and the statistical material (number of dives investigated) is small.

9.2.2 Long-Term Risk - Results

The long-term health effects on divers have been investigated in two Norwegian studies and in a recently issued comprehensive UK study. The main results reported are interpreted based on these studies.

Compared with offshore workers, a significantly higher percentage of divers complain about "forgetfulness and loss of concentration". Phase 1 of the ELTH1 Study shows that this percentage increases significantly with increasing diving dose, i.e. number of days in saturation in the case of saturation diving. On the other hand, Phase 2 of the Study (on a much smaller number of divers) was not able to establish a significant correlation between the degree of memory reduction and number of days in saturation. The results are not conclusive and more research is needed in this area.

Clear, measurable and statistically significant effects were found for lung damage, based on measurement of certain performance values (forced expired volume, forced expired flow etc.) which were compared to expected values.

In addition other health effects are found to be typical, at least for some of the pioneer divers. Although the basis for the statistics may be discussed it seems that these divers have higher probabilities than the general population to experience:

- Reduced health status which hinders them in their work and leisure activities and which reduces their possibilities for social contacts
- Mental problems
- Pain in joints or muscle stiffness
- Impaired hearing
- Tiredness
- Post-traumatic Stress Disorder (PTSD).

In particular, the UK study intends to clarify any reduced health-related quality of life due to diving. Generally it was concluded that the health-related quality of life was similar for divers as for offshore workers and within normative values.

However, the symptom of forgetfulness and loss of concentration was found to be associated with a moderate, but significant, reduction of quality of life.

An indirect indication of the health status is the percentage of divers who are temporarily or permanently disabled. The Lossius Commission had information on 335 pioneer divers of whom 63 (19 %) were disabled. This is a factor 2 - 4 higher than the general population for the age groups 36 - 55 years old. It should be noted that there are considerable uncertainties w.r.t. to these figures especially since the number of disabled divers should be related to a much higher number of total divers. The UK study does not confirm an increased disability rate among UK divers.

There is agreement among experts that decompression illness (DCI) is under control and can be almost completely avoided by proper saturation diving procedures. Certain health effects are more frequent among divers who experienced DCI than among divers who did not. These health effects will be reduced by avoiding DCI. Despite this long-term health effects will still occur and so-called "silent bubbles" (not defined as DCI) may be experienced in all types of diving. It is also concluded that there are significant individual differences in the response to decompression procedures.
There are indications that the high-pressure nervous syndrome (HPNS) (which is not really a long-term effect since the symptoms disappear after a few days at constant

pressure) has a threshold at approx 180 msw (Ref. /30/). There is still insufficient knowledge about all risk aspects of deep diving. There are indications that the importance of stricter selection of divers and improved diving procedures increases with diving depth. An important work task has been initiated by the oil companies to investigate further the results and experience from performed deep dives in order to further qualify and improve diving procedures

9.2.3 Expected Development

The Norwegian investigations of long-term health effects reflect the situation of divers who were mainly active during 1976 - 1990. There is reason to believe that improvements since then will result in reduced long-term health effects in the future. Divers today may be less prone to long-term health effects than the pioneer divers due to self selection. Divers starting their career today are expected to experience a reduced risk of being disabled due to significantly reduced probability for decompression illness (DCI), and reduced exposure to traumatic incidents. The ELTHI study, on the other hand, shows that the complaint of forgetfulness had the same prevalence among active divers as among divers who have stopped diving. So this is not just a problem of the seventies and eighties.

In the Kromberg report it is emphasized that "… a good and safe working environment is very important because of the special risk factors divers are exposed to. Psycho-sociological factors such as subjectively perceived well-being and safe working conditions are crucial for problem solving during diving".

9.3 Suicides

The suicide rate among divers, both in Norway and the UK, has been reported to be high. In Norway the suicide rate for certain time periods is reported to be up to 12 times higher and in the UK up to 3 times higher than for the general population of the same sex and age in Norway. Although there are uncertainties in these figures, they are an indication of a difficult life situation experienced by many divers.

The reported suicide rates for divers are historical values and illustrate the life situation for veteran divers. It is important to understand the possible causes for the high suicide rates in order to evaluate the necessity for changes and to avoid similar situations for present and future divers. It is therefore recommended to pursue this subject further. Based on a preliminary evaluation, possible influencing factors for the high reported suicide rate may be:

- Unemployment due to reduced diving activity and low ability to find other relevant work
- Reduced physical health due to the diving experience and experienced incidents/ accidents
- Reduced mental health due to insufficient handling of Post Traumatic Stress Disorder
- Low recognition of their health problems due to lack of knowledge in the public health service
- Etc.

Some characteristic differences in personality (risk taking, impulsivity) have been reported between divers and the general population. This may be an influencing factor on suicide rates. However, no data have been found to support or eliminate a correlation between risk taking and impulsivity on the one hand, and a tendency towards suicide on the other hand.

The way diving is carried out today, the risk of both life threatening incidents and decompression illness is considerably reduced and the activity level is relatively stable. It is, hence, expected that the suicide risk is reduced for the presently active divers.

The organization of the diving industry will influence the risk for suicides and it is recommended to consider this aspect further. Important issues in this respect are considered to be:

- Better screening/selection of divers
- Better medical follow-up
- Better debriefing after incidents
- Better employment conditions
- Better planning for ending diving career and re-education.

See Chapter 4.7 for more details.

9.4 External Risk Factors

The risk involved in diving operations is influenced by external risk factors like laws, regulations, national and international standards, market conditions, research and development, customer's requirements, etc.

The drop in the activity level and the efforts by some of the operators involved in the Norwegian offshore petroleum industry to replace divers by diverless technologies has lead to a reduced ability to maintain and improve the resources required for safe and efficient diving. Diving vessels and systems are ageing and technological development is limited. Furthermore there has been very limited recruitment of new diving personnel in all positions as well as personnel with diving medical/technological specialist competence. These concerns should be addressed if the industry is to maintain the appropriate safety level in future diving operations.

Future diving will also be needed as a contingency to handle incidents with large economical or environmental consequences both in connection with accidents in the oil and gas industry, but also in connection with ship, aircraft or submarine accidents in or near Norwegian waters.

In the future marginal fields will be developed and tied in to the already existing infrastructure. Such work can often be cost effectively performed by divers, and in some cases diving might be the only possible method to perform such work. Abandonment of "empty" fields and wells is another area where diving in many cases may be an easier, cheaper and safer way to perform the necessary work.

The Norwegian regulations have been under constant development in this period. Some new concepts and principles have been introduced. The intention has been to place the responsibility for the operation with the industry and to give the industry a better chance to implement solutions that are "fit for purpose".

Norwegian Authorities continue to focus on diving activities as having a high incident potential. The supervisory activities are important in order to maintain an acceptable safety level.
The investigation reports examined were of a varying quality. This could indicate that the potential for learning from experience is not fully employed.

See Chapter 8.7 for more details.

9.5 Risk Management

The diving industry is in a special situation with challenges requiring special risk management efforts. The diving industry can in this respect be described as follows:

- It is strongly governed by demand and the market situation
- It is demanding on technological and human resources
- It is by its nature an industry with a high risk potential (humans under water), in particular for immediate fatality risk, but also for long-term health effects
- It operates at a low or even sub-critical activity level in the Norwegian sector
- It is an international industry and as such difficult to adapt to special requirements and Norwegian risk management practices
- It suffers from very limited recruitment of new diving personnel and lacks educational possibilities in Norway
- The effort put into technological development in recent years has been limited
- There is still a lack of scientific knowledge of diving limitations w.r.t. both immediate and long-term health effects. This is a challenge in particular when operational requirements shall be established for deep diving while maintaining the so-called precautionary principle
- The extensive use of short-term contracts makes it difficult to achieve improvements in work performance, safety culture and follow-up of health aspects.

9.6 Recommendations

Scandpower has identified the following recommendations as part of the present study:

<u>Immediate Risk during Diving</u>

- The present fatality risk level was found to be roughly equal to the risk level used in this study as an "upper acceptability limit". The ambition expressed by the Authorities and the oil companies is to further reduce the risk level.

  Therefore it is recommended to initiate further work to continue the process of identifying cost effective risk-reducing measures. In this study a work session method is proposed with an expert panel to identify and quantify risk-reducing measures. It is also recommended to analyze further the "near misses" reported to NPD since 1990, as part of this work

- Understanding and controlling risk at a high level in the organization is an important step towards risk reduction. The use of fatality risk acceptance criteria and risk analysis are beneficial in this respect.

Therefore it is recommended that the oil companies and contractors formalize acceptance criteria for immediate fatality risk to be used for diving activities. Since fatalities are very rare events fatality rates are not suited for day-to-day risk control purposes. Hence, it is recommended that the industry also establishes risk management routines which aim at limiting the frequencies of reportable incidents (e.g. rate of near misses and rate of injuries)

- The criteria for reporting of diving incidents to the NPD differ from the criteria applied in other parts of the petroleum industry. This makes comparison of observed incident rates difficult.

  Therefore it is recommended to evaluate if reporting criteria for diving incidents can be adjusted to suit criteria applied elsewhere in the petroleum industry.

<u>Long-term Health Effects</u>

- The statistical basis for establishing quantitatively the long-term health effects of diving has been - and still is - weak.

  Therefore it is recommended to improve the basis for future statistics on long–term health effects of diving. In cooperation with Rikstrygdeverket and NPD it should be established a system for determining the rate of disablement of divers in order to compare this rate with the corresponding rate in the general public. Already established systems for the general public could be used.

- Proper debriefing after incidents may reduce the risk of Post Traumatic Stress Disorder.

  Therefore it is recommended to evaluate the current practice and routines applied in the diving industry, also in the light of both experience in other comparable professions (e.g. among firemen and pilots), and of other knowledge on the effect of debriefing

- The employment and working conditions of divers are found to be important for the ability to improve HSE matters. Observations made are:

  * There are large individual differences between divers regarding their ability and suitability to withstand the physiological and psychological stresses in connection with diving

  * In some interviews it was stated that there is a fear to report hazardous incidents and possible individual health effects of diving. This fear is related to the possibility of not being rehired in the case of hazardous incidents, and to the possibility for loss of the diving certificate and, thus, of job and income, in the case of health effects

  * Supervisory activities performed by the Authorities and incident statistics since 1990 indicate that the potential for learning from experience is not fully utilized. The supervisory activities also indicate that training in regulations and familiarization to the operations are weak points. It is anticipated

that the use of short-term contracts and personnel hired from project to project limits efficient implementation of improvements.

Therefore it is recommended to:

- **Improve the routines for medical screening, selection and follow-up both for individual particularly demanding diving tasks and for diving career as a whole**
- **Evaluate alternative employment conditions and post diving career plans to improve reporting of hazardous incidents and health effects as well as assuring continuity in improvements of work performance**

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APPENDIX A

SPREAD SHEETS FOR STATISTICAL EVALUATION OF DIVING INCIDENTS

TABLE OF CONTENTS

A1. SATURATION DIVING NORWEGIAN SECTOR

A1.1 Yearly Data

						Frequencies per 100,000 manhours in saturation											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1967	5456					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	42,203	42,203	42,203	42,203
1968	10912					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	21,101	21,101	21,101	21,101
1969	16368					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	14,068	14,068	14,068	14,068
1970	21824					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	10,551	10,551	10,551	10,551
1971	27280					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	8,441	8,441	8,441	8,441
1972	32736					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	7,034	7,034	7,034	7,034
1973	43648					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	5,275	5,275	5,275	5,275
1974	60016					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	3,837	3,837	3,837	3,837
1975	70928	1				1,410	0,000	0,000	0,000	0,072	0,000	0,000	0,000	6,688	3,246	3,246	3,246
1976	81840					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	2,814	2,814	2,814	2,814
1977	98208					0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	2,345	2,345	2,345	2,345
1978	120000	1	54	50		0,833	45,000	41,667	0,000	0,043	35,423	32,471	0,000	3,953	56,450	52,739	1,919
1979	180000		40	38		0,000	22,222	21,111	0,000	0,000	16,775	15,811	0,000	1,279	28,927	27,671	1,279
1980	145000		15	19		0,000	10,345	13,103	0,000	0,000	6,377	8,581	0,000	1,588	15,929	19,227	1,588
1981	175000		9	14		0,000	5,143	8,000	0,000	0,000	2,683	4,837	0,000	1,316	8,974	12,507	1,316
1982	165000		11	9		0,000	6,667	5,455	0,000	0,000	3,739	2,846	0,000	1,396	11,035	9,518	1,396
1983	267841	4	10	24		1,493	3,734	8,961	0,000	0,510	2,026	6,179	0,000	3,418	6,333	12,602	0,860
1984	386136		10	30		0,000	2,590	7,769	0,000	0,000	1,405	5,592	0,000	0,596	4,393	10,538	0,596
1985	206145		4	31		0,000	1,940	15,038	0,000	0,000	0,663	10,888	0,000	1,117	4,440	20,295	1,117
1986	182573		4	24		0,000	2,191	13,145	0,000	0,000	0,748	9,064	0,000	1,261	5,014	18,487	1,261
1987	202982	1	2	28	19	0,493	0,985	13,794	9,360	0,025	0,175	9,804	6,130	2,337	3,102	18,912	13,735
1988	157110		6	18	14	0,000	3,819	11,457	8,911	0,000	1,663	7,405	5,387	1,466	7,538	16,989	13,931
1989	207569		7	21	8	0,000	3,372	10,117	3,854	0,000	1,583	6,779	1,918	1,109	6,334	14,569	6,954
1990	167431		1	30	18	0,000	0,597	17,918	10,751	0,000	0,031	12,897	6,949	1,375	2,833	24,303	15,942
1991	172018			35	22	0,000	0,000	20,347	12,789	0,000	0,000	15,039	8,658	1,339	1,339	26,976	18,262
1992	177752			49	19	0,000	0,000	27,566	10,689	0,000	0,000	21,424	7,000	1,295	1,295	34,976	15,684
1993	165138		2	20	14	0,000	1,211	12,111	8,478	0,000	0,215	8,026	5,125	1,394	3,812	17,599	13,253
1994	88303			26	2	0,000	0,000	29,444	2,265	0,000	0,000	20,632	0,402	2,608	2,608	40,856	7,130
1995	45872			9	1	0,000	0,000	19,620	2,180	0,000	0,000	10,236	0,112	5,020	5,020	34,237	10,342
1996	28670			11	6	0,000	0,000	38,368	20,928	0,000	0,000	21,517	9,114	8,031	8,031	63,508	41,306
1997	101606			14	19	0,000	0,000	13,779	18,700	0,000	0,000	8,330	12,245	2,266	2,266	21,541	27,439
1998	80275			26	2	0,000	0,000	32,389	2,491	0,000	0,000	22,695	0,443	2,868	2,868	44,941	7,843
1999	57339			9	4	0,000	0,000	15,696	6,976	0,000	0,000	8,188	2,383	4,016	4,016	27,390	15,964
2000	58257			12	8	0,000	0,000	20,598	13,732	0,000	0,000	11,886	6,833	3,952	3,952	33,374	24,778
2001	73394			20	3	0,000	0,000	27,250	4,088	0,000	0,000	18,059	1,114	3,137	3,137	39,597	10,564
2002	12426		1	3	0	0,000	8,048	24,143	0,000	0,000	0,413	6,580	0,000	18,530	38,177	62,399	18,530
2003	38229			10	1	0,000	0,000	26,158	2,616	0,000	0,000	14,192	0,134	6,023	6,023	44,370	12,409

A1.2 Five-Year Moving Averages

						Frequencies per 100,000 manhours in saturation											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1967 - 1971	81840	0	0	0		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	2,814	2,814	2,814	2,814
1968 - 1972	109120	0	0	0		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	2,110	2,110	2,110	2,110
1969 - 1973	141856	0	0	0		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,623	1,623	1,623	1,623
1970 - 1974	185504	0	0	0		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,241	1,241	1,241	1,241
1971 - 1975	234608	1	0	0		0,426	0,000	0,000	0,000	0,022	0,000	0,000	0,000	2,022	0,981	0,981	0,981
1972 - 1976	289168	1	0	0		0,346	0,000	0,000	0,000	0,018	0,000	0,000	0,000	1,641	0,796	0,796	0,796
1973 - 1977	354640	1	0	0		0,282	0,000	0,000	0,000	0,014	0,000	0,000	0,000	1,338	0,649	0,649	0,649
1974 - 1978	430992	2	54	50		0,464	12,529	11,601	0,000	0,082	9,863	9,041	0,000	1,461	15,717	14,684	0,534
1975 - 1979	550976	2	94	88		0,363	17,061	15,972	0,000	0,064	14,273	13,278	0,000	1,143	20,251	19,069	0,418
1976 - 1980	625048	1	109	107		0,160	17,439	17,119	0,000	0,008	14,785	14,491	0,000	0,759	20,447	20,101	0,368
1977 - 1981	718208	1	118	121		0,139	16,430	16,847	0,000	0,007	14,024	14,410	0,000	0,661	19,144	19,593	0,321
1978 - 1982	785000	1	129	130		0,127	16,433	16,561	0,000	0,007	14,128	14,246	0,000	0,604	19,020	19,156	0,293
1979 - 1983	932841	4	85	104		0,429	9,112	11,149	0,000	0,146	7,549	9,414	0,000	0,981	10,913	13,122	0,247
1980 - 1984	1138977	4	55	96		0,351	4,829	8,429	0,000	0,120	3,810	7,065	0,000	0,804	6,045	9,987	0,202
1981 - 1985	1200122	4	44	108		0,333	3,666	8,999	0,000	0,114	2,807	7,624	0,000	0,763	4,714	10,559	0,192
1982 - 1986	1207695	4	39	118		0,331	3,229	9,771	0,000	0,113	2,428	8,340	0,000	0,758	4,218	11,385	0,191
1983 - 1987	1245677	5	30	137		0,401	2,408	10,998	0,000	0,158	1,734	9,499	0,000	0,844	3,267	12,674	0,185
1984 - 1988	1134946	1	26	131		0,088	2,291	11,542	0,000	0,005	1,605	9,935	0,000	0,418	3,179	13,344	0,203
1985 - 1989	956379	1	23	122		0,105	2,405	12,756	0,000	0,005	1,644	10,918	0,000	0,496	3,407	14,826	0,241
1986 - 1990	917665	1	20	121		0,109	2,179	13,186	0,000	0,006	1,444	11,278	0,000	0,517	3,167	15,334	0,251
1987 - 1991	907110	1	16	132	81	0,110	1,764	14,552	8,929	0,006	1,106	12,533	7,363	0,523	2,679	16,814	10,742
1988 - 1992	881881	0	14	153	81	0,000	1,588	17,349	9,185	0,000	0,960	15,108	7,573	0,261	2,482	19,840	11,049
1989 - 1993	889908	0	10	155	81	0,000	1,124	17,418	9,102	0,000	0,610	15,182	7,505	0,259	1,906	19,901	10,950
1990 - 1994	770642	0	3	160	75	0,000	0,389	20,762	9,732	0,000	0,106	18,138	7,960	0,299	1,006	23,672	11,793
1991 - 1995	649083	0	2	139	58	0,000	0,308	21,415	8,936	0,000	0,055	18,517	7,097	0,355	0,970	24,652	11,120
1992 - 1996	505734	0	2	115	42	0,000	0,395	22,739	8,305	0,000	0,070	19,367	6,315	0,455	1,245	26,549	10,742
1993 - 1997	429587	0	2	80	42	0,000	0,466	18,623	9,777	0,000	0,083	15,335	7,435	0,536	1,466	22,429	12,646
1994 - 1998	344725	0	0	86	30	0,000	0,000	24,947	8,703	0,000	0,000	20,693	6,264	0,668	0,668	29,847	11,804
1995 - 1999	313761	0	0	69	32	0,000	0,000	21,991	10,199	0,000	0,000	17,825	7,425	0,734	0,734	26,870	13,699
1996 - 2000	326147	0	0	72	39	0,000	0,000	22,076	11,958	0,000	0,000	17,978	8,992	0,706	0,706	26,859	15,619
1997 - 2001	370872	0	0	81	36	0,000	0,000	21,840	9,707	0,000	0,000	18,008	7,208	0,621	0,621	26,274	12,819
1998-2002	281692	0	1	70	17	0,000	0,355	24,850	6,035	0,000	0,018	20,174	3,845	0,817	1,684	30,318	9,052
1999-2003	239646	0	1	54	16	0,000	0,417	22,533	6,677	0,000	0,021	17,738	4,188	0,961	1,980	28,267	10,140

A1.3 Ten Year Moving Averages

						Frequencies per 100,000 manhours in saturation											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1967 - 1976	371008	1	0	0	0	0,270	0,000	0,000	0,000	0,014	0,000	0,000	0,000	1,279	0,621	0,621	0,621
1968 - 1977	463760	1	0	0	0	0,216	0,000	0,000	0,000	0,011	0,000	0,000	0,000	1,023	0,497	0,497	0,497
1969 - 1978	572848	2	54	50	0	0,349	9,427	8,728	0,000	0,062	7,420	6,802	0,000	1,099	11,825	11,048	0,402
1970 - 1979	736480	2	94	88	0	0,272	12,763	11,949	0,000	0,048	10,678	9,934	0,000	0,855	15,150	14,266	0,313
1971 - 1980	859656	2	109	107	0	0,233	12,679	12,447	0,000	0,041	10,750	10,536	0,000	0,732	14,867	14,616	0,268
1972 - 1981	1007376	2	118	121	0	0,199	11,714	12,011	0,000	0,035	9,998	10,273	0,000	0,625	13,649	13,969	0,229
1973 - 1982	1139640	2	129	130	0	0,175	11,319	11,407	0,000	0,031	9,731	9,813	0,000	0,552	13,101	13,195	0,202
1974 - 1983	1363833	6	139	154	0	0,440	10,192	11,292	0,000	0,192	8,813	9,838	0,000	0,868	11,733	12,907	0,169
1975 - 1984	1689953	6	149	184	0	0,355	8,817	10,888	0,000	0,155	7,663	9,602	0,000	0,701	10,101	12,304	0,136
1976 - 1985	1825170	5	153	215	0	0,274	8,383	11,780	0,000	0,108	7,300	10,490	0,000	0,576	9,586	13,189	0,126
1977 - 1986	1925903	5	157	239	0	0,260	8,152	12,410	0,000	0,102	7,112	11,120	0,000	0,546	9,306	13,814	0,120
1978 - 1987	2030677	6	159	267	19	0,295	7,830	13,148	0,936	0,129	6,837	11,853	0,613	0,583	8,931	14,551	1,373
1979 - 1988	2067787	5	111	235	33	0,242	5,368	11,365	1,596	0,095	4,558	10,173	1,168	0,508	6,285	12,662	2,134
1980 - 1989	2095356	5	78	218	41	0,239	3,723	10,404	1,957	0,094	3,057	9,273	1,483	0,502	4,494	11,640	2,539
1981 - 1990	2117787	5	64	229	59	0,236	3,022	10,813	2,786	0,093	2,429	9,665	2,217	0,496	3,721	12,065	3,460
1982 - 1991	2114805	5	55	250	81	0,236	2,601	11,821	3,830	0,093	2,052	10,619	3,158	0,497	3,256	13,127	4,608
1983 - 1992	2127557	5	44	290	100	0,235	2,068	13,631	4,700	0,093	1,583	12,341	3,955	0,494	2,659	15,023	5,550
1984 - 1993	2024854	1	36	286	114	0,049	1,778	14,124	5,630	0,003	1,320	12,779	4,792	0,234	2,348	15,578	6,578
1985 - 1994	1727021	1	26	282	116	0,058	1,505	16,329	6,717	0,003	1,055	14,763	5,725	0,275	2,089	18,021	7,837
1986 - 1995	1566747	1	22	260	117	0,064	1,404	16,595	7,468	0,003	0,951	14,939	6,370	0,303	2,005	18,390	8,707
1987 - 1996	1412844	1	18	247	123	0,071	1,274	17,482	8,706	0,004	0,823	15,694	7,456	0,336	1,889	19,426	10,112
1988 - 1997	1311468	0	16	233	123	0,000	1,220	17,766	9,379	0,000	0,765	15,896	8,032	0,176	1,853	19,804	10,894
1989 - 1998	1234633	0	10	241	111	0,000	0,810	19,520	8,991	0,000	0,439	17,499	7,634	0,186	1,374	21,718	10,526
1990 - 1999	1084404	0	3	229	107	0,000	0,277	21,118	9,867	0,000	0,075	18,876	8,352	0,212	0,715	23,561	11,586
1991 - 2000	975229	0	2	211	97	0,000	0,205	21,636	9,946	0,000	0,036	19,246	8,346	0,236	0,646	24,251	11,775
1992 - 2001	876606	0	2	196	78	0,000	0,228	22,359	8,898	0,000	0,041	19,798	7,308	0,263	0,718	25,170	10,742
1993-2002	711279	0	3	150	59	0,000	0,422	21,089	8,295	0,000	0,115	18,339	6,602	0,324	1,090	24,149	10,303
1994-2003	584371	0	1	140	46	0,000	0,171	23,957	7,872	0,000	0,009	20,727	6,065	0,394	0,812	27,565	10,065

A1.4 Other Time Intervals

						Frequencies per 100 million manhours in saturation											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1975 - 1981	870976	2	118	121		230	13548	13892		41	11564	11882		723	15786	16156	264
1992-2003	927261	0	3	209		0	324	22540		0	88	20038		248	836	25278	248
1989-2003	1475000	0	11	295		0	746	20000		0	418	18124		156	1234	22024	156
1990-2003	1266710	0	4	274		0	316	21631		0	108	19527		182	723	23907	182

A1.5 UK and Norway Combined

						Frequencies per 100 million manhours in saturation											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1976-1985	14528210	20				138	0	0		91	0	0		200	16	16	16
1984-1993	13700854	2				15	0	0		3	0	0		46	17	17	17
1992-2001	6230206	3				**48**	0	0		**13**	0	0		**124**	37	37	37
1993-2002	5436559	3				**55**	0	0		**15**	0	0		**143**	42	42	42
1999-2003	2334046	1				**43**	0	0		**2**	0	0		**203**	99	99	99
1992-2003	7143261	3				**42**	0	0		**11**	0	0		**109**	32	32	32
1990-2003	10940379	3				**27**	0	0		**7**	0	0		**71**	21	21	21

A2. SURFACE ORIENTED DIVING NORWEGIAN SECTOR

A2.1 Yearly Data

						Frequencies (per 100,000 manhours in water)											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in water	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1987	4774		2	4	7	0,000	41,891	83,783	146,620	0,000	7,443	28,618	68,813	48,229	131,870	191,727	275,396
1988	3322		2	5	3	0,000	60,207	150,517	90,310	0,000	10,698	59,308	24,615	69,316	189,524	316,477	233,411
1989	2858		2	4	2	0,000	69,970	139,940	69,970	0,000	12,432	47,801	12,432	80,556	220,258	320,236	220,258
1990	2704		2	2	2	0,000	73,968	73,968	73,968	0,000	13,143	13,143	13,143	85,159	232,844	232,844	232,844
1991	2060		1	3	0	0,000	48,542	145,625	0,000	0,000	2,490	39,692	0,000	111,771	230,275	376,375	111,771
1992	4069			6	2	0,000	0,000	147,468	49,156	0,000	0,000	64,223	8,734	56,593	56,593	291,063	154,738
1993	1236			4	0	0,000	0,000	323,611	0,000	0,000	0,000	110,539	0,000	186,286	186,286	740,545	186,286
1994	567			2	1	0,000	0,000	353,030	176,515	0,000	0,000	62,727	9,054	406,442	406,442	1111,302	837,364
1995	206				0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1117,715	1117,715	1117,715	1117,715
1996	77				1	0,000	0,000	0,000	1294,444	0,000	0,000	0,000	66,396	2980,572	2980,572	2980,572	6140,669
1997	525			1	0	0,000	0,000	190,359	0,000	0,000	0,000	9,764	0,000	438,319	438,319	903,040	438,319
1998	258			4	0	0,000	0,000	1553,333	0,000	0,000	0,000	530,586	0,000	894,172	894,172	3554,615	894,172
1999	386		1	2	0	0,000	258,889	517,778	0,000	0,000	13,279	91,999	0,000	596,114	1228,134	1629,910	596,114
2000	52				0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	4428,054	4428,054	4428,054	4428,054
2001	52				0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	4470,858	4470,858	4470,858	4470,858
2002	1				0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	230258,806	230258,806	230258,806	230258,806
2003	25				0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	9210,352	9210,352	9210,352	9210,352

A2.2 Five-Year Moving Averages

						Frequencies (per 100,000 manhours in water)											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in water	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1987 - 1991	15718,45494	0	9	18	14	0,000	57,258	114,515	89,067	0,000	29870,773	74,017	53,847	14,649	99,916	169,812	139,241
1988 - 1992	15012,87554	0	7	20	9	0,000	46,627	133,219	59,949	0,000	21883,322	88,289	31,275	15,337	87,579	193,581	104,612
1989 - 1993	12927,03863	0	5	19	6	0,000	38,679	146,979	46,414	0,000	15240,518	96,247	20,214	17,812	81,326	215,666	91,609
1990 - 1994	10635,19313	0	3	17	5	0,000	28,208	159,847	47,014	0,000	7688,532	101,852	18,525	21,651	72,906	239,763	98,851
1991 - 1995	8137,339056	0	1	15	3	0,000	12,289	184,335	36,867	0,000	630,343	113,628	10,049	28,297	58,297	283,841	95,285
1992 - 1996	6154,506438	0	0	12	4	0,000	0,000	194,979	64,993	0,000	0,000	112,506	22,200	37,413	37,413	315,908	148,729
1993 - 1997	2611,158798	0	0	7	2	0,000	0,000	268,080	76,594	0,000	0,000	125,818	13,609	88,183	88,183	503,535	241,111
1994 - 1998	1632,618026	0	0	7	2	0,000	0,000	428,759	122,503	0,000	0,000	201,230	21,766	141,037	141,037	805,339	385,625
1995 - 1999	1452,360515	0	1	7	1	0,000	68,853	481,974	68,853	0,000	3531,707	226,205	3,532	158,541	326,631	905,292	326,631
1996 - 2000	1298,351931	0	1	7	1	0,000	77,021	539,145	77,021	0,000	3950,633	253,037	3,951	177,347	365,376	1012,677	365,376
1997 - 2001	1272,600858	0	1	7	0	0,000	78,579	550,055	0,000	0,000	4030,574	258,158	0,000	180,936	372,769	1033,168	180,936
1998-2002	748,27897	0	1	6	0	0,000	133,640	801,840	0,000	0,000	6854,813	349,203	0,000	307,718	633,970	1582,617	307,718
1999-2003	515,7682403	0	1	2	0	0,000	193,886	387,771	0,000	0,000	9944,994	68,900	0,000	446,439	919,767	1220,662	446,439

A2.3 Ten Year Moving Averages

						Frequencies (per 100,000 manhours in water)											
	Exposure	Numbers				Mean				Lower 90% limit				Upper 90% limit			
Year	Manhours in water	Fatalities	Decompr. sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses	Fatalities	Decompr. Sickness	Other injury	Near misses
1987 - 1996	21873	0	9	30	18	0,000	41,147	137,156	82,293	0,000	21465,881	98,725	53,190	10,527	71,802	186,031	122,031
1988 - 1997	17624	0	7	27	11	0,000	39,718	153,200	62,415	0,000	18641,111	108,137	35,003	13,065	74,603	211,269	103,311
1989 - 1998	14560	0	5	26	8	0,000	34,341	178,576	54,946	0,000	13531,553	125,130	27,341	15,815	72,207	247,785	99,141
1990 - 1999	12088	0	4	24	6	0,000	33,092	198,551	49,638	0,000	11303,498	136,910	21,617	19,049	75,727	279,233	97,972
1991 - 2000	9436	0	2	22	4	0,000	21,196	233,157	42,392	0,000	3766,148	157,845	14,480	24,403	66,723	332,936	97,009
1992 - 2001	7427	0	1	19	4	0,000	13,464	255,820	53,857	0,000	690,620	167,521	18,396	31,002	63,872	375,371	123,245
1993-2002	3359	0	1	13	2	0,000	29,767	386,970	59,534	0,000	1526,836	228,895	10,578	68,541	141,210	615,239	187,406
1994-2003	2148	0	1	9	2	0,000	46,547	418,919	93,093	0,000	2387,519	218,547	16,541	107,178	220,811	731,024	293,047

A3. DIVING BRITISH SECTOR

A3.1 Yearly Data

	Northern Europe		UK Sector									
Year	Number of divers	Number of fatalities	Number of divers	Number of fatalities total	Number of fatalities saturation	Number of hours in saturation	Fatalities per 100,000 hours in sat.	Risk per diver year	Major incidents	Over 3 days absence	Disease (DCI)	Dangerous occurences
1971	200	3	100	1	1	112001	0,893	1,0E-02				
1972	300	1	200	1	1	224001	0,446	5,0E-03				
1973	400	2	300	2	1	336002	0,298	3,3E-03				
1974	800	10	500	5	4	560003	0,714	8,0E-03				
1975	1000	9	600	6	6	672003	0,893	1,0E-02				
1976	1500	9	800	9	6	896004	0,670	7,5E-03				
1977	2000	5	100	3	2	112001	1,786	2,0E-02				
1978	2200	3	1500	2	2	1680008	0,119	1,3E-03				
1979	2300	3	1400	3	2	1568008	0,128	1,4E-03				
1980	2000	0	1000	0	0	1120006	0,000	0,0E+00				
1981	2100	0	1100	0	0	1232006	0,000	0,0E+00				
1982	2200	1	1300	1	0	1456007	0,000	0,0E+00				
1983	2400	7	1400	1	0	1568008	0,000	0,0E+00				
1984	not known	1	1344	1	0	1505288	0,000	0,0E+00				
1985	2362	0	1398	0	0	1565768	0,000	0,0E+00				
1986		not known	1065	0	0	1192806	0,000	0,0E+00				
1987		not known	1013	0	0	1134566	0,000	0,0E+00				
1988		not known	1026	0	0	1149126	0,000	0,0E+00				
1989		not known	927	0	0	1038245	0,000	0,0E+00				
1990		not known	896	0	0	1003525	0,000	0,0E+00				
1991		not known	921	0	0	1031525	0,000	0,0E+00				
1992		not known	951	0	0	1065125	0,000	0,0E+00				
1993		not known	884	0	0	990085	0,000	0,0E+00				
1994		not known	799	0	0	894584	0,000	0,0E+00	The figures below are from pic04664 sendt by mail from			
1995		not known	714	1	1	799387	0,125	1,4E-03				
1996		not known	629	1	1	704189	0,142	1,6E-03	0	10	8	14
1997		not known	544	0	0	609283	0,000	0,0E+00	1	4	7	14
1998		not known	430	0	0	481602	0,000	0,0E+00	2	4	3	19
1999		not known	307	1	1	343842	0,291	3,3E-03	0	11	2	18
2000	519+270	not known	400	0	0	448002	0,000	0,0E+00	1	4	2	24
2001			393	0	0	440162	0,000	0,0E+00	2	3	8	24
2002			390	0	0	436802	0,000	0,0E+00	0	1	4	19
2003			380	0	0	425602	0,000	0,0E+00				

A3.2 Five-Year Moving Averages

					Frequencies per 100,000 manhours in saturation								
	Exposure	Numbers			Mean			Lower 90% limit			Upper 90% limit		
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Fatalities	Decompr. Sickness	Other injury	Fatalities	Decompr. Sickness	Other injury	Fatalities	Decompr. Sickness	Other injury
1971 - 1975	1904010	13	0	0	0,683	0,000	0,000	0,404	0,000	0,000	1,086	0,121	0,121
1972 - 1976	2688013	18	0	0	0,670	0,000	0,000	0,433	0,000	0,000	0,993	0,086	0,086
1973 - 1977	2576013	19	0	0	0,738	0,000	0,000	0,483	0,000	0,000	1,082	0,089	0,089
1974 - 1978	3920020	20	0	0	0,510	0,000	0,000	0,338	0,000	0,000	0,741	0,059	0,059
1975 - 1979	4928025	18	0	0	0,365	0,000	0,000	0,236	0,000	0,000	0,542	0,047	0,047
1976 - 1980	5376027	12	0	0	0,223	0,000	0,000	0,129	0,000	0,000	0,362	0,043	0,043
1977 - 1981	5712029	6	0	0	0,105	0,000	0,000	0,046	0,000	0,000	0,207	0,040	0,040
1978 - 1982	7056035	4	0	0	0,057	0,000	0,000	0,019	0,000	0,000	0,130	0,033	0,033
1979 - 1983	6944035	2	0	0	0,029	0,000	0,000	0,005	0,000	0,000	0,091	0,033	0,033
1980 - 1984	6881314	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,033	0,033	0,033
1981 - 1985	7327077	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,031	0,031	0,031
1982 - 1986	7287876	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,032	0,032	0,032
1983 - 1987	6966435	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,033	0,033	0,033
1984 - 1988	6547553	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,035	0,035	0,035
1985 - 1989	6080510	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,038	0,038	0,038
1986 - 1990	5518268	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,042	0,042	0,042
1987 - 1991	5356987	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,043	0,043	0,043
1988 - 1992	5287546	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,044	0,044	0,044
1989 - 1993	5128506	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,045	0,045	0,045
1990 - 1994	4984845	0	0	0	0,000	0,000	0,000	0,000	0,000	0,000	0,046	0,046	0,046
1991 - 1995	4780706	1	0	0	0,021	0,000	0,000	0,001	0,000	0,000	0,099	0,048	0,048
1992 - 1996	4453371	2	8	10	0,045	0,180	0,225	0,008	0,089	0,122	0,141	0,324	0,381
1993 - 1997	3997529	2	15	15	0,050	0,375	0,375	0,009	0,231	0,231	0,157	0,578	0,578
1994 - 1998	3489046	2	18	21	0,057	0,516	0,602	0,010	0,333	0,403	0,180	0,765	0,867
1995 - 1999	2938304	3	20	32	0,102	0,681	1,089	0,028	0,451	0,793	0,264	0,989	1,463
1996 - 2000	2586919	2	22	37	0,077	0,850	1,430	0,014	0,576	1,067	0,243	1,214	1,882
1997-2001	2322892	1	22	32	0,043	0,947	1,378	0,002	0,641	1,003	0,204	1,352	1,850
1998-2002	2150411	1	19	28	0,047	0,884	1,302	0,002	0,579	0,925	0,221	1,296	1,785
1999-2003	2094410	1	16	22	0,048	0,764	1,050	0,002	0,479	0,711	0,227	1,160	1,500

A3.3 Ten-year Moving Averages

					Frequencies per 100,000 manhours in saturation								
	Exposure	Numbers			Mean			Lower 90% limit			Upper 90% limit		
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Fatalities	Decompr. Sickness	Other injury	Fatalities	Decompr. Sickness	Other injury	Fatalities	Decompr. Sickness	Other injury
1976 - 1985	12703104	12			0,094			0,055			0,153		
1977 - 1986	12999905	6			0,046			0,020			0,091		
1978 - 1987	14022470	4			0,029			0,010			0,065		
1979 - 1988	13491587	2			0,015			0,003			0,047		
1980 - 1989	12961825	0			0,000			0,000			0,018		
1981 - 1990	12845344	0			0,000			0,000			0,018		
1982 - 1991	12644863	0			0,000			0,000			0,018		
1983 - 1992	12253981	0			0,000			0,000			0,019		
1984 - 1993	11676058	0			0,000			0,000			0,020		
1985 - 1994	11065355	0			0,000			0,000			0,021		
1986 - 1995	10298974	1			0,010			0,000			0,046		
1987 - 1996	9810358	2			0,020			0,004			0,064		
1988 - 1997	9285075	2			0,022			0,004			0,068		
1989 - 1998	8617552	2			0,023			0,004			0,073		
1990 - 1999	7923148	3			0,038			0,010			0,098		
1991 - 2000	7367625	3			0,041			0,011			0,105		
1992 - 2001	6776262	3			0,044			0,012			0,114		
1993-2002	6147939	3			0,049			0,013			0,126		
1994-2003	6979321	3			0,043			0,012			0,111		

A3.4 Other Time Intervals

					Frequencies per 100,000 manhours in saturation								
	Exposure	Numbers			Mean			Lower 90% limit			Upper 90% limit		
Year	Manhours in saturation	Fatalities	Decompr. sickness	Other injury	Fatalities	Decompr. Sickness	Other injury	Fatalities	Decompr. Sickness	Other injury	Fatalities	Decompr. Sickness	Other injury
7-year average													
1975 - 1981	7280036	18			0,247	0,000	0,000	0,160	0,000	0,000	0,367	0,032	0,032
1976 - 1982	8064040	12			0,149	0,000	0,000	0,086	0,000	0,000	0,241	0,029	0,029
12 year average													
1992-2003	7638667	3			0,039	0,000	0,000	0,011	0,000	0,000	0,102	0,030	0,030
14 year average													
1990-2003	9673717	3			0,031	0,000	0,000	0,008	0,000	0,000	0,080	0,024	0,024

APPENDIX B

ANALYSIS OF SYNERGI INCIDENT REPORTS

TABLE OF CONTENTS

B1. SPREAD SHEET TABLE FOR SYNERGI INCIDENT REPORTS

	A	B	C	D	E	F	G	H
1	**Company**	**Number**	**Date**	**Man**	**Technology**	**Type**	**Organisation**	**Type**
2	Company 1	83	18.12.99		equipment design	helmet		saturation
3	Company 1	122	29.10.99	work execution			procedures	saturation
4	Company 1	670	16.05.00		malfunctioning equipment	diving suit		saturation
5	Company 1	935	27.06.00		equipment design	umbilical		saturation
6	Company 1	937	04.07.00	work execution			planning	saturation
7	Company 1	1106	11.08.00	mental state				saturation
8	Company 1	1206	24.08.00		malfunctioning equipment	power generator		saturation
9	Company 1	1207	27.08.00		malfunctioning equipment	power generator		saturation
10	Company 1	1357	11.09.00		ergonomics	power switch		saturation
11	Company 1	1378	17.09.00	communication				saturation
12	Company 1	1637	02.11.00		malfunctioning equipment	socket		saturation
13	Company 1	1753	20.12.00	physical state				saturation
14	Company 1	2876	14.07.00	physical state				saturation
15	Company 1	3731	09.07.00	work execution			planning	saturation
16	Company 1	3735	09.07.00	work execution			planning	saturation
17	Company 1	4941	16.09.00	work execution			planning	saturation
18	Company 1	5504	26.06.99	communication			planning	saturation
19	Company 1	6337	16.11.00	physical state				saturation
20	Company 1	7517	24.11.00		malfunctioning equipment	release from dive gas	maintenance	saturation
21	Company 1	7705	05.12.01	physical state	ergonomics	bell design		saturation
22	Company 1	8591	23.12.01	work execution				saturation
23	Company 1	9713	15.12.01	physical state				saturation
24	Company 1	10116	04.04.02	work execution	equipment design	markings	planning	saturation
25	Company 1	11049	07.06.03	violation			procedures	saturation
26	Company 1	11204	06.09.03		malfunctioning equipment	control fuse		saturation
27	Company 1	11207	08.09.03				competence	saturation
28	Company 2	6272	06.08.99		malfunctioning equipment	gas release		saturation
29	Company 2	6312	14.08.99	work execution			planning	saturation
30	Company 2	6356	18.08.99	work execution			procedures	saturation
31	Company 2	6366	12.08.99	mental state				saturation
32	Company 2	6626	31.10.99	physical state			maintenance	saturation
33	Company 2	8713	20.03.00	mental state			supervision	saturation
34	Company 2	8714	21.03.00	work execution			procedures	saturation
35	Company 2	9309	20.08.00	work execution			maintenance	saturation
36	Company 2	9310	20.08.00		malfunctioning equipment	door bracket		saturation
37	Company 2	9337	29.08.00	physical state				saturation
38	Company 2	9378	05.09.00	physical state				saturation
39	Company 2	9585	01.11.00	work execution			procedures	saturation
40	Company 2	9630	14.11.00	mental state			competence	saturation
41	Company 2	9643	22.11.00		malfunctioning equipment	retaining dogs	maintenance	saturation
42	Company 2	9657	04.12.00	physical state			maintenance	saturation
43	Company 2	9669	09.09.00	work execution			procedures	saturation
44	Company 2	9679	07.12.00	physical state				saturation
45	Company 2	9682	09.12.00	work execution			procedures	saturation
46	Company 2	9720	20.12.00	physical state				saturation
47	Company 2	9766	30.12.00	mental state	ergonomics	gas supply valve	safety culture	saturation
48	Company 2	9868	30.11.00		malfunctioning equipment	door dogs		saturation
49	Company 2	9923	04.09.00		malfunctioning equipment	position control		saturation
50	Company 2	9924	04.10.00	work execution			planning	saturation
51	Company 2	9954	28.10.00		malfunctioning equipment	crane hook		saturation
52	Company 2	9959	02.11.00	violation			procedures	saturation
53	Company 2	9961	02.11.00		equipment design		maintenance	saturation
54	Company 2	9962	02.11.00	violation			procedures	saturation
55	Company 2	10005	27.10.00	work execution	malfunctioning equipment	buoyancy bead	procedures	saturation
56	Company 2	10051	03.08.00	mental state			supervision	saturation
57	Company 2	10269	16.01.01		malfunctioning equipment	fitting failure		saturation
58	Company 2	10325	13.01.01	mental state			supervision	saturation
59	Company 2	10336	25.01.01	work execution			safety culture	saturation
60	Company 2	10338	29.01.01	work execution				saturation
61	Company 2	10339	29.01.01		malfunctioning equipment	big rig		saturation
62	Company 2	10343	02.02.01	work execution			planning	saturation
63	Company 2	10352	15.02.01		equipment design		procedures	saturation
64	Company 2	10370	06.02.01	physical state				saturation
65	Company 2	10376	05.02.01	work execution			planning	saturation
66	Company 2	10377	05.02.01	work execution			procedures	saturation
67	Company 2	10390	18.02.01	work execution			planning	saturation
68	Company 2	10566	20.02.01		malfunctioning equipment	divers pheumo	planning	saturation
69	Company 2	10567	25.02.01	mental state	ergonomics	ladder		saturation
70	Company 2	10769	13.05.01	work execution			planning	saturation
71	Company 2	10778	29.04.01		equipment design	straps	procedures	saturation
72	Company 2	10786	07.05.01	physical state				saturation
73	Company 2	10788	09.05.01	work execution			maintenance	saturation
74	Company 2	10791	10.05.01	physical state			safety culture	saturation
75	Company 2	10792	10.05.01	communication	equipment design	headsets		saturation
76	Company 2	11124	28.06.01	violation			planning	saturation
77	Company 2	11176	03.07.01	work execution			supervision	saturation
78	Company 2	11177	07.07.01				supervision	saturation
79	Company 2	11178	07.07.01	violation			supervision	saturation
80	Company 2	11188	07.07.01		malfunctioning equipment	chain rails	maintenance	saturation
81	Company 2	11192	08.07.01		malfunctioning equipment	power supply	maintenance	saturation
82	Company 2	11213	14.07.01	physical state				saturation
83	Company 2	11214	08.07.01	mental state			supervision	saturation
84	Company 2	11231	17.07.01	violation			supervision	saturation
85	Company 2	11238	17.07.01		malfunctioning equipment	mushroom valves	maintenance	saturation
86	Company 2	11252	21.07.01	violation			supervision	saturation
87	Company 2	11254	27.07.01	work execution			competence	saturation
88	Company 2	11256	29.07.01		equipment design	thrusters	supervision	saturation
89	Company 2	11258	23.07.01		ergonomics	stairs		saturation
90	Company 2	11264	23.07.01	work execution			supervision	saturation
91	Company 2	11267	28.07.01	physical state				saturation

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92	**Company**	**Number**	**Date**	**Man**	**Technology**	**Type**	**Organisation**	**Type**
93	Company 2	11306	31.07.01		equipment design	chains and shackles	maintenance	saturation
94	Company 2	11517	17.09.01	physical state				saturation
95	Company 2	11986	30.08.01		equipment design	ploy rope	maintenance	saturation
96	Company 2	13666	30.05.02		equipment design	rubber protection	maintenance	saturation
97	Company 2	14261	09.07.02	physical state				surface
98	Company 2	14280	13.06.02	mental state			competence	saturation
99	Company 2	14363	22.07.02	work execution			planning	saturation
100	Company 2	14381	08.07.02	violation			supervision	saturation
101	Company 2	14382	23.07.02	physical state				saturation
102	Company 2	14385	23.07.02		malfunctioning equipment	anode		saturation
103	Company 2	14556	06.08.02		malfunctioning equipment	lip seal on door	maintenance	saturation
104	Company 2	14601	17.08.02	mental state			planning	saturation
105	Company 2	14668	20.08.02	mental state			planning	saturation
106	Company 2	14708	17.08.02	violation			planning	saturation
107	Company 2	14772	29.08.02	physical state				saturation
108	Company 2	14817	27.08.02		malfunctioning equipment	hot water supply		saturation
109	Company 2	14867	10.09.02	work execution			planning	saturation
110	Company 2	14869	12.09.02	violation			supervision	saturation
111	Company 2	14913	23.09.02		malfunctioning equipment	compression joint		saturation
112	Company 2	14994	30.09.02	physical state				saturation
113	Company 2	15195	09.10.02	work execution			maintenance	saturation
114	Company 2	15273	30.09.02		equipment design	suit		saturation
115	Company 2	15306	13.10.02	violation			supervision	saturation
116	Company 2	15422	10.10.02		equipment design	regulator HP		saturation
117	Company 2	15427	22.10.02	physical state				saturation
118	Company 2	15467	09.11.02	violation			procedures	saturation
119	Company 2	15557	06.12.02	mental state			supervision	saturation
120	Company 2	15678	24.12.02	mental state			planning	saturation
121	Company 2	15679	27.12.02	physical state			planning	saturation
122	Company 2	15682	01.01.03	mental state			competence	saturation
123	Company 2	15920	30.01.02		malfunctioning equipment	DP status	procedures	saturation
124	Company 2	15984	05.02.03	physical state			procedures	saturation
125	Company 2	16233	07.03.02	physical state			procedures	saturation
126	Company 2	16318	21.03.03		malfunctioning equipment	guide weight	maintenance	saturation
127	Company 2	16481	22.04.03	physical state	ergonomics	door handle		saturation
128	Company 2	16483	24.04.03	work execution			procedures	saturation
129	Company 2	16545	29.04.03	physical state				saturation
130	Company 2	16635	06.05.03		ergonomics	pressure relief valve		saturation
131	Company 2	16640	08.05.03		equipment design	air quads	supervision	saturation
132	Company 2	17112	20.06.03	physical state			safety culture	saturation
133	Company 2	17204	25.06.03	mental state			supervision	saturation
134	Company 2	17205	27.06.03	physical state				saturation
135	Company 2	17206	19.06.03	physical state				saturation
136	Company 2	17212	23.06.03	violation			procedures	saturation
137	Company 2	17213	23.06.03		equipment design	toilet valves		saturation
138	Company 2	17216	24.06.03	mental state			procedures	saturation
139	Company 2	17267	29.05.03	mental state			safety culture	saturation
140	Company 2	17268	17.06.03	mental state			safety culture	saturation
141	Company 2	17347	22.06.03	physical state				saturation
142	Company 2	17700	13.05.03	work execution			planning	saturation
143	Company 2	17859	13.08.03	work execution			supervision	surface
144	Company 3	29451	26.10.98		malfunctioning equipment	communication equipment	planning	surface
145	Company 3	30579	27.10.98	work execution				surface
146	Company 3	30600	28.10.98		malfunctioning equipment	extention lead	maintenance	surface
147	Company 3	39039	29.10.98		equipment design	basket	procedures	surface
148	Company 3	39045	30.10.98	work execution			maintenance	surface
149	Company 3	40501	31.10.98	work execution			procedures	surface
150	Company 3	49456	01.11.98	physical state			procedures	surface
151	Company 3	50395	02.11.98	work execution			planning	surface
152	Company 3	51399	03.11.98	work execution				surface
153	Company 3	51413	04.11.98		equipment design	helmet	maintenance	surface
154	Company 3	51415	05.11.98	physical state				surface
155	Company 3	51417	06.11.98		malfunctioning equipment	manometer	procedures	surface
156	Company 3	51558	07.11.98	physical state				surface
157	Company 3	51560	08.11.98		malfunctioning equipment	fuse	maintenance	surface
158	Company 3	51561	09.11.98		equipment design	harness		surface
159	Company 3	55681	10.11.98	violation			organisational issues	surface
160	Company 3	65182	11.11.98		malfunctioning equipment	cooling coil	maintenance	surface
161	Company 3	65187	12.11.98		malfunctioning equipment	power supply		surface
162	Company 3	73179	13.11.98				procedures	surface
163	Company 3	74641	14.11.98	work execution			procedures	surface
164	Company 3	74669	15.11.98				safety culture	surface
165	Company 3	74711	16.11.98	work execution			procedures	surface
166	Company 3	74716	17.11.98	mental state				surface
167	Company 3	74726	18.11.98		malfunctioning equipment	oxygen chamber		surface
168	Company 3	74727	19.11.98		equipment design	safety hook/harness	planning	surface
169	Company 3	80791	20.11.98	work execution			organisational issues	surface
170	Company 3	80797	21.11.98		equipment design	pressure chamber/air caisson		surface
171	Company 3	95003	22.11.98	work execution			planning	surface
172	Company 3	95009	23.11.98		equipment design	safety hook/harness	planning	surface
173	Company 3	95015	24.11.98		equipment design	fuel supply		surface
174	Company 3	118086	25.11.98		malfunctioning equipment	pressure equalizing		surface
175	Company 3	144512	26.11.98	work execution	equipment design	helmet		surface
176	Company 3	146857	27.11.98	communication			safety culture	surface
177	Company 3	147652	28.11.98		ergonomics	ladder	procedures	surface
178	Company 3	157889	29.11.98	violation			safety culture	surface
179	Company 3	163558	30.11.98	violation			safety culture	surface
180	Company 3	163563	01.12.98		equipment design	mobilization boat	procedures	surface
181	Company 3	185909	02.12.98	work execution	ergonomics	ladder	procedures	surface

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182	**Company**	**Number**	**Date**	**Man**	**Technology**	**Type**	**Organisation**	**Type**
183	Company 3	185911	03.12.98		equipment design	monitor	maintenance	surface
184	Company 3	188994	04.12.98	communication			supervision	surface
185	Company 3	189704	05.12.98	work execution			competence	surface
186	Company 3	189719	06.12.98	work execution	equipment design	diving suit	procedures	surface
187	Company 3	189755	07.12.98		malfunctioning equipment	air hose coupling	maintenance	surface
188	Company 3	196335	08.12.98				planning	surface
189	Company 3	196613	09.12.98	violation			competence	surface
190	Company 3	196882	10.12.98				competence	surface
191	Company 3	197161	11.12.98	violation			organisational issues	surface
192	Company 3	197180	12.12.98	violation			organisational issues	surface
193	Company 3	197379	13.12.98	work execution			procedures	surface
194	Company 3	197380	14.12.98	violation			organisational issues	surface
195	Company 3	197381	15.12.98	violation			organisational issues	surface
196	Company 3	197383	16.12.98				competence	surface
197	Company 3	197384	17.12.98	communication			procedures	surface
198	Company 3	197385	18.12.98				procedures	surface
199	Company 3	197386	19.12.98	work execution			procedures	surface
200	Company 3	197387	20.12.98	violation			organisational issues	surface
201	Company 3	197399	21.12.98				organisational issues	surface
202	Company 3	197401	22.12.98		equipment design	pressure chamber/air caisson		surface
203	Company 3	199108	23.12.98				safety culture	surface
204	Company 3	199617	24.12.98		equipment design	basket		surface
205	Company 3	200359	25.12.98				organisational issues	surface
206	Company 3	200464	26.12.98	violation			organisational issues	surface
207	Company 3	200465	27.12.98				organisational issues	surface
208	Company 3	200466	28.12.98				organisational issues	surface
209	Company 3	200467	29.12.98	communication			organisational issues	surface
210	Company 3	200827	30.12.98				safety culture	surface
211	Company 3	200829	31.12.98		ergonomics	basket	safety culture	surface
212	Company 3	200830	01.01.99	violation			organisational issues	surface
213	Company 3	201167	02.01.99	violation			organisational issues	surface
214	Company 3	201172	03.01.99	violation			organisational issues	surface
215	Company 3	201205	04.01.99	work execution				surface
216	Company 3	205046	05.01.99		equipment design	bailout	planning	surface
217	Company 3	205072	06.01.99		equipment design	helmet	planning	surface
218	Company 3	205075	07.01.99		malfunctioning equipment	bailout	maintenance	surface
219	Company 3	206585	08.01.99				safety culture	surface
220	Company 3	206586	09.01.99	communication			safety culture	surface
221	Company 3	206587	10.01.99		equipment design	rescue bed		surface
222	Company 3	206588	11.01.99				safety culture	surface
223	Company 3	206593	12.01.99				safety culture	surface
224	Company 3	206594	13.01.99	violation			organisational issues	surface
225	Company 3	209341	14.01.99	mental state			procedures	surface
226	Company 3	210870	15.01.99				organisational issues	surface
227	Company 3	210871	16.01.99				organisational issues	surface
228	Company 3	210873	17.01.99				organisational issues	surface
229	Company 3	218729	18.01.99		malfunctioning equipment	lantern		surface
230	Company 3	219689	19.01.99		equipment design	helmet hose		surface
231	Company 3	228782	20.01.99				organisational issues	surface
232	Company 3	231793	21.01.99	mental state				surface
233	Company 3	233113	22.01.99		equipment design	WV flush pump		surface
234	Company 3	24008	16.09.1998	work execution		straps	safety culture	saturation
235	Company 3	23103	14.09.1998		malfunctioning equipment	sjakkel		saturation
236	Company 3	24115	22.09.1998	work execution		main umbilical	competence	saturation
237	Company 3	24247	15.09.1998	physical state		toe		saturation
238	Company 3	24271	12.09.1998		equipment damage	wire		saturation
239	Company 3	24288	14.09.1998	mental state		bail out		saturation
240	Company 3	24859	23.09.1998	physical state	malfunctioning equipment	air lift		saturation
241	Company 3	25089	27.09.1998	physical state		ear infection		saturation
242	Company 3	29260	05.08.1998	work execution	equipment damage	helmet		saturation
243	Company 3	29261	06.08.1998		malfunctioning equipment	valve		saturation
244	Company 3		03.03.1999	physical state		ear infection		saturation
245	Company 3	40524	17.04.1999	physical state		hot water suit		saturation
246	Company 3	42094	07.05.1999	work execution		safety chain	procedures	saturation
247	Company 3	43104	30.04.1999		malfunctioning equipment	lift winch		saturation
248	Company 3	42112	30.04.1999	work execution		bell umbilical		saturation
249	Company 3	42194	17.04.1999	work execution		stabilizer strap		saturation
250	Company 3	42200	16.04.1999		malfunctioning equipment	diver hot water machine	maintenance	saturation
251	Company 3	42267	19.04.1999		malfunctioning equipment	hot water hose		saturation
252	Company 3	42278	19.04.1999		malfunctioning equipment	umbilical winch	maintenance	saturation
253	Company 3	42843	24.04.1999		malfunctioning equipment	back up communication lines		saturation
254	Company 3	46029	27.06.1999		equipment design	blindflens	maintenance	saturation
255	Company 3	46108	26.06.1999		malfunctioning equipment	manometer		saturation
256	Company 3	46380	04.07.1999	physical state		finger		saturation
257	Company 3	46412	03.07.1999	violation		disp from regulation	safety culture	saturation
258	Company 3	47070	11.07.1999	work execution		logistic	planning	saturation
259	Company 3	47902	27.07.1999	physical state		ancle		saturation
260	Company 3	48080	15.07.1999	physical state		ear		saturation
261	Company 3	48105	15.07.1999	physical state		ear		saturation
262	Company 3	48571	27.07.1999		malfunctioning equipment	computer in control room		saturation
263	Company 3	48527	21.07.1999		malfunctioning equipment	span set		saturation
264	Company 3	48711	03.07.1999	violation		parallell operations	planning	saturation
265	Company 3	48720	04.07.1999	work execution		unplanned spill	planning	saturation
266	Company 3	51553	24.08.1999	physical state		back		saturation
267	Company 3	63935	12.03.2000	work execution		unplanned spill	planning	saturation
268	Company 3	70668	09.07.2000	violation		regulation	supervision	saturation
269	Company 3	72513	04.07.2000		equipment damage	SLS bail out system		saturation
270	Company 3	72682	05.07.2000		equipment damage	SLS bail out system		saturation
271	Company 3	73076	04.07.2000		malfunctioning equipment	helmet		saturation

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272	**Company**	**Number**	**Date**	**Man**	**Technology**	**Type**	**Organisation**	**Type**
273	Company 3		11.08.2000	mental state		uncontrolled decompression		saturation
274	Company 3	74052	16.08.2000	communication		tautwire moved	procedures	saturation
275	Company 3	74056	17.08.2000	work execution		lost grip of equipment		saturation
276	Company 3	74145	17.08.2000	physical state		hit by falling object in back		saturation
277	Company 3	74153	20.08.2000		malfunctioning equipment	door		saturation
278	Company 3	74156	20.08.2000	physical state		wet paint		saturation
279	Company 3	74158	23.08.2000		equipment design	drain system		saturation
280	Company 3	74163	18.08..2000	work execution	equipment design	safety bolt		saturation
281	Company 3	74464	25.08.2000	communication		technicians	competence	saturation
282	Company 3	74474	24.08.2000	communication		radio frequenses	planning	saturation
283	Company 3	74603	23.08.2000		equipment design	heavy doors		saturation
284	Company 3	74604	27.08.2000		malfunctioning equipment	camera on helmet		saturation
285	Company 3	74605	27.08.2000	violation		control room	safety culture	saturation
286	Company 3	74611	29.08.2000	physical state		ear infection		saturation
287	Company 3	74613	29.08.2000	work execution		misplacement of equipment		saturation
288	Company 3	74614	29.08.2000	work execution		monitoring equipm.not in us	planning	saturation
289	Company 3	74615	29.08.2000		malfunctioning equipment	defect diving equipment	maintenance	saturation
290	Company 3	74616	29.08.2000		malfunctioning equipment	telephone		saturation
291	Company 3	74634	30.08.2000		ergonomics	ergonomi, noise,ventillation	maintenance	saturation
292	Company 3	74651	21.08.2000		equipment design	klokke - kammerflens		saturation
293	Company 3	74805	03.09.2000	violation		dive without permission		saturation
294	Company 3	756666	04.09.2000		equipment design	lack of flow indicator		saturation
295	Company 3	75672	05.09.2000		equipment design	aircondition		saturation
296	Company 3	75685	04.09.2000		malfunctioning equipment	VHF radio in lifeboat		saturation
297	Company 3	775687	04.09.2000		malfunctioning equipment	communication system HRV		saturation
298	Company 3	75717	03.09.2000		equipment design	door in wet pot		saturation
299	Company 3	75721	03.09.2000		equipment design	leakage in wet pot		saturation
300	Company 3	76882	06.10.2000		malfunctioning equipment	irregular decompression		saturation
301	Company 3	76884	13.09.2000		malfunctioning equipment	electricty supply to wet pot		saturation
302	Company 3	76935	06.10.2000	work execution		regulation	competence	saturation
303	Company 3	76970	17.09.2000	communication		bell and chamber		saturation
304	Company 3	76971	25.09.2000	communication		ballast vann utløp	planning	saturation
305	Company 3	76974	08.10.2000	violation		permission to dive	planning	saturation
306	Company 3	77752	16.10.2000	physical state		ear infection		saturation
307	Company 3	78509	09.10.2000	physical state		ear infection		saturation
308	Company 3	79000	01.11.2000	work execution		equipment not in place	planning	saturation
309	Company 3	79193	06.11.2000		equipment design	fitting lost under testing	competence	saturation
310	Company 3	79194	06.11.2000		malfunctioning equipment	leakage in valveplug	maintenance	saturation
311	Company 3	79198	01.11.2000	physical state		smoke from el component	maintenance	saturation
312	Company 3	799219	27.10.2000	work execution		violation of norw.regs	safety culture	saturation
313	Company 3	80393	14.11.2000	physical state		finger		saturation
314	Company 3	80396	12.11.2000	violation		use of safety equipment		saturation
315	Company 3	80403	08.11.2000	mental state		gas sample for test		saturation
316	Company 3	80821	22.11.2000	work execution		bolted door		saturation
317	Company 3	82034	18.12.2000		malfunctioning equipment	leakage SLS		saturation
318	Company 3	82036	19.12.2000	physical state		fingers		saturation
319	Company 3	82054	16.12.2000		equipment design	too short umbilical		saturation
320	Company 3	82056	12.12..2000		malfunctioning equipment	camera and light		saturation
321	Company 3	82061	12.12.2000	violation		NPD regs § 66 - disp	safety culture	saturation
322	Company 3	82774	07.12.2000	physical state		ear infection		saturation
323	Company 3	82775	04.12.2000	physical state		ear infection - 82774		saturation
324	Company 3	82778	12.12.2000	physical state		nose bleede		saturation
325	Company 3	91662	20.05.2001		malfunctioning equipment	mushroom valve		saturation
326	Company 3	121095	29.05.1996		malfunctioning equipment	SLS reserve pustegass		saturation
327	Company 3	121440	08.06.1996		malfunctioning equipment	SLS bail out system		saturation
328	Company 3	133579	28.03.1997	work execution		umbilical		saturation
329	Company 3	1344138	02.04.1997	physical state	malfunctioning equipment	hole in hose caused burns		saturation
330	Company 3	134153	05.04.1997	work execution		hit by falling object		saturation
331	Company 3	134354	31.03.1997	physical state		gas analysed	procedures	saturation
332	Company 3	134355	03.04.1997	physical state	malfunctioning equipment	dykker fikk støt		saturation
333	Company 3	134357	04.04.1997		malfunctioning equipment	external light		saturation
334	Company 3	134358	06.04.1997	physical state		knee		saturation
335	Company 3	134359	01.04.1997	physical state		slippery floor		saturation
336	Company 3	135012	19.04.1997	work execution		SLS bail out lacked soda		saturation
337	Company 3	135019	22.04.1997	physical state		ear irritation		saturation
338	Company 3	135022	24.04.1997	work execution		umbilical		saturation
339	Company 3	135853	01.05.1997		malfunctioning equipment	breathing gas		saturation
340	Company 3	135857	03.05.1997		equipment damage	neck seal		saturation
341	Company 3	135994	09.05.1997	mental state		slippery floor		saturation
342	Company 3	136559	16.05.1997		malfunctioning equipment	bolts		saturation
343	Company 3	140667	31.07.1997	work execution	equipment design	lift bag dump line for climb		saturation
344	Company 3	140671	08.08.1997	work execution		5 tons nearly slipped		saturation
345	Company 3	141282	02.08.1997	work execution		umbilical		saturation
346	Company 3	141287	04.08.1997	work execution		equipment handling		saturation
347	Company 3	141296	05.08.1997	work execution		umbilical		saturation
348	Company 3	141317	07.08.1997	work execution		lifting operation		saturation
349	Company 3	147657	01.11.1997	communication		DP brigde and diverespons		saturation
350	Company 3	147659	01.11.1997	mental state		spill		saturation
351	Company 3	147661	02.11.1997	work execution		equipment under pressure		saturation
352	Company 3	147667	06.11.1997	work execution		floating piece of wood		saturation
353	Company 3	148084	09.11.1997	work execution	equipment design	cabel between deck/sub se	procedures	saturation
354	Company 3	148091	10.11.1997	work execution		umbilical/lifting		saturation
355	Company 3	148094	10.11.1997		malfunctioning equipment			saturation
356	Company 3	148099	10.11.1997		equipment damage	SLS breathing gas		saturation
357	Company 3	148108	29.11.1997	work execution		umilical trapped,loss og communication		saturation
358	Company 3	156410	24.02.1998	work execution		umbilical	planning	saturation
359	Company 3	159618	30.04.1998	work execution		Kevlar door	procedures	saturation
360	Company 3	160036	12.05.1998		malfunctioning equipment	leaking o-ring on SLS		saturation
361	Company 3	160040	04.05.1998	work execution		burner gear		saturation

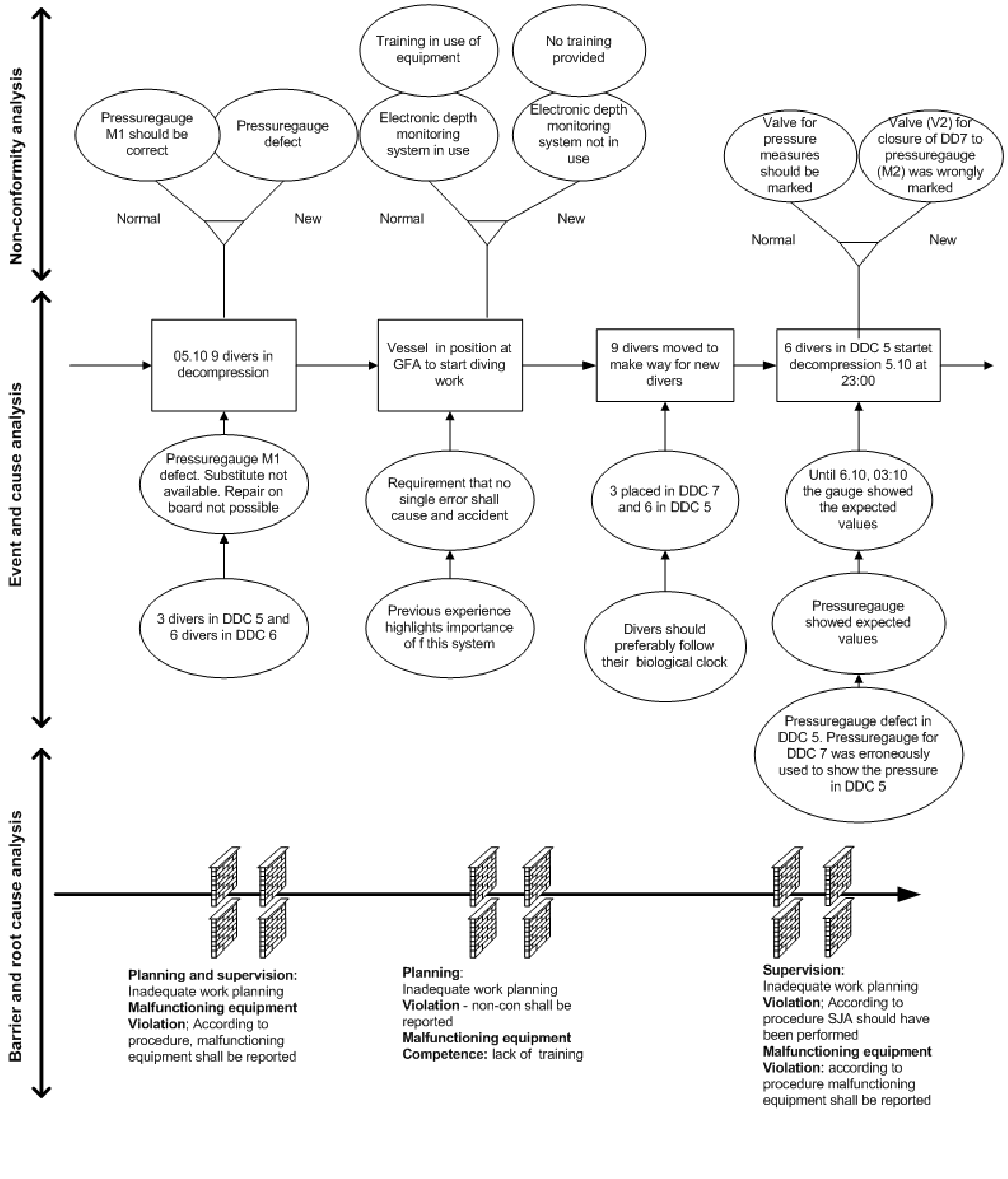
	A	B	C	D	E	F	G	H
362	**Company**	**Number**	**Date**	**Man**	**Technology**	**Type**	**Organisation**	**Type**
363	Company 3	160155	18.05.1998	work execution		high pressure waterjetting	procedures	saturation
364	Company 3	162300	18.06.1998	work execution		welding	planning	saturation
365	Company 3	163619	29.06.1998	physical state		hand		saturation
366	Company 3	163688	28.06.1998	physical state		chin		saturation
367	Company 3	163693	25.06.1998		equipment damage	SLS manometer brakk		saturation
368	Company 3	163696	21.06.1998		malfunctioning equipment	SLS had wet lime		saturation
369	Company 3	164156	01.07.1998	physical state		cheek inection		saturation
370	Company 3	166063	31.07.1998	work execution		lifting operation		saturation
371	Company 3	166648	05.08.1998		malfunctioning equipment	high pressure valve		saturation
372	Company 3	166649	08.08.1998		equipment damage	helmet		saturation
373	Company 3	167714	04.08.1998	work execution	malfunctioning equipment	power failure, TV control		saturation
374	Company 3	198195	04.10.2002	work execution		hard hat		saturation
375	Company 3	199240	04.10.2002	violation		mobile phone		saturation
376	Company 3	199246	04.10.2002	communication		unauthorised access		saturation
377	Company 3	199248	04.10.2002		malfunctioning equipment	power failure,		saturation
378	Company 3	199250	05.10.2002	work execution			procedures	saturation
379	Company 3	199251	05.10.2002		equipment design	functional requirements toilet		saturation
380	Company 3	199252	01.10.2002	violation		mobile phone		saturation
381	Company 3	209005	31.01.2003	physical state		test dive		saturation
382	Company 3	221774	20.05.2003	violation	equipment design	markings NPD regs		saturation
383	Company 3	221845	25.05.2003		equipment design	markings on dump line		saturation
384	Company 3	221849	26.05.2003	mental state		forgot valves on form		saturation
385	Company 3	221855	26.05.2003		equipment design	bad smell		saturation
386	Company 3	235476	12.09.2003		malfunctioning equipment	power failure communication		saturation
387	Company 3	235604	11.09.2003	violation		deviation from NPD regs	maintenance	saturation
388	Company 3	235621	19.09.2003		malfunctioning equipment	fire in el heater		saturation
389	Company 3	235631	26.08.2003	physical state		ear infection		saturation
390	Company 3	235712	24.08.2003		equipment design	SLS lime container		saturation
391	Company 3	236497	08.09.2003	violation		NPD regs	safety culture	saturation
392	Company 3	236501	07.09.2003	communication		parallell operations		saturation
393	Company 3	236507	06.09.2003		malfunctioning equipment	power failure		saturation
394	Company 3	237216	08.09.2003	communication		parallell operations		saturation
395	Company 3	237217	06.09.2003		malfunctioning equipment	SLS		saturation
396	Company 3	237268	08.09.2003		malfunctioning equipment	winch		saturation
397	Company 3	237269	01.09.2003	work execution	malfunctioning equipment	electronic monotoring system		saturation
398								
399			**PERCENTAGES OVERALL**					
400	**Man**							
401	physical state		66	16,9 %				
402	mental state		28	7,2 %				
403	work execution		91	23,3 %				
404	communication		17	4,3 %				
405	violation		40	10,2 %				
406	Sum Man			61,9 %				
407								
408	**Technology**							
409	ergonomics		11	3 %				
410	equipment design		51	13 %				
411	malfunctioning equipment		79	20 %				
412	equipmen damage		8	2 %				
413	Sum Technology			38 %				
414					Counting check:			
415	Sum Man and Technology		391	100 %	There are 20 reports with entries both for M and T, They are counted twice			
416					There are 21 reports with entries for O only, not for M or T			
417	**Organisation**				Therefore: 391 - 20 + 21 = 392, which is the total number of all reports.			
418	supervision		20	10 %	Check OK			
419	competence		13	7 %				
420	safety culture		23	12 %				
421	organisational issues		21	11 %				
422	procedures		43	22 %				
423	planning		41	21 %				
424	maintenance		32	17 %				
425	Sum Organisation		193	100 %				

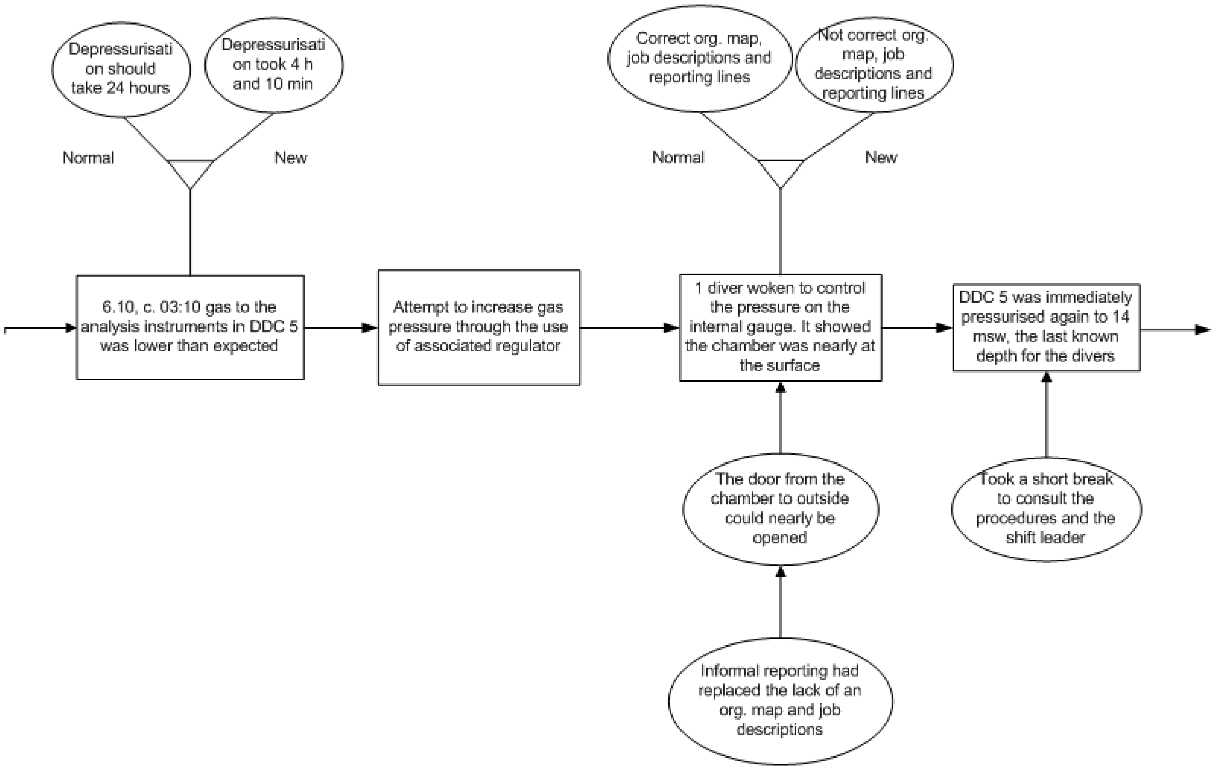
APPENDIX C

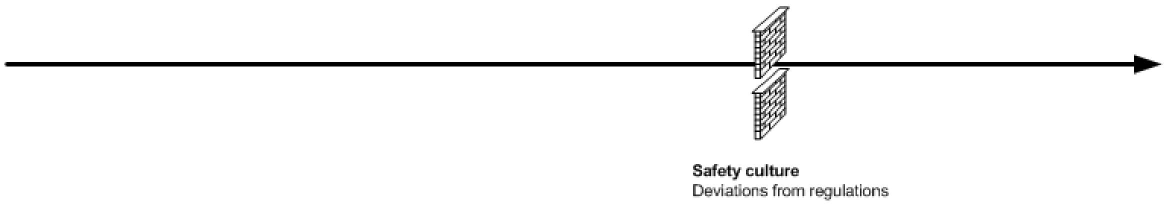
GRAPHICAL DESCRIPTION OF THREE INCIDENTS

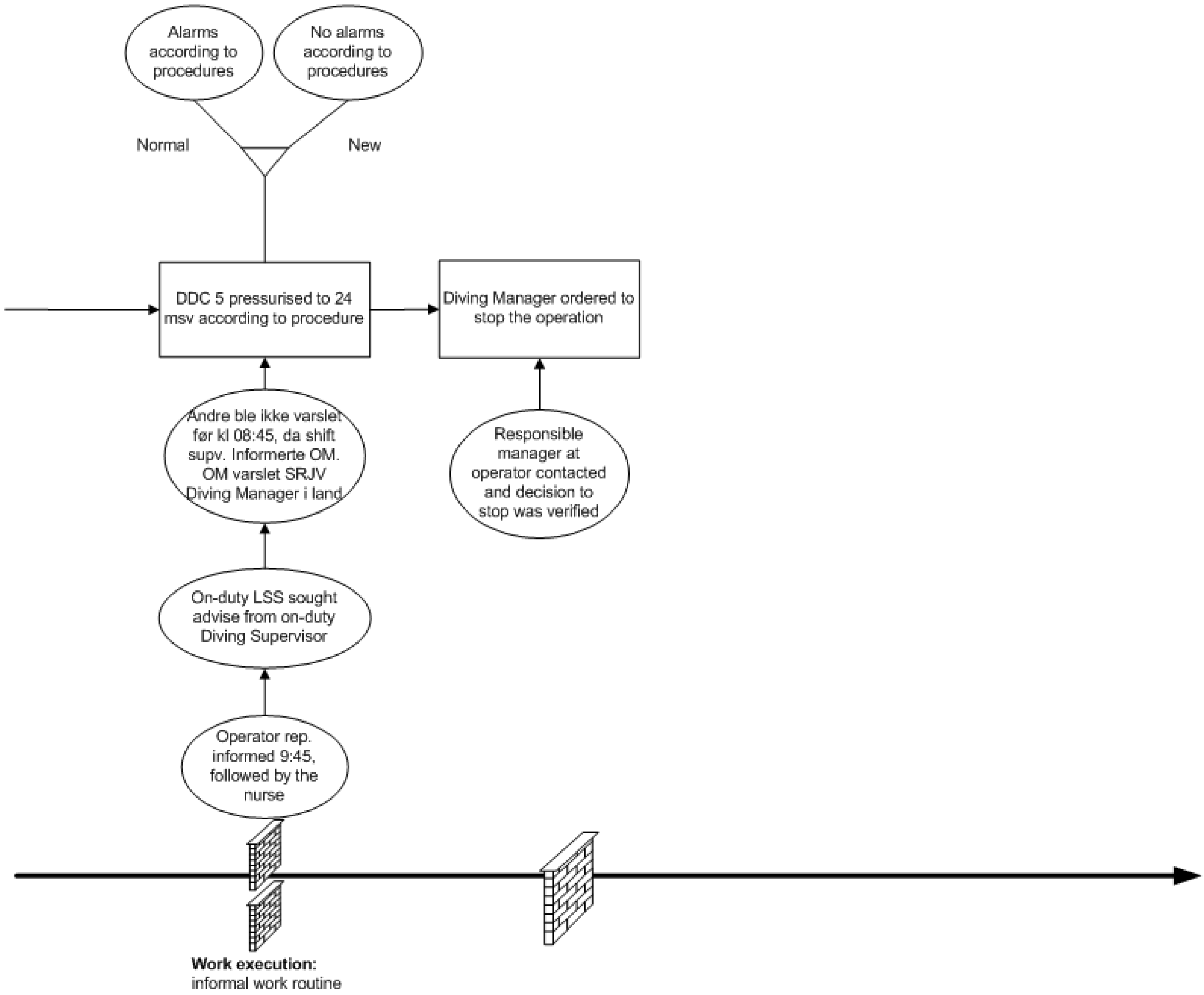
TABLE OF CONTENTS

C1. ACCIDENTAL EXPOSURE TO PRESSURE REDUCTION



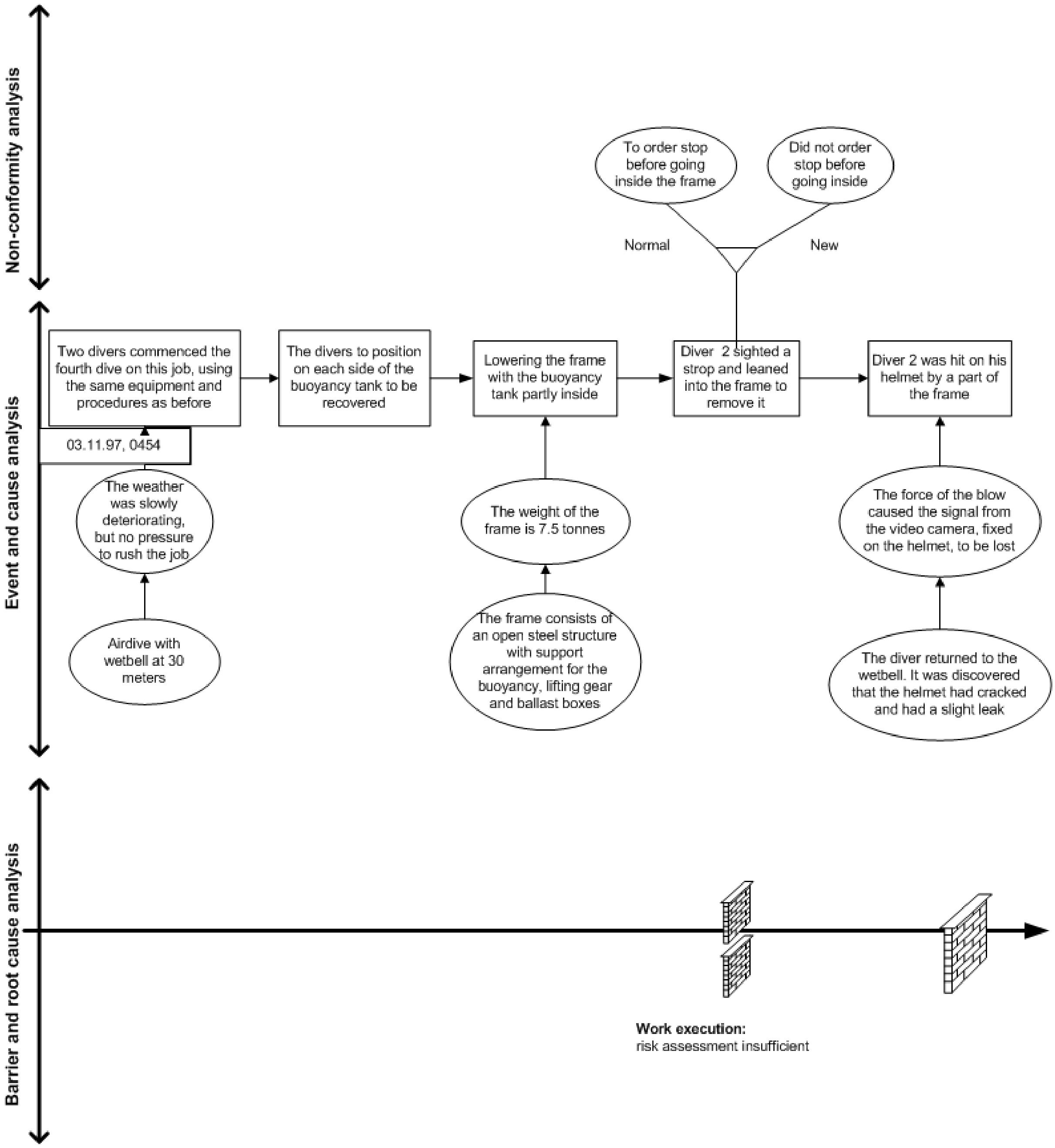

Depressurisati on should take 24 hours
Depressurisati on took 4 h and 10 min
Normal
New
Correct org. map, job descriptions and reporting lines
Not correct org. map, job descriptions and reporting lines
Normal
New
6.10, c. 03:10 gas to the analysis instruments in DDC 5 was lower than expected
Attempt to increase gas pressure through the use of associated regulator
1 diver woken to control the pressure on the internal gauge. It showed the chamber was nearly at the surface
DDC 5 was immediately pressurised again to 14 msw, the last known depth for the divers
The door from the chamber to outside could nearly be opened
Took a short break to consult the procedures and the shift leader
Informal reporting had replaced the lack of an org. map and job descriptions


Safety culture
Deviations from regulations

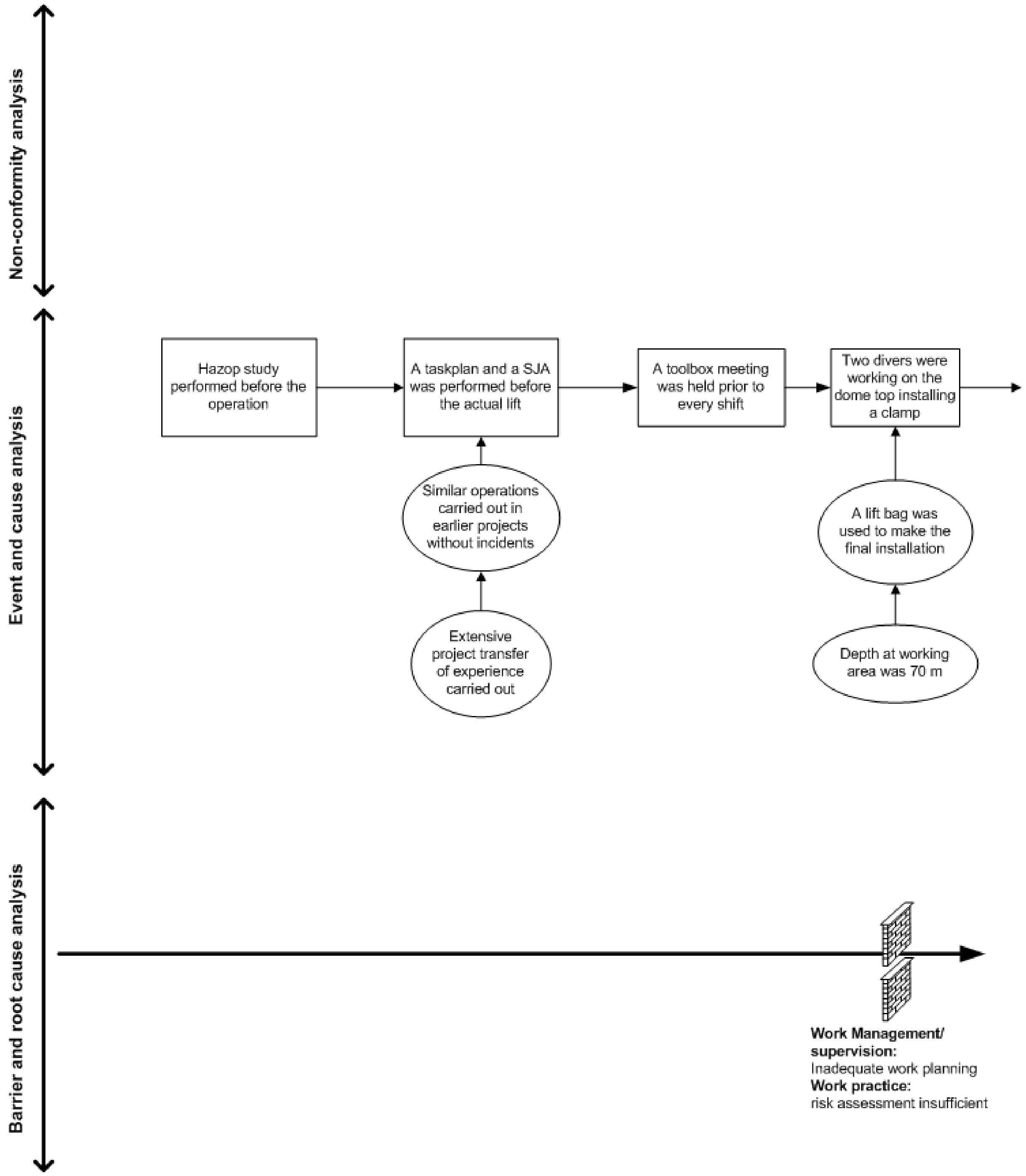


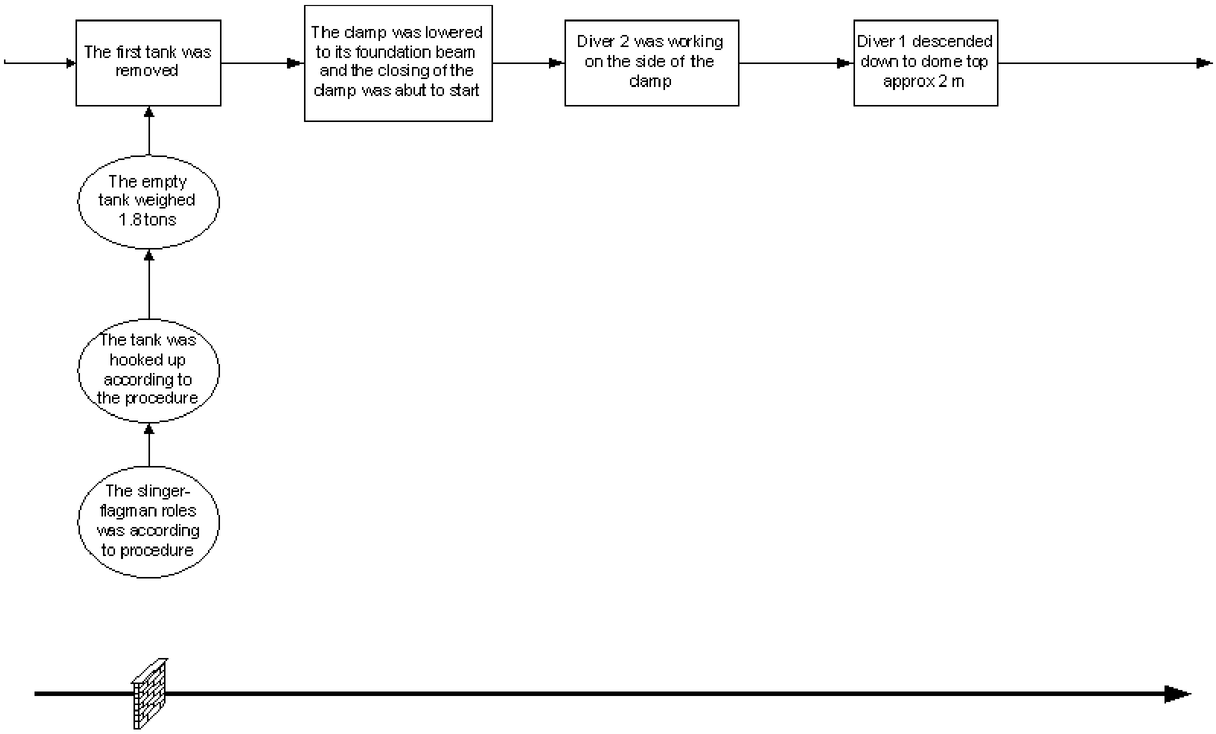
Alarms according to procedures
No alarms according to procedures
Normal
New
DDC 5 pressurised to 24 msv according to procedure
Diving Manager ordered to stop the operation
Andre ble ikke varslet før kl 08:45, da shift supv. Informerte OM. OM varslet SRJV Diving Manager i land
Responsible manager at operator contacted and decision to stop was verified
On-duty LSS sought advise from on-duty Diving Supervisor
Operator rep. informed 9:45, followed by the nurse
Work execution:
informal work routine

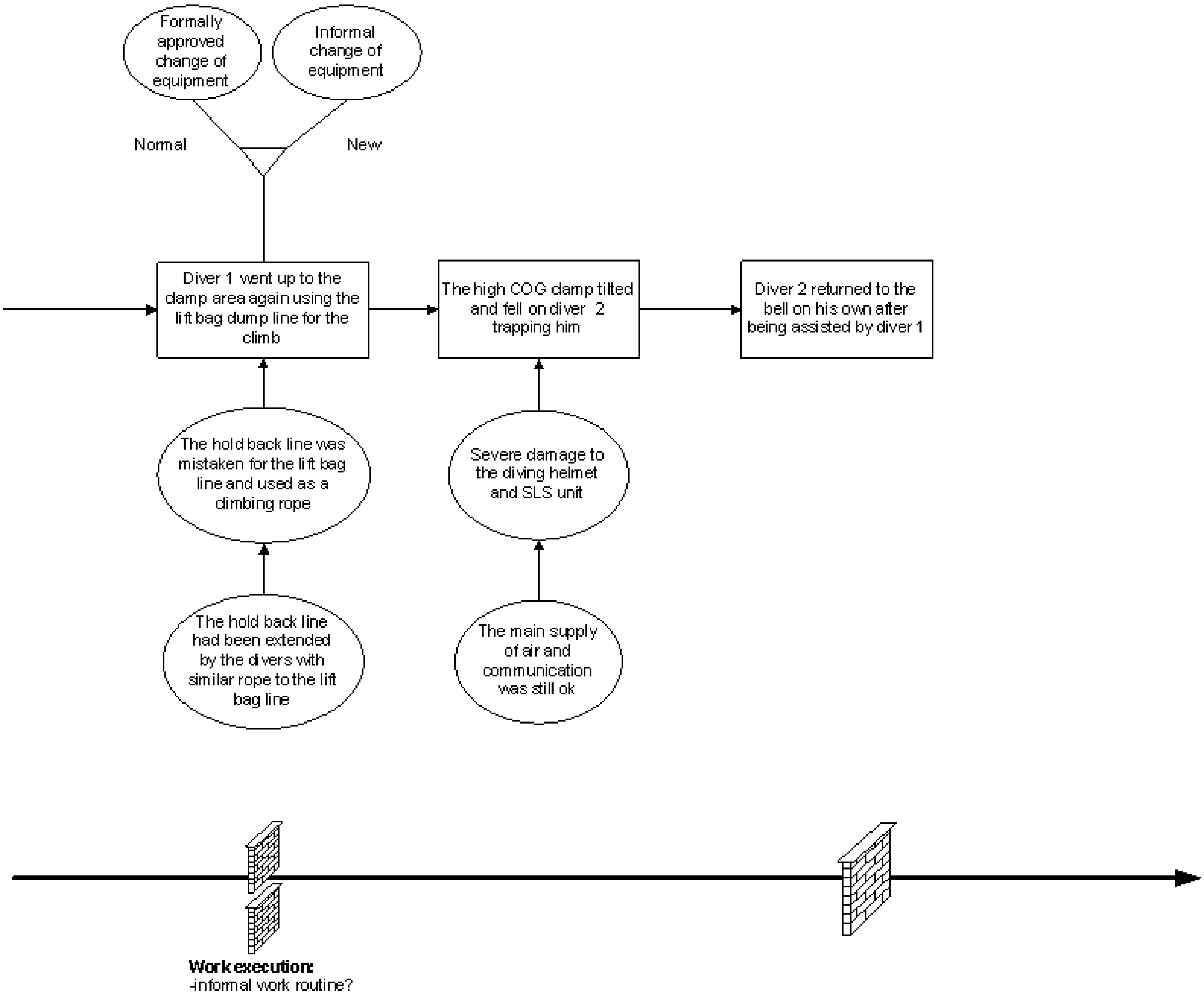
C2. DIVER HIT ON HELMET BY FRAME STRUCTURE



C3. CLAMP TILTING AND FALLING ON DIVER




The first tank was removed
The clamp was lowered to its foundation beam and the closing of the clamp was abut to start
Diver 2 was working on the side of the clamp
Diver 1 descended down to dome top approx 2 m
The empty tank weighed 1.8 tons
The tank was hooked up according to the procedure
The slinger-flagman roles was according to procedure


Formally approved change of equipment
Informal change of equipment
Normal
New
Diver 1 went up to the clamp area again using the lift bag dump line for the climb
The high COG clamp tilted and fell on diver 2 trapping him
Diver 2 returned to the bell on his own after being assisted by diver 1
The hold back line was mistaken for the lift bag line and used as a climbing rope
Severe damage to the diving helmet and SLS unit
The hold back line had been extended by the divers with similar rope to the lift bag line
The main supply of air and communication was still ok
Work execution:
-informal work routine?