Retrospective assessment of exposure to carcinogens in Norway’s offshore petroleum industry

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Til Øyvind, Oda, Bendik og Iben

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Acknowledgements

"Are you lost?"

"Yes."

"Because we don't know when we will die, we get to think of life as an inexhaustible well, yet everything happens only a certain number of times, and a very small number, really.

How many more times will you remember a certain afternoon of your childhood, some afternoon that's so deeply a part of your being that you can't even conceive of your life without it? Perhaps four or five times more, perhaps not even that.

How many more times will you watch the full moon rise? Perhaps twenty.

And yet it all seems limitless."

– Paul Bowles in *The Sheltering Sky*

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A happy ending

Oh, what a wonderful feeling when you have eaten up everything, drunk everything, talked of everything and danced your feet off, to go home in the quiet hour before the dawn to sleep!

– Tove Jansson *in Finn Family Moomintroll*

Abstract

Objectives

The main research objective of the four articles comprising this dissertation was to provide retrospective exposure information for a planned study on cancer in a cohort within Norway's offshore petroleum industry.

Methods

Background information on possible exposure was obtained through company visits, including interviewing key personnel ($n = 83$) and collecting monitoring reports ($n = 118$) and other relevant documents ($n = 329$). The collected material was used to identify relevant carcinogens. Twenty-seven job categories were defined based on a previous questionnaire administered to present and former offshore employees in 1998. Descriptions of products containing known and suspected carcinogens, exposure sources and processes were extracted from the collected documentation and the interviews of key personnel (Article II).

Exposure data on oil mist and oil vapour covered 37 drilling facilities and were analysed by descriptive statistics and by constructing linear mixed-effects models (Article I).

A group of three university and five industry experts individually assessed the likelihood (unlikely, possible or probable) of exposure for combinations of 17 carcinogens, 27 job categories and four time periods (1970–1979, 1980–1989, 1990–1999 and 2000–2005). Each rater was to assess 1836 combinations based on summary documents on carcinogenic agents, which included descriptions of sources of exposure and products, descriptions of work processes carried out within the different job categories and monitoring data. Interrater agreement was calculated using Cohen's kappa index and single and average score intraclass correlation coefficients. Differences in interrater agreement between the different time periods, raters, carcinogen class and amount of information provided were then studied (Article III).

In subsequent plenary discussions, the experts agreed on exposed combinations. Agreement between the individual and the panel assessments was calculated using Cohen's kappa index. Using the panel assessment as reference, sensitivity and specificity were estimated (Article IV).

Results

This study indicated possible exposure to the following known and suspected carcinogenic agents, mixtures or exposure circumstances: benzene; mineral oil – inhalation exposure; mineral oil – skin exposure; crystalline silica; asbestos; refractory ceramic fibres; formaldehyde; tetrachloroethylene; trichloroethylene; welding; nickel compounds; chromium [VI]; lead; crude oil – skin exposure; diesel engine exhaust; dichloromethane; ionising radiation; and occupational exposure as a painter (Article II). Monitoring reports were obtained on seven agents: benzene, mineral oil mist and vapour, respirable and total dust, asbestos fibres, refractory ceramic fibres, formaldehyde and tetrachloroethylene (Article II). The arithmetic mean of 367 personal samples of benzene was 0.037 ppm (range: less than the limit of detection – 2.6 ppm). Asbestos fibres were detected (0.03 fibres/cm^3) when asbestos-containing brake bands were used in drilling draw work in 1988. The personal exposure to formaldehyde in the process area ranged from 0.06 to 0.29 mg/m^3.

Samples of oil mist and oil vapour had been taken during the use of three generations of hydrocarbon base oils: diesel oils (1979–1984), low-aromatic mineral oils (1985–1997) and nonaromatic mineral oils (1998–2004). Sampling done before 1984 showed high exposure to diesel vapour (arithmetic mean = 1217 mg/m^3). Downward time trends were indicated for both oil mist (6% per year) and oil vapour (8% per year) when the year of monitoring was introduced as a fixed effect in a linear mixed-effects model analysis. Rig type, technical control measures and mud temperature significantly determined exposure to oil mist. Rig type, type of base oil, viscosity of the base oil, work area, mud temperature and season significantly determined exposure to oil vapour. In these models major decreases in variability were found for the between-rig components (Article I).

In the individual expert assessment overall, 336 (18%) of the 1836 combinations were denoted possible exposure, and 253 (14%) scored probable exposure. Stratified on the 17 carcinogenic agents, the prevalence of probable exposure ranged from 3.8% for refractory ceramic fibres to 30% for crude oil. The overall mean kappa (κ) was 0.42; single score intraclass correlation coefficient was 0.62, and the average intraclass correlation coefficient was 0.93. Providing limited quantitative measurement data was associated with less agreement than for equally well-described carcinogens without sampling data.

The eight experts assessed 1157 (63%) of the 1836 combinations in plenary, resulting in 265 (14%) agreed exposed combinations. The agreement between the experts' individual assessments and the panel assessment was $\kappa = 0.53–0.74$. The sensitivity was 0.55–0.86 and specificity 0.91–0.97. For these parameters, there were no apparent differences between the university experts and the industry experts.

Conclusions

For defined job categories in Norway's offshore petroleum industry this study describes possible exposure to known and suspected carcinogenic agents, mixtures or exposure circumstances. An expert panel agreed on probable exposure for 265 of 1836 possible combinations of 17 agents, 27 job categories and four time periods. Measurement data on seven agents are presented. Benzene and mineral oil mist and vapour were considered to have the best potential for development of quantitative estimates of exposure.

Exposure to oil mist and oil vapour declined over time in the mud-handling areas of offshore drilling facilities. Exposure was associated with rig type, mud temperature, technical control measures, base oil, viscosity of the base oil, work area and season.

The eight raters in the expert group seemed to have enough documentation on which to base their individual estimates. However, providing limited monitoring data leads to more incongruence among raters. The group was large enough to give reliable estimates.

The experts' individual ratings highly agreed with the succeeding panel assessment. The university experts and the industry experts' assessments did not apparently differ.

List of publications

Article I **Steinsvåg K**, Bråtveit M, Moen BE. Exposure to oil mist and oil vapour during offshore drilling in Norway, 1979–2004. *Annals of Occupational Hygiene* 2006;**50**:109–22.

Article II **Steinsvåg K**, Bråtveit M, Moen BE. Exposure to carcinogens for defined job categories in Norway's offshore petroleum industry, 1970–2005. *Occupational and Environmental Medicine* 2006 Oct 16; [Epub ahead of print].

Article III **Steinsvåg K**, Bråtveit M, Moen BE, Kromhout H. Interrater agreement in the assessment of exposure to carcinogens in the offshore petroleum industry. *Occupational and Environmental Medicine*. 2007 Jan 16; [Epub ahead of print].

Article IV **Steinsvåg K**, Bråtveit M, Moen BE, Austgulen LT, Hollund BE, Haaland IM, Nærheim J, Svendsen K, Kromhout H. Expert assessment of exposure to carcinogens in Norway's offshore petroleum industry. Submitted.

1. Introduction

This chapter presents the background of the study followed by an introduction to retrospective exposure assessment for studies of industry-specific cohorts. I describe the classification of carcinogenic agents and outline Norway's offshore petroleum industry, highlighting the drilling area, and briefly introduce previously published studies of offshore exposure.

1.1 Background

In response to the increasing concern about cancer in Norway's oil industry, Lærum et al. (1983) concluded in a review article that the risk of cancer in oil production and in exposure to oil products was not alarming but that more research and continuous control of hazardous substances were needed. Eide (1990) pursued this concern, questioning the possible long-term effects of exposure to low-aromatic oil-based drilling fluids. The recent media focus on exposure to chemicals offshore and a subsequent report from Norway's Ministry of Labour and Social Inclusion on exposure to chemicals on Norway's Continental Shelf in December 2005 (Sjonfjell et al., 2005) have further strengthened the call for more research.

In 1998, the Cancer Registry of Norway established a Norwegian offshore cohort including 27,986 former and current offshore workers who completed a questionnaire on job history, lifestyle and demographics (Strand & Andersen, 2001). The development of cancer in this cohort will be analysed in the years to come. To increase the power of the cancer study, the follow-up time of the cohort needs to be extended. Thus, the first cancer analysis is planned in 2010.

The Norwegian offshore cohort is designed to be a prospective industry-specific cohort study in which the main health outcome will be cancer and cause-specific mortality. The main focus of the present study was to provide exposure information to support the cancer studies to be done in this cohort. For diseases with long latency time such as cancer, the past exposure and not the current exposure is of most interest (Nieuwenhuijsen, 2003). Historical exposure needs to be reconstructed or exposure assessed retrospectively; for the Norwegian offshore cohort, occupational exposure to carcinogens from 1970 until 2005 was assessed.

1.2 Retrospective assessment of occupational exposure in industry-specific cohorts

Definitions

An industry-specific cohort includes all workers ever employed in one factory or manufacturing complex or workers from multiple plants operated by different companies but engaged in the same industrial processes (Checkoway et al., 2004). “Exposure” may be characterised as the presence of a substance or factor in the environment external to the subject that affects the subject’s health (Checkoway et al., 2004). In occupational epidemiology, exposure implies substances found in the occupational environment assessed to find possible associations with morbidity and/or mortality. Occupational exposure assessment is the study of the distribution and determinants of occupational substances or factors affecting human health (Nieuwenhuijsen, 2003).

Table 1 presents a selection of studies from the medical database PubMed (2007) for industry-specific cohorts related to cancer mortality and morbidity.

Table 1. Retrospective occupational exposure assessment approaches in cancer or mortality studies of industry-specific cohorts

Authors (year)	**Study description**	**Country** **Industry**	**Morbidity or mortality outcome**	**Exposure information source(s)**	**Exposure agent(s) or exposure surrogate**	**Exposure metric or model**
Burstyn et al. (2003)	International cohort study	Denmark Finland France Germany Netherlands Norway Sweden Israel Asphalt industry	Cancer risk	Company questionnaire Expert judgement Statistical models Historical monitoring data	See next column	Exposure-intensity matrix (data-driven), including: • Semiquantitative estimates of exposure to coal tar, bitumen fumes, organic vapour, polycyclic aromatic hydrocarbons, diesel fume, silica, and asbestos • Regression models of exposure of road-paving workers to bitumen fumes, organic vapour and benzo(*a*)pyrene
Chen et al. (2006)	Cohort study	China Tin mines	Mortality from all causes	Measurement data Employment records	Silica mixed dust	Cumulative dust exposure in four semi-quantitative classes Mine work
Drummond et al. (2006)	Exposure assessment study to support epidemiological cohort study	Canada Petroleum company	Mortality Cancer morbidity	Company records on employee demographic information and work history Historical personal air monitoring data: short-term and full-shift measurements Historical industrial hygiene survey reports Expert assessment to set	Work history Hydrogen sulphide Petroleum coke and spent catalyst Hydrocarbon solvents and fuels Hydrocarbon lubricants	Frequency Intensity Cumulative exposure Substitution of chemicals and organisational changes

Authors (year)	**Study description**	**Country** **Industry**	**Morbidity or mortality outcome**	**Exposure information source(s)**	**Exposure agent(s) or exposure surrogate**	**Exposure metric or model**
				exposure groups (industrial hygienist familiar with the site in consultation with the site safety adviser) Interviews with workers	Exposure groups (workers with similar exposure) Agents connected to each exposure group: frequency and intensity of exposure	
Friis et al. (1999)	Cohort study	Sweden Sewage workers	Cancer incidence	Company employment records	Work task and work as a sewage worker Historical changes in process and work environment	Duration of employment Work department and exposure class Employment before 1965
Grimsrud et al. (2000)	Exposure assessment study by the job–exposure matrix approach to support the epidemiological analysis of a cohort	Norway Nickel refinery	Respiratory cancer incidence	Historical stationary dust or nickel measurement data Historical personal measurements of total nickel in the breathing zone	Nickel and nickel compounds Departments and time periods	Quantitative estimates of exposure connected to departments and time periods
Hall et al. (2006)	Analysis of industrial hygiene samples to support subsequent epidemiological studies of the cohort	United States Northern Ireland France Synthetic rubber industry	Mortality	All available industrial hygiene exposure monitoring data Interviews and discussions with on-site industrial hygiene personnel	Chloroprene (β-CD) Other substances	Modelling of historical exposure
Lewis et al. (2003)	Cohort study	Canada Petroleum company	Mortality Cancer morbidity	For 1987–2003, the exposure was assessed by: • Interviews • Chemical inventories • Occupational hygiene measurements (where available) • Expert knowledge of	Hydrogen sulphide Petroleum coke Hydrocarbon solvents and fuels Hydrocarbon lubricants	Cumulative exposure

Authors (year)	**Study description**	**Country** **Industry**	**Morbidity or mortality outcome**	**Exposure information source(s)**	**Exposure agent(s) or exposure surrogate**	**Exposure metric or model**
				the workplace For 1964–1987: - Expert assessment		
Lewis et al. (2000)	Cohort study	Canada Petroleum company	Mortality Cancer morbidity	Expert assessment of potential exposure for similar exposed workers groups based on: - Interviews - Chemical inventories - Industrial hygiene measurements (where available) - Expert's knowledge of the workplace	Job title Hydrogen sulphide Petroleum coke and spent catalyst Hydrocarbon solvents and fuels Hydrocarbon lubricants	Duration of employment Period of hire Cumulative exposure
Meguellati-Hakkas et al. (2006)	Historical cohort study	France Telephone line workers	Lung cancer mortality	Work history records Expert assessment by company workers, occupational physicians and occupational hygienists Self-administered questionnaire If differences: consensus during meetings Intensity assessed by industrial hygienist: semiquantitative and fibres per cubic centimetre (asbestos)	Asbestos Other occupational carcinogens	Duration of employment Job titles Semiquantitative indices for exposure: proportion, frequency and intensity Cumulative exposure (asbestos) A priori exposure cut points
Park et al. (2002)	Cohort study	United States Diatomaceous	Mortality from lung disease other	Demographic and exposure history files (previously constructed)	Respirable crystalline silica dust	Work history Cumulative exposure

Authors (year)	Study description	Country Industry	Morbidity or mortality outcome	Exposure information source(s)	Exposure agent(s) or exposure surrogate	Exposure metric or model
		earth industry	than cancer Onset of radiographic silicosis	Estimated exposure for total dusts, silica and asbestos		
Pastides et al. (1994)	Retrospective-cohort study of occupational exposure to support design and implementation of surveillance system for monitoring the health of chromate production workers	United States Chromate chemicals manufacturing facility	Mortality Cancer incidence Other adverse health outcomes	Historical personal measurement data Questionnaire	Hexavalent chromium	Duration of employment Department (new or old facility)
Plato et al. (1997)	Retrospective exposure assessment study to support epidemiological analysis of the cohort	Sweden Prefabricated wooden house industry	Mortality Cancer incidence	Due to lack of historical measurements, levels were calculated by applying a matrix of multipliers representing changes over time in production rate, technical properties of the fibres, manual handling versus automation and ventilation control to recently measured concentrations of man-made vitreous fibres Based on a previous matrix for the man-made vitreous fibre manufacturing industry	Man-made vitreous fibres	Exposure levels estimated by statistical exposure models
Proctor et al. (2004)	Exposure estimates by job–exposure matrix approach	United States Chromate production	Mortality from lung cancer	Area monitoring data	Chromium [VI] concentration	Job title Levels of airborne chromium [VI]

Authors (year)	Study description	Country Industry	Morbidity or mortality outcome	Exposure information source(s)	Exposure agent(s) or exposure surrogate	Exposure metric or model
						concentration
Romundstad et al. (1999)	Exposure assessment study to support subsequent epidemiological analysis of a cohort	Norway Aluminium industry	Cause-specific mortality Cancer incidence	Job task knowledge based on information available from personal measurements, informal interview with plant personnel and written job descriptions Historical area and personal industrial hygiene measurements	Polycyclic aromatic hydrocarbons Fluoride Process parameters	Exposure levels Technology periods Exposure groups Multivariate linear regression model based on process parameters and existing area measurements
Romundstad et al. (1998)	Exposure assessment study by the job–exposure matrix approach to support subsequent epidemiological analysis of a cohort	Norway Aluminium industry (coke plant)	Current health Cause-specific mortality Cancer incidence	Historical personal and area measurements	Job group Polycyclic aromatic hydrocarbons Carbon monoxide Asbestos Benzene Arsenic Quartz	Time-weighted average exposure to polycyclic aromatic hydrocarbons Semiquantitative estimates of carbon monoxide and heat Qualitative estimates of asbestos, benzene and arsenic Quartz exposure based on carbonaceous particulate measurements
Satin et al. (2002)	Cohort study	United States Petroleum refineries	Mortality	Work history records	Work history	Duration or length of employment Period of hire
Schnatter et al.	Cohort study	Canada	Mortality	Work history records	Work history as ever-drivers	Duration or length of employment

Authors (year)	Study description	Country Industry	Morbidity or mortality outcome	Exposure information source(s)	Exposure agent(s) or exposure surrogate	Exposure metric or model
(1993)		Petroleum company: marketing and distribution workers		Expert judgement on exposure frequency score for combinations of job title, function and department	Exposure to finished petroleum products	Ever-drivers Exposure frequency: none, less than daily and daily
Stewart et al. (1991)	Exposure assessment study	United States Aircraft maintenance facility	Mortality	Walk-through surveys Interviews with long-term employees Available historical industrial hygiene data	Chemicals: trichloroethylene, and a category of mixed solvents including trichloroethylene, Stoddard solvent, carbon tetrachloride, JP4 gasoline, Freon, alcohols, 1,1,1-trichloroethane, acetone, toluene, methyl ethyl ketone, methylene chloride, *o*-dichlorobenzene, perchloroethylene, chloroform, styrene and xylene	Job titles Tasks (for each job title) Chemicals used in each task Presence or absence of 23 chemicals or groups of chemicals Estimates of levels of trichloroethylene and mixed solvents
Tsai et al. (2004)	Haematology surveillance study	United States Petrochemical company	Changes to or effects on the blood or blood-forming organs	Historical biological measurements (complete blood counts) Available industrial hygiene data on benzene	Benzene	Time-weighted average for 8 hours for benzene
Tsai et al. (2005)	Haematology surveillance study	United States Petrochemical company	Changes to or effects on the blood or blood-forming organs	Historical biological measurements (complete blood counts) Available historical industrial hygiene data on 1,3-butadiene	1,3-Butadiene	Mean butadiene exposure
Wong &	Meta-analysis of	United States	Cell-type-	Described in the different	Benzene	Cumulative exposure

Authors (year)	Study description	Country Industry	Morbidity or mortality outcome	Exposure information source(s)	Exposure agent(s) or exposure surrogate	Exposure metric or model
Raabe (1995)	cohort studies	and United Kingdom Petroleum industry – mainly refineries	specific leukaemia	studies comprising this meta-analysis		

Morbidity or mortality outcome

Exposure is usually retrospectively assessed when health outcomes have a certain latency time, such as with cancer morbidity or mortality. This is the objective for all the studies listed in Table 1, except for the study of Park et al. (2002), which deals with mortality from lung disease other than cancer and onset of radiographic silicosis, and the studies by Tsai et al. (2004, 2005), which concern changes and effects to the blood and blood-forming organs, which might eventually be connected to development of leukaemia.

Exposure information sources

Retrospective exposure assessment for industry-specific cohorts requires researchers to have a good overview of processes, organisation, job titles and sometimes company culture within this industry. There are usually several ways to attain knowledge about an industry: peer-reviewed scientific literature, books, popular science publications, museum exhibitions, company Web sites and publications and annual reports from relevant authorities and companies.

For many studies, the job titles are available from company employment records (Chen et al., 2006; Drummond et al., 2006; Friis et al., 1999; Meguellati-Hakkas et al., 2006; Satin et al., 2002; Schnatter et al., 1993). Sometimes job titles are identified through a questionnaire (Strand & Andersen, 2001). Identifying the tasks connected to each job title (back in time) is important. For each task, knowledge of hazardous chemicals and physical agents is vital as well as changes in process parameters such as technical changes and substitution of chemicals. Visiting the plants or facilities in question, preferably with walk-through surveys, is a good way to get an overview of job titles, tasks and processes (Stewart et al., 1991). Further, interviews (either structured or semistructured) or discussions with key personnel such as long-term workers, occupational physicians, occupational hygienists and site safety advisers are valuable for collecting specific information on job titles and tasks (Drummond et al., 2006; Hall et al., 2006; Lewis et al., 2000, 2003; Romundstad et al., 1999; Stewart et al., 1991). Company survey reports, monitoring reports, chemical inventories, written job descriptions, process descriptions, flow diagrams, plant production records and other written items also often contain important information (Table 1) (Checkoway et al., 2004).

If historical monitoring data are scarce, one option is to reconstruct the work area and perform new measurements. Laboratory studies have reconstructed historical exposure to measure exposure to man-made mineral fibres and the effects of changes in products, process, and controls (Dodgson et al., 1987). However, to ensure validity, these measurements should be anchored in existing monitoring data.

Exposure agents or surrogates

The health outcomes of interest address the type of exposure data to seek (Checkoway et al., 2004). Specific chemical or physical agents might be of interest, such as asbestos (Meguellati-Hakkas et al., 2006), hexavalent chromium (Pastides et al., 1994; Proctor et al., 2004) or benzene (Tsai et al., 2004; Wong et al., 1995). However, usually in occupational settings there is a mix of chemicals and physical agents, leading many studies to use exposure outcome such as “hydrocarbon solvents and fuels” (Drummond et al., 2006; Lewis et al., 2000) and “exposure to finished petroleum products” (Schnatter et al., 1993). Job title (Lewis et al., 2000), job group (Drummond et al., 2006; Romundstad et al., 1998) or “ever worked” have also been used as surrogates of exposure (Friis et al., 1999; Schnatter et al., 1993).

Exposure metrics

The minimum level of assessing exposure for an industry cohort is comparing the health outcome for people who ever worked in the industry with a normal population (presuming that they never worked in the industry). Many exposure metrics have been used, such as job title (Meguellati-Hakkas et al., 2006; Proctor et al., 2004) substitution of chemicals (Drummond et al., 2006), a site such as a mine (Chen et al., 2006) or department (Grimsrud et al., 2000), employment before and after historical changes in process and work environment (Friis et al., 1999), tasks (Friis et al., 1999), duration of employment (Friis et al., 1999; Satin et al., 2002; Schnatter et al., 1993) or specific time periods (Friis et al., 1999; Grimsrud et al., 2000). However, the main objective is usually to obtain knowledge of the association between exposure levels to hazardous agents and health outcome (often studying differences in health outcome and exposure for groups of workers) within the industry cohort. Quantitatively measuring personal exposure to contaminants through air monitoring, skin deposition or biomonitoring is considered the most valid way to assess occupational exposure in epidemiological studies (Teschke, 2003). Historical monitoring data, both personal and area samples, is important for estimating the intensity for specific tasks or job titles back in time. Estimating frequency, obtained by information given in interviews or in written reports or provided by expert assessment, together with knowledge of duration of employment and intensity, gives the opportunity to estimate cumulative exposure, a common exposure metric (Chen et al., 2006; Drummond et al., 2006; Lewis et al., 2000, 2003; Meguellati-Hakkas et al., 2006; Park et al., 2002; Wong et al., 1995). Sometimes health surveys provide access to historical biological measurements, which have been used to study association with haematological parameters (Tsai, 2004, 2005).

Different approaches have been used to compensate for exposure information lacking for combinations of job titles and time periods. Expert judgement has been used to assign scale factors by which current, measured data are adjusted to approximate exposure in time periods for which no measurements are available (Hallock et al., 1994). Kriebel et al. (1988) performed simple arithmetic interpolation. More sophisticated statistical models are increasingly being used to make the best use of sparse exposure data.

Some studies create statistical models of the historical exposure (Burstyn et al., 2003; Hall et al., 2006; Plato et al., 1997; Romundstad et al., 1999). For instance, Burstyn et al. (2003) made a data-driven exposure matrix for an international cohort within the European asphalt industry.

When the quantity of historical personal exposure measurements is very sparse or absent, developing quantitative estimates might not be possible (Checkoway et al., 2004). To compensate for lack of data, several proxy measures of exposure have been used such as job–exposure matrices, self-reported exposure assessment or expert assessment. Some studies combine elements of different methods (Teschke, 2003). Exposure potential might then be dichotomised (exposed versus nonexposed) or ranked in an ordinal fashion (such as high, moderate, low or none) (Checkoway et al., 2004).

Intensity or frequency might be assessed by expert judgement and placed into semiquantitative indices of exposure (Meguellati-Hakkas et al., 2006; Schnatter et al., 1993).

Validity aspects of retrospective exposure assessment: misclassification

For studies that require retrospective exposure assessment, such as many cohort studies and essentially all case–control studies, collecting reliable and valid historical exposure data is a challenge (Teschke, 2003). There are usually many changes over time, for example in production processes, job titles and tasks carried out within a job title (Nieuwenhuijsen, 2003). In the present study, offshore installations may have closed, data may have been lost due to change in position of key personnel (occupational hygienists etc), or data are archived in incompatible data systems or are otherwise inaccessible.

Personal exposure measurements spanning a complete hiring time period are rare in historical exposure data in industry-based studies. One exception is radiation-exposed workers who are monitored with personal dosimeters, but even these sources may suffer from incomplete or inaccurate monitoring data (Cardis & Esteve, 1991). Usually nonsystematic exposure monitoring has taken place to compare with limit values. Such measurement has often been performed in areas and/or by job titles considered to have the highest and least well-controlled exposure. Thus, data on less severely exposed job titles and tasks are less frequently monitored, which can be a severe limitation for overall study validity, as exposure will be misclassified. Not obtaining measurements during normal operations may lead to overestimation of exposure and increased non-differential exposure misclassification, which will tend to bias exposure estimates towards null. Quantitative data may suffer from measurement errors due to uncertainty of sample timing, duration and placement or to inadequate calibration of equipment. This might especially be the case when exposure fluctuates widely over short time periods. However, repeated sampling of personal or stationary measurements is rare, leading to difficulty in estimating the precision of the exposure estimates.

Subgroups of workers may experience especially high exposure, either during special tasks or due to accidents such as spills and leaks. Inspection and accident reports may be valuable to identify these groups. However, the difference between routine and normal exposure versus unusual exposure is important in analysing data from such reports.

Personal exposure may vary considerably between workers who have the same job title and carry out the same tasks. The underlying assumption of job grouping is that the defined categories have some degree of exposure homogeneity (Gamble et al., 1976). Sources of exposure level variability are numerous, including differences in specific tasks conducted for the same job title, proximity to exposure sources, variability in the use of protective equipment and idiosyncrasies of workers' practices as they perform their duties (Burstyn & Teschke, 1999).

Variation in exposure monitoring data might reflect sampling artefacts or biases. If biases are undetected, job groupings can be erroneous (Seixas & Checkoway, 1995).

The use of expert assessment has increased in recent decades. Occupational hygienists, chemists, engineers and other professionals are regarded to understand occupational exposure better than workers do. However, the experts may not be familiar with the jobs and industries to be considered (Teschke et al., 2002); their background and the information provided may influence how they assess exposure (Teschke et al., 1989). Hawkins & Evans (1989) showed that, without measurement data, experts tended to overestimate exposure.

1.3 Classification of carcinogens

Hundreds of chemicals are capable of inducing cancer in humans or animals after prolonged or excessive exposure (Scorecard, 2007). Several countries and agencies list carcinogens. In the United States, the National Institute for Occupational Safety and Health (2007) publishes a list of occupational carcinogenic agents, currently 134 agents, and the National Toxicology Program (2007) lists carcinogens according to a two-category scale: “known to be a human carcinogen” (currently 54 agents) and “reasonably anticipated to be a human carcinogen” (currently 183 agents). In Norway, a working group initiated by the authorities has classified potential cancer-causing substances into three categories according to the present knowledge of association between exposure and cancer (Lovdata, 2007). Many such lists draw heavily on and adapt to the purposes of the International Agency for Research on Cancer (IARC) programme (Siemiatycki et al., 2004). IARC is part of the World Health Organization, and its mission is to coordinate and conduct research on the causes of human cancer and the mechanisms of carcinogenesis and to develop scientific strategies for controlling cancer (IARC, 2007b). Since 1972 the IARC has published 86 monographs on available research on many carcinogenic agents, mixtures and exposure circumstances. IARC classifies exposure into five categories according to the strength of the published scientific evidence for carcinogenicity (IARC, 2007a):

- group 1: carcinogenic to humans (87);
- group 2A: probably carcinogenic to humans (63);
- group 2B: possibly carcinogenic to humans (234);
- group 3: not classifiable as to carcinogenicity to humans (493); and
- group 4: probably not carcinogenic to humans (1).

This study used IARC’s classification of carcinogens.

1.4 The offshore petroleum industry

Offshore oil and gas drilling and production are carried out worldwide, with operations in many countries, such as Canada, the United States, Venezuela, Brazil, Norway, United Kingdom, Nigeria, Angola, Azerbaijan, Iran, China and Australia (International Association of Oil & Gas Producers, 2007).

In December 1969, a significant oil field was discovered on Norway's Continental Shelf. In the following years a number of major discoveries were made, and today Norway is the world's third largest oil and gas exporter. Oil and gas production is Norway's largest industry, accounting for 21% of the gross domestic product (Ministry of Petroleum and Energy, 2005).

Employees in the offshore petroleum industry

About 6000 people are employed full time in offshore production and drilling operations at 48 oil and gas fields in Norway (Statistics Norway, 2005). In addition, several thousand workers have short-term engagements every year in maintaining, modifying and demolishing offshore installations.

Figure 1. The oil platform Gullfaks A with its three main sections: the drilling area to the left with the characteristic derrick tower, in the middle; the process area; and, to the right, the white-coloured living accommodations with the helicopter deck on top. To the right a supply ship, and in the background a tanker is tanking oil. Photo: Statoil.

Offshore job categories

Offshore oil and gas production platforms usually comprise three main sections: the drilling area, the process area and living accommodations. These are run by drilling crews, process operators and catering personnel, respectively. In addition, there are maintenance workers such as painters, insulators, welders, machinists and mechanics, and support functions such as deck crew, health and safety personnel and helicopter assistants. On most installations today the workers have 12-hour shifts for 14 days and have 28 days off.

The following description of offshore work sections is based on information presented in Bøhmer et al. (2000), Schlumberger Limited (2007), Statoil (2007), Steinsvåg et al. (2005), Norwegian Petroleum Museum (2004) and Norwegian Oil Pioneer Club (2007).

Figure 2. Norwegian oil companies have preferred building more easily removable production ships in the past decade due to smaller oil and gas fields and for environmental reasons. This picture shows an oil and condensate processing production and storage vessel: Åsgard A. Photo: Statoil.

1. Health, office and administration section

Figure 3. Chief executive of Statoil, Helge Lund, visiting the Gullfaks A-platform on 10 July 2004. Right: platform manager Sisle Stjern. Photo: Statoil.

An offshore installation can be viewed both as a factory and a hotel and needs several administrative job categories for management and operations. Due to development in technology, many engineering tasks and parts of the supervision of process and drilling operations are now performed onshore. This has reduced the number of job categories offshore.

The platform manager is responsible for operations and the safety on the installation.

The nurse and/or health, safety and environment coordinator prevent and treat injuries and diseases.

The receptionist is in charge of booking helicopter seats and accommodation for everyone who arrives at an installation.

2. Drilling and well maintenance section

Figure 4. Drill pipes. Photo: Statoil.

Specialised drilling companies hired on contracts perform drilling operations. The drilling crew typically consists of roustabouts, roughnecks, motor workers, derrick employees, assistant drillers and drillers.

Figure 5. Driller cabin in the 1990s. Photo: Statoil.

The drilling section leader is in charge of the drilling crew. He or she supervises technical data, arranges engineers to assist special operations and can step in for all drilling operations if required.

The driller manages the daily routines based on instructions from the drilling section leader. From the drilling cabin he or she operates all the equipment used during drilling. The computer-driven drilling equipment (robots) performs many tasks previously performed by the roughneck, roustabout and the derrick. The driller also has a driller assistant.

Measure-while-drilling operators collect and evaluate data information from downhole geological logging measurements, which provide information on the azimuth and inclination of the well in addition to the type of rock, the fluids stored in this rock and the porosity of the rock. This information is used by the directional driller, measure-while-drilling operator and geologist, operating both onshore and offshore, who can guide – or geosteer – the drilling operation. These specialists often represent the operating company. In mature areas, geosteering may be used to keep a wellbore in a particular section of a reservoir to minimise gas or water breakthrough and maximise economic production of the well. This will also benefit the work environment in the mud-handling areas. This drilling technology, which improves drainage of oil and gas reservoirs, has developed since the late 1980s.

Figure 6. The derrick employee, standing on the fingerboards in this view, moved pipe between the pipe racks and the wellbore during trips in and out of the hole. This job was physically demanding and required wearing a safety harness when up in the derrick. Today the operation of drill pipes has been automatised. Photo: Schlumberger Limited.

In drilling, the drill bit eventually becomes dull or broken and less efficient and must be changed. This requires a round trip; removal of the drillstring from the wellbore and running it back in the whole. Due to improved quality and knowledge of the wear of the drill bit, together with new downhole geological monitoring technology, the number of drill bit changes has been reduced and therefore reduced the time needed to drill a well.

The derrick employees worked on a monkeyboard (1 m^2 platform), typically 26 m above the rig floor, during trips of the drillstring. They wore a special safety harness that enabled them to lean out from the monkeyboard to reach the drill pipe in the centre of the derrick, threw a line around the pipe and pulled it back into its storage location, called the fingerboards, until it was time to run the pipe back into the well. This used to be one of the

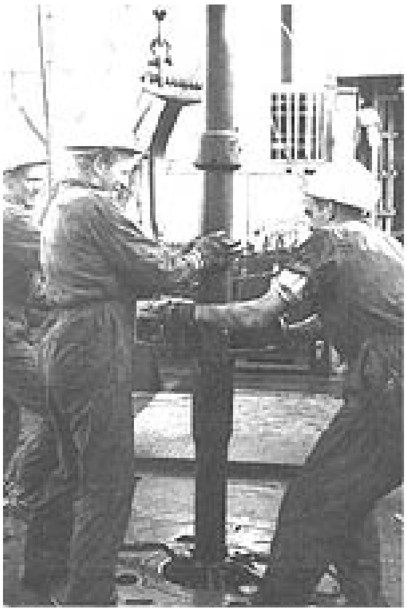

Figure 7. Roughnecks at Ocean Traveller, 1966. Photo: Norwegian Oil Pioneer Club.

most demanding jobs of the rig crew. From the mid-1970s, mechanisation and automation of the tasks on the drill floor started, such as a mechanical pipe-handling system run by the derrick to handle the pipes in and out of the fingerboard when tripping. Today, modern drilling facilities have automated pipe-handling equipment, mainly handled by the driller. Another important task for the derrick employee is to mix the mud according to the instructions given by the mud engineers. The mud engineer is responsible for analysing the mud and for prescribing treatments to maintain the properties and chemistry of the mud within recommended limits. The mud engineer works closely with the derrick employee.

The motor worker is responsible for maintenance and minor repair of the engines used in drilling operations.

The roughneck usually performs semiskilled and unskilled manual labour on the drill floor or at the cellar deck (deck below the drill floor).

The roughnecks clean and maintain the drill floor, earlier often using caustic soda or diesel. On the cellar deck, the roughnecks installed and made ready different types of equipment, including blowout preventers, and supported the riser. The roughnecks also mix mud and supervise the shale shakers.

A roustabout may be part of the drilling contractor’s workforce or may be on location temporarily for special operations. Roustabouts are commonly hired to ensure that the skilled personnel that run an expensive drilling rig or facility are not distracted by peripheral tasks, such as cleaning up locations and threads, digging trenches and scraping and painting rig components.

Figure 8. Operator surveying open shale shakers at Oseberg B, 2005. Photo: Hydro.

Casing is a steel pipe lowered into an open hole and cemented in place during the construction process to stabilise the wellbore. The casing forms a major structural component of the wellbore and serves several important functions: preventing the formation wall from caving into the wellbore, isolating the different formations to prevent the flow or cross-flow of formation fluids and providing a means of maintaining control of formation fluids and pressure as the well is drilled. The casing string provides a means of securing surface pressure control equipment and downhole production equipment, such as the drilling blowout preventer or production packer. The casing is available in a range of sizes and material grades. Special contractors deliver casing and employ casing operators to handle the pipes. However, this task is now automated.

During drilling, production and well completion, cementing is required to permanently seal annular spaces between casing and borehole walls. Cement is also used to seal formations to prevent loss of drilling fluid and for setting kick-off plugs, plugging and abandonment. Dedicated cementers manage the cementing.

A well service operator drills, tests and maintain production wells. The well service operator operates electric, pneumatic, hydraulic and engine-driven tools, machines and equipment. Several previous specific job titles may be called well service operator today: casing operator, cementer, wireline operator and snubber.

3. Production and process section

To produce oil and gas, a production string is put down the well. When oil and gas reach the surface, the temperature is rather high (60–80°C), and the pressure might be several hundred atmospheres. In the production area, the petroleum stream from the reservoir undergoes separation. Gas and water are separated from the oil phase. Sand and stone particles are also removed. Before transport to shore via pipelines or by tank ships, the oil is cooled, and the water vapour in the gas is dried by glycol before transport to shore through

Figure 9. Oil sample, probably early 1980s. Photo: Norwegian Petroleum Museum.

Figure 10. Process technician at Heidrun. Photo: Statoil.

pipelines. The process area is analogous to a refinery. The processes are enclosed, but sampling, maintenance, leaks, spill and repair may cause workers to be exposed to the petroleum stream.

Process technicians supervise all steps in the upstream process: the oil and gas arrive at the platform, are processed and sent via pipelines or by tank ships to shore. They survey and regulate the production processes by using computers in the control room. The process technicians also survey the process area, where they sample oil and gas and look for leaks and spills.

Figure 11. Process technicians in the control room in the 1970s. Photo: Norwegian Petroleum Museum.

Figure 12. Crane operator at Gullfaks. Photo: Statoil.

Roustabouts in the production area, together with the crane operator, are responsible for transporting and unloading material and equipment to and from the platform. The roustabouts also carry out unskilled manual labour such as cleaning and odd jobs.

Laboratory engineers and technicians assess and analyse samples of petroleum from the process stream for composition, density, water, dew point, oil-in-water etc. In addition, production chemicals such as glycol are controlled, and cooling water is tested. They also analyse samples taken to monitor water and air spill.

Figure 13. Sampling at Kvitebjørn. Photo: Statoil.

4. Maintenance, inspection, deck and construction section

Figure 14. A selection of hard hats used by personnel from many companies and countries on Statfjord B. Photo: Statoil.

Operating, maintaining and repairing offshore installations require crafts similar to those needed in most heavy industries.

The engine mechanic repairs and maintains driving gear, aggregates, hydraulic, pneumatic and electric systems on mobile and stationary combustion engines and driving gear. From simple engine constructions previously used, the mechanic today must handle advanced electronic control systems. Other job titles with similar work: turbine operator, hydraulic technician and machinist.

Figure 15. Hydraulic system on Statfjord B. Photo: Statoil.

The industrial mechanic maintains mechanical machinery and equipment.

Due to the high safety level achieved today, building of scaffolds has increased, and specialised contractors with scaffold crews are now responsible for this. Previously craft workers themselves assembled scaffolds. From the 1990s, the use of mountain climbers has replaced some of the most challenging scaffold building.

Figure 16. Mountain climber on Gullfaks A. Photo: Statoil.

Insulators install and remove insulation where needed, especially in the production area.

Electricians handle various kinds of current-carrying installations.

Nondestructive testing operators inspect structures and welding seams in pipes and pressure tanks to control the quality of welding and to detect corrosion damages. If weaknesses are detected, welders and sheet metal workers repair them. Due to high fire hazard in the production areas, welding is reduced to a minimum, and separate areas – welding cabins – are used for minor welding tasks.

Figure 17. Welding on Heidrun. Photo: Statoil.

Every 2–3 years, the process area is shut down for about 14 days and processing equipment is opened and cleaned before extensive maintenance work, including welding, is done.

Roustabouts in this section are involved in unskilled manual labour such as corrosion scaling, scraping, painting, cleaning of bulkhead and deck, flushing and lubrication of cranes, lifeboat systems and jacking equipment.

Figure 18. Helicopter guard pointing the direction for new arrivals at Heidrun. Photo: Statoil.

The helicopter guard assists helicopter pilots during landing and takeoff and is also in charge of fire preparedness. Roustabouts often perform these tasks.

Dedicated storekeepers control and order the parts needed on a platform.

An offshore installation has many electronic, pneumatic and hydraulic monitoring and control systems. Electric instrument technicians and mechanics maintain and repair this equipment.

Due to the rough weather conditions, salty seawater and wear and tear, the need for surface treatment is constant on an offshore installation. Painters and, to a lesser extent, sheet-metal workers remove rust and carry out sandblasting and water-jetting before painting the surfaces.

Radio engineers used to maintain contact between the rig and shore, supply ships, other installations and helicopters. Today few installations have dedicated radio engineers.

5. Catering

A catering crew is needed to keep an offshore installation tidy and clean and to provide food for all employees. Chefs prepare food day and night. Stewards assist in the kitchen, clean the accommodation rooms and do the laundry. On some installations catering employees operate laundry units; others have all laundry done onshore.

1.5 Previously reported exposure in the offshore petroleum industry

The workers in the drilling crews may be exposed to drilling mud, either by inhaling aerosols and vapour or by skin contact (Davidson et al., 1988). The drilling mud is used for many purposes such as lubricating and cooling the drill stem and bit, providing pressure support in the well and transporting cuttings to the surface (Figure 19). The fluid is a complex mixture of water- or oil-based fluids and a large number of additives, depending on the system used (Hudgins, 1991). The water-based system is often used in the upper sections of a well, whereas oil-based mud is the only option in long or deep wells. The composition of these mud systems has varied considerably both in time and between suppliers (Health and Safety Executive, 2000a). A typical oil-based drilling fluid used on the United Kingdom's sector of the North Sea comprises (by volume) 52% base oil, 30% water and additives such as weight materials (11%), emulsifiers (3%), brines (2%), pH increasers (1%) and viscosifiers (1%) (Health and Safety Executive, 2000a). The original oil-based drilling muds contained diesel as the base oil (Davidson et al., 1988). Diesel was phased out in the early 1980s and gradually replaced by petroleum-based oils with a reduced aromatic content (Health and Safety Executive, 2000a).

Using oil-based mud systems may generate airborne hydrocarbon contaminants (oil mist and oil vapour) in the mud-handling areas (Davidson et al., 1988). The Norwegian Oil Industry Association (1996) assumes a potential for inhaling oil mist and oil vapour along the flow line from the top of the well to the separation equipment, which includes shale shakers, desanders, desilters, centrifuge and the mud pits (Figure 19). They specifically state that cleaning and changing screens on the shale shakers may lead to high exposure. Originally these areas were designed for water-based mud by being open, and the control of aerosols and vapour relied on general ventilation.

Under such circumstances, personal exposure to total hydrocarbon compounds has been reported to be up to 450 mg/m^3 during work at the shale shakers when drilling with oil-based mud (Davidson et al., 1988). At an installation with a higher level of enclosure of the mud systems, James et al. (2000) reported results from two personal samples in the shale shaker room to be 0.06 and 0.40 mg/m^3 for oil mist and 3.2 and 35.0 mg/m^3 for oil vapour. Published results from this working environment are scarce.

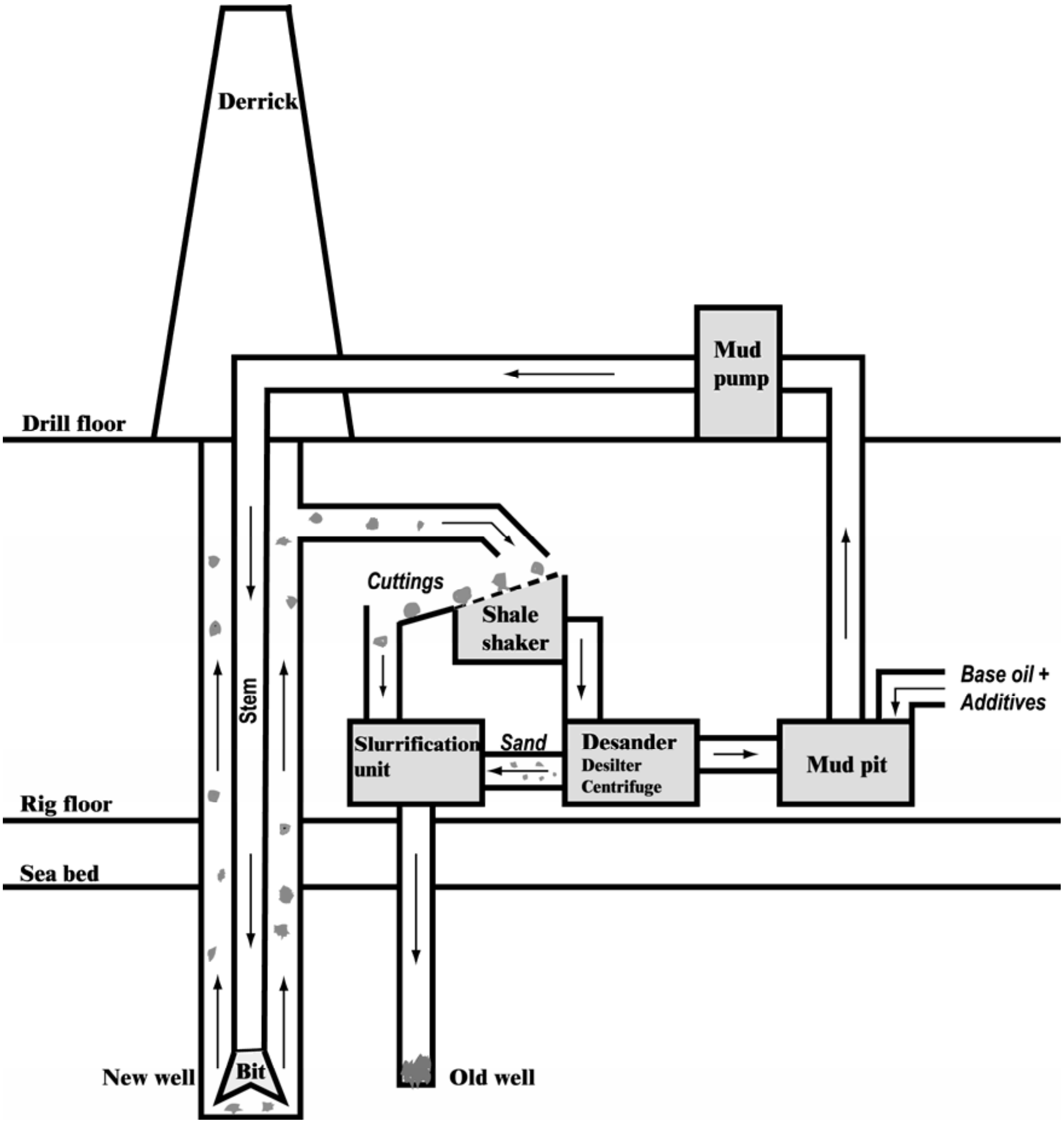

Figure 19. **The drilling mud process. Base oil and additives are mixed in the mud pit. The mud leaves the pumps at high pressure, flows inside the drill stem, passes the nozzles of the drill bit, returns on the outside of the stem and transports rock cuttings to the platform surface. The solids and liquids are separated by vibrating screens and by other cleaning equipment. The mud returns to the mud pit and is recycled, while the cuttings and sand are crushed in slurrification units, blended with water and pumped to an old well for storage.**

Published results from systematic sampling of other hazardous agents than drilling mud on offshore installations are also scarce. A few studies have reported data on benzene exposure in the process area (Glass et al., 2000; Health and Safety Executive, 2000b; Kirkeleit et al., 2006) and dust levels in a shale shaker room (Hansen et al., 1991). Gardner (2003) reviewed various types of occupational exposure on offshore oil and gas installations, whereas other reports have provided overviews of chemicals used offshore (Cottle & Guidotti, 1990; Health and Safety Executive, 2000a; Hudgins, 1991).

2. Objectives

The main research objective of the four articles in this dissertation was to provide retrospective exposure information for a planned study on cancer in a cohort within Norway's offshore petroleum industry.

This was to be done by:

- identifying and describing exposure to selected known and suspected carcinogens for defined job categories from 1970 to 2005 (Article II);
- presenting the consensus decisions on exposure to carcinogens for defined job categories in specific time periods made by an expert group (Article IV);
- quantifying and identifying the determinants of personal exposure to oil mist and oil vapour when drilling with oil-based muds from 1979 to 2004 (Article I);
- evaluating and identifying determinants of interrater agreement when an expert group assesses exposure (Article III); and
- evaluating agreement between experts' individual ratings and the following plenary expert assessments (Article IV).

3. Material and methods

3.1 Organisation

A University of Bergen research group comprising three researchers, two secretaries and a research fellow carried out this study between December 2002 and November 2005. An external advisory group included three occupational hygienists each representing different oil companies, one occupational hygienist from the petroleum authorities and the health, safety and environment manager of the Norwegian Oil Industry Association.

3.2 Preparation for data collection

In the Cancer Registry of Norway's questionnaire from 1998, 27,986 replying offshore workers stated their entire work history including job titles, the respective installation and work section as well as leisure activities (Strand & Andersen, 2001). The inclusion criteria for that cohort were to have a Norwegian personal identification number and to have worked full or part time on an offshore oil or gas producing or drilling installation for at least 20 days within a 4-month period. About 60% of these offshore workers responded. Printouts of every possible version of the first and last job titles resulted in lists of thousands of occupations. Prior to our study, a researcher from the Cancer Registry of Norway and an occupational hygienist representing the Norwegian Petroleum Directorate had regrouped the original job titles into 294 job titles.

The University research group identified 29 known and suspected carcinogens in the industry from the lists of the IARC (2007a), the report of Strand & Andersen (2001) and from published literature on chemical exposure offshore. This study defined known carcinogens as agents, mixtures or occupational circumstances classified in IARC Groups 1, 2A and 2B. Suspected carcinogens are selected from Group 3.

3.3 Data collection

Key personnel were interviewed and relevant documents collected during visits to oil and contractor companies selected from the list of members of the Norwegian Oil Industry Association and from the report on the establishment of the offshore cohort (Strand & Andersen, 2001). The companies were chosen to represent as many job titles as possible and to have employed the majority of participants in the cohort.

Initially, heads of health and safety departments in 20 companies employing offshore workers were contacted by phone followed by an official enquiry sent by e-mail. Attached to the e-mail was a letter from the Norwegian Oil Industry Association requesting that the companies let a University research group of 2–4 people visit the company to carry out interviews and to collect data on exposure to radiation and chemicals with particular attention to carcinogens. Visits were made to oil companies (8), drilling companies (5), chemical suppliers (3), maintenance, modification and operation contractors (3) and a catering service supplier (1). In addition, one trade union, one employer's association and three relevant authorities, the Norwegian Radiation Protection Authority, the Norwegian Petroleum Directorate and the Norwegian Pollution Control Authority, were visited in a similar manner. Everyone contacted agreed to the visits and interviews.

Interviews

The companies selected key informants, generally long-term workers, representing different job categories, and they were interviewed on the work processes, chemical products used and relevant exposure on offshore facilities. The 83 interviewees were from the drilling and well maintenance section (18); production and process (8); maintenance, inspection, deck and construction (24); catering (1); and health, office and administration (7) in addition to occupational hygienists (14) and occupational physicians (11).

The 294 job titles regrouped from the Cancer Registry of Norway's questionnaire and processes with associated possible exposure to carcinogens formed checklists used in interviewing the key personnel. The informants were also given the opportunity to outline issues of probable significance for the project.

A report was written after each visit and returned to the informants for feedback. Then the reports were evaluated in cooperation with the main contact in the respective companies and revised.

Documents

In addition to the 20 reports from the company visits, the background material included an April 2003 issue of an offshore chemical database including about 150 products containing carcinogenic compounds, 15 risk assessment reports, 118 sampling reports, 102 product data sheets and 191 other relevant documents. The research material was mainly based on information made accessible on the visiting day. When companies promised access to more exposure reports, the data collection process continued by 3–15 personal contacts with each company, either through phone (1–4), e-mail (2–12) or additional meetings with the main contact either at the company or at the University (0–1). The research group conducted archive searches in the Norwegian Petroleum Directorate and in one of the oil companies. In the other companies, the main contact provided relevant documents.

3.4 Extraction of key information from interviews and documents

Information on carcinogen exposure such as processes entailing exposure, job titles involved, technical changes significant for exposure, substitution of chemicals and products and exposure measurements was extracted from the data collected. Based on the available information, the 18 carcinogenic agents, mixtures or exposure situations assumed to be of greatest importance for personal exposure were selected to be presented in this study.

Selected carcinogens

The carcinogens selected were: benzene; mineral oil – inhalation exposure; mineral oil – skin exposure; crystalline silica; asbestos; refractory ceramic fibres; formaldehyde; tetrachloroethylene; trichloroethylene; welding; nickel compounds; chromium [VI]; lead; crude oil – skin exposure; diesel engine exhaust; dichloromethane; ionising radiation; and occupational exposure as a painter. For crude oil and mineral oil, skin exposure is explicitly described since skin exposure might occur even when exposure through inhalation is negligible.

Defined job categories

Based on the information provided by the key informants and the data collected, the researchers grouped the 294 job titles from the offshore cohort into 27 job categories into five work sections according to similarity in job tasks and expected type of carcinogen exposure (Table 2).

Table 2. A summary of sections and job categories (with abbreviations or short versions) based on a questionnaire survey among offshore workers in Norway from 1998

Section and job category	Abbreviation or short version of job category
Catering section	
Catering crew	Catering
Chefs	Chef
Drilling and well maintenance section	
Derrick employees	Derrick
Drill floor crew (roughnecks, roustabouts)	Drill floor
Drillers	Driller
Measure-while-drilling operators and mud loggers	Measure-while-drilling and logger
Mud engineers and shale shaker operators	Mud
Well service crew	Well service
Health, office and administration sections	
Health, office and administration personnel	Health, office and admin.
Maintenance, inspection, deck and construction section	
Deck crew	Deck
Electric instrument technicians	Instrument
Electricians	Electrician
Industrial cleaners	Industrial cleaner
Insulators	Insulator
Machinists	Machinist
Mechanics	Mechanic
Nondestructive testing inspector	Nondestructive testing
Painters	Painter
Plumbers, piping engineers and inspectors	Piping
Radio, tele-technicians and radio employees	Radio
Scaffold crew	Scaffold
Sheet metal workers	Sheet metal
Turbine operators and hydraulics technicians	Turbine/hydraulics
Welders	Welder
Production and process section	
Control room operators	Control room
Laboratory engineers and technicians	Laboratory
Process technicians	Process

3.5 Individual expert assessment of exposure

During a one-day session, eight experts individually assessed the likelihood of exposure (unlikely, possible or probable) to 17 carcinogens for 27 job categories and four time periods (1970–1979, 1980–1989, 1990–1999 and 2000–2005), resulting in 1836 combinations per rater. Prior to the expert rating, three-dimensional forms were prepared with one cell for each combination of carcinogen, job category and time period. The agents tetrachloroethylene and trichloroethylene given in Article II, which mainly represent metal degreasing, were merged before expert assessment into a “chlorinated hydrocarbons” category in Article III and Article IV, thus reducing the number of carcinogens from 18 to 17.

Each member of the expert group scored the likelihood of exposure. The expert group comprised eight individuals: three occupational hygienists from the offshore industry, two occupational hygienists from consulting companies affiliated with the offshore industry and three university researchers with experience in offshore projects.

To familiarise the experts with the methods of the assessment, they were handed the structure of the blank forms with instructions and guidance for completion 14 days before the meeting. Exposure was divided into three probability categories:

- unlikely: it is unlikely that workers were exposed;
- possible: it is possible that workers were exposed, but the probability is low; or less than 50% of the workers were probably exposed; and
- probable: probably at least 50% of the workers were exposed.

It was stressed that the most important task was to identify job categories with “probable exposure” and to avoid unexposed groups being denoted as probably exposed.

“Exposure” is defined when exposure for the respective job categories exceeds the assumed background levels in the living quarters of offshore installations.

Descriptions of products containing carcinogens, exposure sources and processes carried out within the different job categories were extracted from the documentation collected during the company visits and the interviews of key personnel and summarised for each selected carcinogen. Monitoring reports were found for seven agents (benzene, mineral oil mist and oil vapour, dust, asbestos fibres, refractory ceramic fibres, formaldehyde and tetrachloroethylene).

In the expert session, the method was first presented and discussed. Then the experts filled in their individual forms based both on the written background information for each carcinogen and their own competence and experience. For about every third agent, the expert group had a brief discussion to clear up any misunderstandings as to how to complete the form.

3.6 Expert group panel assessment of exposure

On the second day of the expert meeting, the raters assessed exposure in plenary. If at least one expert scored “probable exposure” for any combination of job category, carcinogen and time period during the individual assessment, a round-table discussion reached consensus on exposure.

3.7 Data processing and statistical analysis

Database on oil mist and oil vapour samples (Article I)

A database containing information from the monitoring reports on oil mist and oil vapour was constructed in SPSS 12.0 for Windows (SPSS Inc., Chicago, IL, USA). This database comprised relevant information to characterise exposure to oil mist and vapour in the mud-handling areas. The parameters entered were: rig name, type of rig, purpose of sampling, base oil, base oil characteristics (aromatic content and viscosity), work area, year and month, process parameters (well section, mud temperature, mud flow and well length) and sampling and analysis methods.

Type of rig was divided into fixed or movable drilling facilities according to the practice of the Norwegian Petroleum Directorate (2007). A fixed facility is a generic term for all facilities placed on a field permanently, whereas movable facilities are not meant to be permanently placed on the field during its lifetime (Norwegian Petroleum Directorate, 2007).

Occupational hygienists in this industry aim to gather samples during worst-case conditions. Drilling at the end of the 12.25-inch section is considered to produce the highest exposure to airborne contaminants because both mud flow and mud temperature are high. Due to rapid and unpredictable changes when drilling, departure delay due to bad weather or fully booked helicopters, drilling in the subsequent, narrower 8.5-inch section may occur when occupational hygienists finally reach the platform to do sampling. The mud flow is lower in the 8.5-inch section, leading to less fluid passing the mud-handling area, which is expected to be associated with lower exposure.

Detailed data on weather conditions were lacking in many of the reports collected. Splitting the months of the year into summer and winter seasons was therefore selected as a rough indicator of weather conditions.

Data analysis of oil mist and oil vapour samples (Article I)

All exposure data from 1979 to 2004 were stratified by sampling method and base oil and presented as arithmetic mean, geometric mean and their respective standard deviations. The frequency distributions of both oil mist and oil vapour exposure levels were skewed, and the estimated geometric standard deviations were <3 for most of the strata. In accordance with Hornung & Reed (1990), the measurements under the limit of detection (LOD) were set as $LOD/2^{0.5}$. Due to the skewed nature of oil mist and oil vapour exposure data, these variables were $\log_e$-transformed before statistical analysis. Differences in exposure levels between groups were analysed by *t*-tests and one-way analysis of variance. Correlations between continuous variables were evaluated using Pearson's correlation coefficient.

Categorical variables were dichotomised before analysis. Variables included in the exposure models were chosen based on a significance level of $P < 0.20$ in univariate analysis or on logical assessment of the potential determinants of exposure. Linear mixed-effects models were developed to model the time trend and to show the influence of different variables (P to enter <0.05) on personal exposure to oil mist or oil vapour. These models have the same general form as described by Rappaport et al. (2003). Since the data were imbalanced, the models were fitted using restricted maximum likelihood estimation. Only 86 of 340 samples had worker identification, reflecting 1–6 repetitions of 16 workers, which was considered to be too few to use worker as a random effect in the mixed models. To account for repeated measurements taken from the same rig, the individual rig was viewed as a random effect. The potential determinants of exposure were set as fixed effects.

SPSS 12.0 for Windows (SPSS Inc.) was used for all statistical analysis and figures for Article I.

Data processing and analysis of other sampling data (Article II)

Data from sampling data collected on benzene, mineral oil mist and oil vapour, dust, asbestos, refractory ceramic fibres, formaldehyde and tetrachloroethylene were entered into SPSS databases and analysed by descriptive statistics (arithmetic mean and standard deviation, geometric mean and geometric standard deviation and range) using SPSS 13.0 for Windows (SPSS Inc.). Measurements below the LOD were treated according to Hornung & Reed (1990): that is, if less than 50% of the data are under the LOD and the geometric standard deviations are below 3.0, the measurements are set to the LOD/$2^{0.5}$, whereas if more than 45% of the data were below the LOD and the data are highly skewed (geometric standard deviation >3.0), the measurements were set to the LOD/2.

Data processing and analysis of individual expert assessments (Article III)

Data were analysed using SPSS 13.0 for Windows (SPSS Inc.).

Unlikely, possible and probable exposure were entered into an SPSS database as the numbers 0, 1 and 2, respectively. Agreement parameters were grouped by carcinogen, rater background, IARC group, amount of information and time period.

To investigate interrater agreement, Cohen's kappa (κ) index (Fleiss, 1981) and intraclass correlation coefficients (Shrout & Fleiss, 1979) were calculated.

One kappa value for each pair of raters was calculated, totally 28 pairs for eight raters. The kappa statistics are presented as the mean and range of kappa for the relevant rater pairs. If one of a pair of raters had not scored in all possible levels (unlikely, possibly or probably exposure), the kappa value could not be estimated. For example, if one rater in a pair had only used the categories "unlikely" and "possible" exposure in his or her assessments and the other had assessed all three categories, the kappa could not be estimated. The number of missing pairs is specified in the relevant table.

The mean and range of the kappa values for the seven rater pairs corresponding to each rater were calculated to examine whether there were apparent differences in agreement regarding the years of experience of the rater.

One-way analysis of variance was performed on the kappa values to detect significant differences between the subgroups within the categories of time periods, raters, IARC groups and amount of information, respectively. To investigate significant differences, Bonferroni post hoc tests were performed.

Intraclass correlation coefficients (ICC) were calculated using a two-way random analysis of variance by including a random effect for each set of eight rater's score per combination and a random rater effect for each of the eight raters. This study presents the two ICC measures, single and average score ICC according to Shrout & Fleiss (1979) and McGraw & Wong (1996): that is, ICC (2,1) and ICC (2,8), respectively, whereas Teschke et al. (1989) use the denotations "individual ICC" and "group ICC". The number "2" refers to cases 2 while 1 and 8 refers to the number of raters. The confidence intervals of the single score ICC were investigated to detect differences between the subgroups within the categories of time period, raters, IARC groups and amount of information, respectively. Applying ICC values assumes normally distributed residuals in the two-way analysis of variance (Altman, 1991). This study used ICC despite these assumptions being violated.

To examine whether there had been any trends throughout the day in the agreement among the raters during the filling of forms, the ICC (2,1) and ICC (2,8) were analysed for groups of three carcinogens corresponding to the order in which they were assessed.

Pearson correlation coefficients were estimated to examine the correlations between the interrater reliability measures and the prevalence of possible and probable exposure. According to Altman (1991), investigated variables should preferably be normally distributed. Shapiro-Wilk *W* tests were therefore performed to test for normality.

Comparing the subgroups within the categories carcinogen, time periods, raters, IARC groups and amount of information requires that the subgroups have homogeneous between-combination variance. The mean square of between-combination ($MS_{combination}$) and residual mean square ($MS_{residual}$) was obtained through two-way analysis of variance when estimating ICC. The numbers were used to calculate the between-combination variance ($\sigma^2_{combination}$):

$$\sigma^2_{combination} = \frac{MS_{combination} - MS_{residual}}{k} \qquad (1)$$

k = number of raters

F-tests were conducted to test for significant differences in the between-combination variance. When these tests are conducted, it is assumed that the two populations under investigation are normally distributed (Altman, 1991).

Data processing and analysis of individual versus panel assessment (Article IV)

The data were analysed using SPSS 13.0 for Windows (SPSS Inc.).

To allow statistical comparison between individual and panel results, the original three exposure categories used in the individual assessments were dichotomised into exposed ("probable exposure") and unexposed ("unlikely" and "possible exposure"). The agreement between individual and panel assessments was calculated using Cohen's kappa index (κ) (Fleiss, 1981). The sensitivity and specificity (Altman, 1991) were calculated with the panel assessment as reference.

To illustrate the effect of possible individual misclassification on relative risk, the individual sensitivity and specificity were used to estimate the potential attenuation of the "true" relative risk of cancer at different prevalence rates of exposure. The resulting observed relative risks were calculated according to Flegal et al. (1986), and the range of minimal number of cancer cases needed to detect the attenuated relative risks was estimated assuming a two-sided significance level of 5% and a power of 80% (Armstrong, 1987).

4. Summary of results

4.1 Article I

Samples of oil mist and oil vapour in the mud-handling areas of offshore drilling facilities operating on the Norwegian continental shelf had been taken during the use of three generations of hydrocarbon base oils: diesel oils (1979–1984), low-aromatic mineral oils (1985–1997) and nonaromatic mineral oils (1998–2004). Sampling done before 1984 showed high exposure to diesel vapour (arithmetic mean = 1217 mg/m^3). When low-aromatic mineral oils were used, the exposure to oil mist and oil vapour was 4.3 mg/m^3 and 36 mg/m^3, and the respective arithmetic means for nonaromatic mineral oils were reduced to 0.54 mg/m^3 and 16 mg/m^3. Downward time trends were indicated for both oil mist (6% per year) and oil vapour (8% per year) when the year of monitoring was introduced as a fixed effect in a linear mixed-effects model analysis. Rig type, technical control measures and mud temperature significantly determined exposure to oil mist. Rig type, type of base oil, viscosity of the base oil, work area, mud temperature and season significantly determined exposure to oil vapour. In these models major decreases in variability were found for the between-rig components.

4.2 Article II

The study indicated possible exposure to 18 known and suspected carcinogenic agents, mixtures or exposure circumstances for 27 defined job categories. Monitoring reports were obtained on seven agents (benzene, mineral oil mist and vapour, respirable and total dust, asbestos fibres, refractory ceramic fibres, formaldehyde and tetrachloroethylene). The arithmetic mean of 367 personal samples of benzene was 0.037 ppm (range: less than the limit of detection – 2.6 ppm). Asbestos fibres were detected (0.03 fibres/cm^3) when asbestos-containing brake bands were used in drilling draw work in 1988. Personal samples of formaldehyde in the process area ranged from 0.06 to 0.29 mg/m^3. Descriptions of products containing known and suspected carcinogens, exposure sources and processes were extracted from the collected documentation and the interviews of key personnel.

4.3 Article III

In individual assessment by eight experts, 18% of the possible combinations of carcinogen, job category and time period were denoted as possible exposure, and 14% scored probable exposure. Stratified on the 17 carcinogenic agents, the probable exposure prevalence ranged from 3.8% for refractory ceramic fibres to 30% for crude oil. The overall mean kappa was 0.42; ICC (2,1) was 0.62 and ICC (2,8) 0.93. The university and the industry experts did not differ in agreement. Agreement was higher for IARC group 1 than for the three other IARC groups (2A, 2B and 3). Providing limited quantitative measurement data was associated with less agreement than for equally well-described carcinogens without monitoring data.

4.4 Article IV

Eight experts assessed 1157 (63%) of 1836 combinations in plenary, resulting in 265 (14%) agreed exposed combinations. Chlorinated hydrocarbons, benzene and inhalation of mineral oils had the highest number of exposed job categories ($n = 14$, 9 and 10, respectively). The job categories classified as exposed to the highest numbers of carcinogens were the mechanics ($n = 10$), derrick employees ($n = 6$) and process technicians ($n = 5$). The agreement between the experts' individual assessments and the panel assessment was $\kappa = 0.53$–0.74. The sensitivity was 0.55–0.86 and specificity 0.91–0.97. For these parameters, there were no apparent differences between the university experts and the industry experts.

5. General discussion

Stewart et al. (1996): “Historical exposure assessment requires an opportunistic approach, taking advantage of what information is available and developing creative and innovative approaches to exploit that information.”

Kauppinen (1996): “In the future occupation will probably be less accurate as a descriptor of exposure.”

Exposure assessment is one of the key aspects in investigating the association between occupational exposure and the development of disease.

To provide exposure data for a planned cohort study on cancer, this study aimed at quantifying and assessing the probability of exposure to selected known and suspected carcinogens in Norway’s offshore petroleum industry. In order to gather information about the industry and to get an overview of carcinogens used and specific milestones in processes and products in this industry, companies were visited, comprising interviews of key workers and collection of documents. The sampling data collected were put into databases for analysis. Due to the relatively large number of measurements done on oil mist and oil vapour in drilling areas, this database was considered sufficiently comprehensive to construct statistical models for exposure to oil mist and oil vapour in the time period 1989–2004 (Article I). The database supported estimates of time trends and determinants of exposure such as rig type, base oil and season.

Descriptions of occupational exposure sources and products involving 18 carcinogens and suggested exposure for 27 defined job categories are based on the key information extracted from documents, monitoring reports and information from the interviews. Exposure measurements were not available for most agents in the time period considered (1970–2005). Thus, an expert team was used to assess the likelihood of exposure for combinations of carcinogen, job category and time period to provide surrogate measures of exposure. The experts were provided with the status of knowledge (Articles I and II), and after an initial individual filling of exposure matrices, a round-table discussion was carried out to agree on the combinations probably exposed. Since this is a disputed method, it was decided to evaluate the performance of the expert group by assessing interrater agreement and by evaluating how the provided information influenced the agreement (Article III). The agreed results of the expert assessments were presented and the validity was evaluated (Article IV).

In this chapter, I place this dissertation into a broader context of methodological developments in retrospective exposure assessment. I evaluate the advantages and limitations of the methods used. I discuss the main results and indicate the limitations in the exposure assessment. Finally, I make suggestions for future studies.

5.1 Methodological considerations

Data collection

Strategy chosen for collecting historical exposure information

Because Norway's Continental Shelf has many installations, getting access to all the workplaces was not feasible, and an assessment strategy involving walk-through surveys was not an option. The walk-through method is often used in retrospective exposure assessment studies where the industry locations are still present (Stewart et al., 1998). Instead the research group had to rely on close contact with key people in the industry to make company visits, including interviews of key personnel representing different job categories and collection of monitoring reports and other relevant documentation. The companies were chosen to represent as many job titles as possible and to have employed the majority of participants in the cohort.

Interview structure

The interviews were semistructured, free-flowing based on checklists of job titles and carcinogens. Stewart et al. (1998) changed to interviews of this character in their study when they realised that the informants' recall did not follow the plan for structured interviews prepared prior to interviewing. Tielemans et al. (1999) suggest that this strategy might provide a more complete understanding of occupational exposure than self-administered job-specific questionnaires.

Representativeness of interviewees

A drawback in this study was that a person representing the leadership of the company often assisted the informants, which might sometimes have led the interviewees to hold back information. Further, the companies themselves selected participants for these meetings. On the other hand, an independent set of interviewees was difficult to achieve both due to logistic constraints and the need for a close relationship with and overview of 20 companies.

Fifteen of the 83 people interviewed had offshore experience from the 1970s, but detailed knowledge on exposure to carcinogens for this period was scarce. Hence, the assessments made for this decade might be less valid.

Representativeness of the documents collected

During the data collection, many companies claimed that retrospective data were filed in complicated archive systems or incompatible computer systems. This might have influenced the results. Another reason for not giving priority to archive searches might be that the top management of the companies in most cases was not sufficiently involved to allocate the health, safety and environment management enough resources to do complete archive searches. Although we do not expect to have a complete set of existing documentation from the industry, the documents provided on carcinogens are considered representative for the industry.

Few sampling reports and other relevant documentation were found from the 1970s. As mentioned above, this might lead to less valid assessments for this decade.

In particular, one aim has been to get access to as many monitoring reports on oil mist and oil vapour as possible. Article I included exposure data on oil mist and oil vapour from all the companies currently involved in drilling on Norway's continental shelf. Most of the reports compiled are from the past decade. The reasons for the few reports from the 1980s and early 1990s are probably less sampling activity, less focus from the authorities, fewer results available due to inaccessible data systems and loss of company history because of retirement or key personnel changing positions. Prior to 1991, no results were accessible from movable drilling rigs. The number of exposure measurements increased from 1989 to 2004, presumably reflecting increased monitoring activity with time. However, some reports, especially from the earliest years, were not expected to be accessible during the collection process. The reports have varying amounts of information, and few provide detailed data on the design of the mud-handling areas, the ventilation system, the physiochemical characteristics of the base oils used and the detailed work tasks. Thus, the models presented in this study are based on the rather coarse set of variables stated in most of the monitoring reports.

According to the newspaper *Dagbladet* (Hansen, 2006), an oil company in Norway conducted an internal investigation of historical documentation of exposure to chemical hazards for its installations on Norway's continental shelf. The article refers to an internal report describing 69 document titles, and 20 contained exposure measurements for the time period 1985–1995. For the subsequent decade 78 documents were found, of which 62 had monitoring data. Their investigation probably included more agents than the ones focused on in this study by counting agents not classified as carcinogens. Nevertheless, it confirms the impression of a low number of documents with chemical exposure data in Norway's offshore petroleum industry.

A complete overview of the offshore petroleum industry is difficult to attain since this includes numerous companies and installations. Presumably, this will result in less document retrieval than in other industry-specific cohort studies concentrating on fewer plants such as previous studies from the aluminium industry (Romundstad et al., 1999), the nickel industry (Grimsrud et al., 2000) and the rubber manufacturing industry (Vermeulen et al., 2000).

Quantitative exposure information based on historical monitoring data

When exposure is being assessed in occupational epidemiology, quantitative approaches are more useful for testing hypotheses and for developing dose–response relationships than qualitative approaches (Smith et al., 2005). Adding qualitative information to measurement data enables a more specific level of estimation (Stewart et al., 1996).

We presented the quantitative data for mineral oil mist and oil vapour, benzene, dust, asbestos, refractory ceramic fibres, formaldehyde and tetrachloroethylene (Articles I and II) using arithmetic mean and geometric mean in addition to range. Since the personal samples are considered to be more representative for workers' exposure than stationary samples, results from stationary sampling have not been stated, either because no such data were available (refractory ceramic fibres and tetrachloroethylene) or because the personal samples were considered to be sufficient to be representative for workers' exposure (mineral oil mist and vapour and benzene). Data were stratified by department, job title, task, sampling time, chemical (such as type of base oil) or physical characteristics such as dust or fibres where appropriate.

The geometric mean is considered to be most representative for the average workers since it puts less weight on extreme values in a data set. The geometric mean and the range of the monitoring data for most of the agents given (Articles I and II) show that a few extreme measurements strongly influence arithmetic means. Such skewed distributions are common in exposure measurement data sets. However, some workers at times may experience high exposure compared with occupational exposure limits, such as for mineral oil mist and vapour exposure in the mud-handling areas and for benzene exposure for the deck job category.

When a large fraction of a data set was below the limit of detection (LOD) for the analytical method used, we followed the recommendation by Hornung & Reed (1990) for estimating means. For the exposure to mineral oil mist and vapour, few measurements were below the LOD (except for oil vapour measurements in the turbine room), and we used the equation $LOD/2^{0.5}$. For benzene, asbestos and oil vapour measurements in the turbine room, we used the recommended equation LOD/2 since more than 45% of the measurements were below the limit of detection and/or there was a high level of variability (geometric standard deviation above 3.0). Benke et al. (2001) questions whether these are optimal approaches for treating measurements under the LOD in hygiene and epidemiology data sets.

Due to the skewed distribution, we $\log_e$-transformed the monitoring data of oil mist and oil vapour when drilling (Article I) to get a distribution of the data closer to normal before performing statistical mixed-effects model analysis (Altman, 1991). We used the statistical models to characterise determinants of exposure when drilling and to examine whether there had been any time trend in exposure. Generalised linear mixed models (Breslow & Clayton, 1993) are obtained from generalised linear models (McCullagh & Nelder, 1989) by incorporating random effects into the linear predictors. These models are useful for modelling the dependence among response variables inherent in longitudinal or repeated-measure studies (Pan & Lin, 2005) and for identifying predictors or determinants of exposure (Seixas & Checkoway, 1995). Linear mixed-effects models as described by Rappaport et al. (2003) allowed us to connect fixed effects such as year, rig type, base oil and mud temperature to the relevant installation by setting “rig” as a random variable. In doing this, we assumed that exposure to oil mist and oil vapour varied both between and within rigs. Studies of retrospective occupational exposure have used mixed-effect modelling since they allow more sophisticated analysis of the data set than ordinary linear regression models (Burstyn et al., 2000).

Seixas & Checkoway (1995) state that validity testing of statistical models is crucial. Burstyn et al. (2002) validated their models of exposure developed for a historical cohort study of asphalt workers in western Europe against data from the United States, Italy and Germany that were not included in the original exposure models. Plato et al. (1997) constructed a matrix of multipliers to current levels of man-made vitreous fibres in Sweden's prefabricated house industry to calculate historical exposure levels but stated that they could not validate the model due to lack of previous exposure measurements. The models in the present study might be validated against new measurement data on oil mist and oil vapour in drilling areas, either monitored after May 2004, newly found historical data or measurements performed in other countries.

Occupational monitoring data might include systematic errors (biases) due to sampling or analytical method and equipment. Random error might occur because of errors by the assessor or laboratory analyst when handling sampling or analysis equipment or information errors in the report such as incorrect monitoring time or process parameters (temperature, department, weather conditions etc.). We could not estimate such errors in the data sets presented in Articles I and II.

This study did not evaluate the use of personal protective equipment. The interviewees gave varying information on the type of personal protective equipment and whether or not it was used. We therefore decided not to take personal protective equipment into account.

Section 5.3 provides more discussion on how limitations in historical monitoring data might influence the epidemiological analysis.

Summary of findings from the data collection (Article II)

Article II gives an overview of the university researchers' findings and interpretation of the information collected through the company visits. The article describes carcinogens, carcinogen-containing products, exposure situation and sources, job categories and the researchers' suggestions on possibly exposed job categories. This was used as background information for the expert assessment of exposure. Few studies describe the background information provided to expert panels in depth (Stewart et al., 1996). The approach and justification of the suggested exposed job categories have been explained but not in a conclusive manner. Stewart et al. (1996) say that researchers or investigators rarely describe this approach and suggest that researchers better describe how they identify and document the development of exposure groups.

Exposure assessment by the expert group

When measurement data are missing from the workplace under investigation or from similar industry or analogous tasks, Stewart et al. (1996) recommend that quantitative estimates not be attempted. In the present study we decided to use a group of eight experts with knowledge of offshore occupational hygiene to assess the likelihood of exposure.

The use of expert assessment has generally increased in recent decades. Occupational hygienists, chemists, engineers and other professionals are regarded to better understand occupational exposure than workers. However, experts may not be familiar with the specific jobs, workplaces and industries to be considered (Teschke et al., 2002), and their background may influence how they assess exposure (Teschke et al., 1989).

Subjective approaches are less accurate and more open to criticism than estimates based on quantitative monitoring data. Nevertheless, when measurements are lacking, expert assessment (or judgement) is often used (Stewart et al., 1996). One strength of this study is that it describes the information provided to the experts (Articles I and II). Few studies describe how the exposure estimates were developed and the information on which the experts based their decision, judgement or assessment (Stewart et al., 1996).

Methods for testing the reliability and validity of expert assessment

Due to the subjective nature of the expert assessment, we decided to investigate the method further.

We examined reliability to get a picture of how the group functioned, whether it was large enough and how the information provided to the experts influenced the agreement between them. According to Benke et al. (1997), the optimum number of experts and the relationships between independent and consensus estimates have rarely been examined. Reliability is synonymous with reproducibility: repeated testing of the same measurement (Checkoway et al., 2004). In this context, the eight experts' assessment of the same exposure combination might be viewed as eight repeated measurements. Analysis of the consistency among raters (interrater reliability) might help in identifying characteristic rater trends (Checkoway et al., 2004). Common measures of reliability of exposure assessment by experts in case–control studies are percentage agreement, Cohen's kappa index and intraclass correlation (Teschke et al., 2002). Van Tongeren et al. (2002) estimated kappa between raters in a population-based cohort study, whereas Roberts & McNamee (2005) focused on the limitation of the single summary-weighted kappa coefficients and suggested a symmetrical matrix of kappa-type coefficients instead.

A valid assessment has no systematic bias, but this is never achieved in retrospective exposure assessment. Validity indicates the discrepancy between measured and true values. Examining validity requires knowledge of the true exposure, and this is rarely, if ever, available. An alternative strategy is to choose a measure believed to be close to the truth and to define this as the gold standard against which other, cruder, measures are assessed for validity (Checkoway et al., 2004). Teschke et al. (2002) states that comparing expert assessment with measured data is a common way of validating expert assessment. This study estimated validity by comparing the individual assessment against the consensus made by the experts in a subsequent plenary discussion, defined as the gold standard.

When the exposure variable is classified as exposed or nonexposed, as in the panel assessment in this study, non-differential misclassification would be expected to bias the ratio measures of association (that is, relative risk) toward the null value of 1.0 (Pearce et al., 2006).

Presentation of the results of the expert group consensus

The job–exposure matrix approach including combinations of carcinogen, time period and job category (Article IV) can be viewed as the final result of the exposure assessment compiled by Articles I–IV that the Cancer Registry of Norway can use in their planned analysis of cancer development in the offshore cohort. The results in Article IV extend the information in Article II by including the time period. The assignment of job categories as being exposed in Article IV is expected to be more valid than the assignment the researchers suggested in Article II.

5.2 Main findings

Consensus decisions on carcinogen exposure by an expert group (Article IV)

Article IV presents the consensus decision by eight experts on exposure to 17 carcinogens for 27 defined job categories in four time periods (1970–1979, 1980–1989, 1990–1999 and 2000–2005) by using a job–exposure matrix approach. Benzene and mineral oil were among the agents with the highest number of exposed job categories. In contrast, chlorinated hydrocarbons had the highest number of exposed job categories due to the use of metal degreasers, but very few measurements were performed (Article II). This study assessed most job categories as being exposed to several carcinogens. This is in accordance with other descriptions of occupational exposure in the offshore petroleum industry (Cottle & Guidotti, 1990; Elliott & Grieve, 1987; Gardner, 2003; Grieve, 1988; Health and Safety Executive, 2000b; Hudgins, 1991).

Identifying and describing exposure to selected carcinogens (Article II)

We collected documentation and interviewed key personnel to describe the products containing known and suspected carcinogens, exposure sources and processes and identified 18 carcinogens and 27 job categories. The research group only got access to sampling data for seven relevant agents, indicating a more ad hoc sampling regimen. However, the quantitative data for benzene in the process section and mineral oil mist and vapour in the mud-handling area might be considered representative of the exposure sources and situations in question. The benzene samples in Article II had low geometric mean levels, in accordance with published data from this industry (Glass et al., 2000; Health and Safety Executive, 2000b; Kirkeleit et al., 2006). Nevertheless, the range for the process and deck categories indicated that some workers are exposed at times to benzene levels exceeding Norway’s occupational exposure limit. Due to lack of information, we could not identify the tasks associated with high benzene exposure.

Turbine room workers had lower exposure to mineral oil than previously described for workers in the mud-handling areas (Davidson et al., 1988; Eide, 1990; James et al., 2000).

Within Norway's offshore industry, the most striking exposure situation involving asbestos is presumably when asbestos was a constituent in dry powder used as a drilling mud additive before 1980. Esmen & Corn (1998) measured high levels of asbestos (range 0.39–1.9 fibres per cm^3) during analogous processes involving cutting sacks and pouring the asbestos-containing content into a container.

Spencer et al. (1999) found asbestos fibre release from the brake pads of overhead industrial cranes in the range of <0.005 to 0.011 fibres per cm^3, which is lower than the results presented in Article II on asbestos fibres from brakes in drilling draw works.

Two studies reported the migration of fibres within the same range as that found when refractory ceramic fibres were installed or removed by insulators (Cheng et al., 1992; Maxim et al., 1997), but van den Bergen et al. (1994) reported higher levels (range 9–50 fibres per cm^3).

In the period 1990–2000, all drilling facilities in Norwegian waters installed automatic sack-cutting machines for dry additives, which probably led to reduced levels of dust in mud-mixing areas. Dust-causing dry drilling additives such as barite and bentonite contain crystalline silica.

To our knowledge, results from dust exposure measurement in the shale shaker room on platforms in Norway have not been published. Hansen et al. (1991) measured airborne dust in the shale shaker room during an offshore drilling operation in Denmark's part of the North Sea and found total dust varying from 0.04 to 1.41 mg/m^3, with barium and silicon being the two most abundant elements.

The petroleum industry has replaced and reduced the number of products containing carcinogens since the 1980s. One example is leaded grease used on drilling and casing pipe threads. The number of such products has been reduced over the years followed by strict restrictions internally in the oil companies in 1995 due to limited discharge permits. The biological uptake of lead among drilling offshore crews has not been examined, but studies indicate that leaded grease might be expected to be absorbed through the skin (Hine et al., 1969; van Peteghem & de Vos, 1974).

The exposure to occupational hazards in the working environment in the offshore petroleum industry has changed significantly since 1970. The cause has been increased focus on reducing the use of hazardous agents, both by the industry and by the relevant public authorities. The agents of concern today probably pose less risk than those in focus previously (such as asbestos). Activity in monitoring chemical and physical agents has increased in this industry with time, especially since 1995. This is in accordance with the descriptions of practice in the United States (Stewart et al., 1996).

Time trends in personal exposure to oil mist and oil vapour when drilling with oil-based muds, 1979–2004 (Article I)

Article I indicated that the exposure to oil mist and vapour decreased during recent decades but still some measurements were above the recommended limits.

The extremely high exposure to diesel vapour in the earliest period of monitoring (1979–1983), which we excluded from the statistical modelling, might be due to the lack of technical control measures in the mud-handling areas. At that time the drilling facilities were designed for water-based mud systems, which were probably expected not to cause harmful health effects. The reduction in exposure from 1979 to 2004 occurred as diesel was being replaced with low-aromatic and later nonaromatic base oils. The boiling point range for the diesel oils includes lower temperatures than the two subsequent generations of base oils. Generally, the vapour pressure decreases as the boiling point increases, indicating less evaporation of base oils with higher boiling points. This might partly explain the high oil vapour exposure when diesel base oils were used. Further, since diesel vapour was actively sampled on charcoal tubes during 12-hour shifts, we cannot exclude that some oil mist might also have been collected, resulting in overestimation of the diesel vapour exposure.

Technical control measures to reduce exposure have mainly comprised constructing cabins for the operators and installing more efficient ventilation systems. Closing open fluid flow lines and mud pits has probably also made the working environment less contaminated. In addition, the purpose of the air-sampling reports has changed through time. Before 1999, sampling almost exclusively focused on testing compliance with limit values, whereas since then the largest fraction of air samples documented technical control measures carried out in the mud-handling areas. If the changes were successful, lower exposure would be expected, as indicated for oil mist in the mixed-effects model. However, the various types of control measures presumably have different relative effects on exposure. An increased focus from the public authorities in the past 7–8 years on documenting the exposure level as an important part of risk assessment might also have initiated the measurement of exposure on newer generations of rigs with lower exposure.

The linear mixed-effects models indicate significant decline over time in exposure to oil mist and vapour from 1989 to 2004 of about 6% and 8% per year, respectively. These time trends were mainly associated with decreases in between-rig variance, which might indicate that rigs with lower exposure were included rather than exposure being reduced over time within the respective rigs. This could be explained by the low number of years sampled for most rigs and also few repeated measurements, which were mostly taken within short time frames within the different rigs. Thus, the time trends might partly be functions of the rigs selected for sampling. These data represent about 50% of the fixed drilling facilities and 20% of the movable drilling rigs. We did not evaluate whether these rigs are representative for all the rigs operating in the time period investigated. Further, the time trend should be interpreted cautiously, especially for exposure to oil mist. This time trend seemed largely affected by the very high exposure concentrations measured in 1989 and 1992, whereas after 1992 the observed exposure to oil mist seems to be relatively independent of time. However, the magnitude of these time trends was in the same range as those reported for long-term exposure trends in other industries such as the asphalt industry (Burstyn et al., 2000), the carbon black industry (van Tongeren et al., 2000) and the rubber manufacturing industry (Vermeulen et al., 2000).

Determinants of personal exposure to oil mist and oil vapour when drilling (Article I)

The estimated exposure to oil mist and vapour on the movable drilling rigs was about twice as high as on fixed drilling facilities. This can be explained by older technologies with more open flow lines, less developed ventilation systems and more time being spent in the exposed areas.

The models indicate that technical control measures prior to sampling have had the most effect on oil mist concentrations. Although the design of the shakers and mud pits has remained unchanged on most drilling facilities, ventilation of the mud-handling area has improved considerably on most rigs.

In bivariate analysis, the mud temperature correlated both with mud flow and well length, but none of these parameters correlated unambiguously positively with oil mist or vapour. Most reports stated the mud temperature, and it was therefore chosen as a variable to enter into the exposure models. The multivariate exposure model agrees with this assumption by indicating that the mud temperature significantly predicts oil mist and vapour exposure, as exposure increases by 19% and 16%, respectively, for an increase in temperature of 10°C.

The section of the well was not a significant determinant and was not included in the final models.

Exposure to oil vapour was significantly lower for drilling with nonaromatic base oil than with the previously used low-aromatic base oil. We have not determined whether this is due to the characteristics of the base oils such as evaporation or to other time-linked changes such as technical control measures or the introduction of newer rigs.

Long and complicated high-temperature and high-pressure wells may require fine-tuned base oils with low viscosity. These low-viscosity base oils have a lower boiling point range and presumably a higher vapour pressure than those with normal viscosity. This might explain the increased oil vapour exposure in this study when low-viscosity base oil was used. Viscosity was not a significant determinant of oil mist, probably because it has little effect on the oil mist produced by mechanical agitation of the shakers.

The workers in the slurrification unit had lower exposure to oil vapour than did workers in the other mud-handling areas. This might partly be because the temperature of the mud was reduced by the time it reached the slurrification unit. The temperature was not measured in these units, so we could not verify this. Few reports stated the actual time spent in the respective work areas and on the specific tasks, and we could not use this for further analysis.

Oil vapour is generated by evaporation from the mud system, especially in the shale shaker area, where solids and liquids separate. Oil mist is presumably produced by a combination of aerosol formation by mechanical agitation of the shale shakers and the condensation of vaporised base oil. Depending on the equilibrium between the vapour and liquid phases, oil vapour produced by evaporation from oil mist might also contribute to the total vapour concentration. One reason for the increased oil vapour exposure during the summer season might be that the higher air temperatures shift the equilibrium between the phases towards increased vapour concentration. Less wind during summer might also contribute to higher exposure. Generation of oil mist appears to be independent of the seasonal effect.

The between-rig components accounted for the major decreases in variability in the mixed models. This might be explained by the relatively small ranges of process conditions and the clusters of repeated measurements within a short time frame for most of the individual rigs.

Interrater agreement (Article III)

Eight raters individually estimated exposure to 17 carcinogens in the offshore petroleum industry. For the 1836 exposure combinations assessed per rater, an overall kappa of 0.42 and a single score ICC of 0.62 indicated that the raters agreed on exposure estimates above chance. The lack of full agreement indicated that their subjective opinions influenced the decisions. The kappa values were in the upper range of comparable studies. In a study scoring the likelihood of exposure in three categories (unlikely (0), possible (1) and probable (2)), van Tongeren et al. (2002) found overall kappa values between the raters of 0.36 for 0 versus 1 or 2 and 0.31 for 0 or 1 versus 2. The authors suggested that the poor agreement was due to lack of information on occupations and tasks. In a case–control study of brain tumours in which five experts assessed the presence or absence of exposure to 21 chemicals in 199 jobs, the kappa values for pairwise interrater agreement ranged from 0 to 0.6, with 0.2 as the median kappa (Benke et al., 1997).

The overall average score for the ICC (2,8) of 0.93 indicates reliable mean estimates of exposure and that the study included enough raters. Reducing the number of raters from eight to five or to three only affected the average score ICC marginally. An ICC >0.81 is defined as nearly perfect agreement (Landis & Koch, 1977; Teschke et al., 1996). The raters seem to have received enough information to give reliable average mean assessments. However, the industry raters represented the industrial sector under investigation, indicating that the assumption of independence between the raters might be questioned. A certain common understanding of exposure among occupational hygienists in this industry is expected since they often work on similar topics to comply with working environment regulations or, at times, to deal with news headlines on chemical exposure. The occupational hygienists also arrange meetings to exchange and discuss mutual professional challenges, which might create a more homogeneous perception of exposure. The agreement between the university experts did not differ from that between the industry experts. In accordance with Teschke’s (2003) recommendations, this study aimed at providing the experts with measurement data, information about the properties of the carcinogens and detailed information about the workplace on which to base their likelihood estimates.

The calculated kappa statistics and single score ICC provide a basis to conclude that providing limited quantitative data is associated with less agreement among raters than for equally well-described carcinogens without sampling data. ICC estimates for different groups might not be comparable if the difference in between-combination variance is great. Analysis of the between-combination variance for the three categories of amount of information gave similar results, and we therefore assumed that comparison is appropriate. Some studies have examined changes in interrater agreement when providing their experts with cycles of increasing amount of information. De Cock et al. (1996) provided information on pesticide exposure among fruit workers to experts in three phases. The interrater agreement in ranking tasks by exposure did not change with increasing information. Stewart et al. (2000) evaluated experts' assessments of formaldehyde exposure in manufacturing plants. Information on exposure was provided in six cycles of increasing amount of information, starting with job category and industry and then adding dates, department title and plant reports. The mean difference between the hygienists' evaluations and a standard, more in-depth evaluation improved slightly with increasing information (kappa). When more quantitative information on captan exposure was given, the interrater agreement (kappa) decreased (de Cock et al., 1996). However, according to Hawkins & Evans (1989), offering measurement data produces less biased expert estimates. They showed that, without measurement data, experts tend to overestimate exposure. When Post et al. (1991) gave measured data to occupational hygienists, their relative exposure ranking of jobs did not improve but their classification of jobs into quantitative exposure categories did, and agreement between the raters increased. Segnan et al. (1996) compared assessments by experts – at different stages – based on occupational histories (median ICC = 0.11), industry-specific questionnaires (median ICC = 0.21), lists of products used (median ICC = 0.65), and where available, exposure measurement data (median ICC = 0.51). In general, increasing the information on monitoring data decreased the agreement among the experts. The main reason for this is presumably the large inherent variability in individual measurement results (Kromhout et al., 1993).

Kappa values were significantly higher for IARC Group 1 carcinogens than the other IARC groups. To the author's knowledge, experts being more likely to agree on established carcinogens (IARC Group 1) than on less-established carcinogens has not been reported previously.

Agreement between experts' individual ratings and subsequent plenary expert assessment (Article IV)

The agreement between the individual and the panel assessments in Article IV ($\kappa = 0.53$–0.74) is considered to be acceptably above chance. The high specificity (0.91–0.97) and moderate sensitivity (0.55–0.86) indicate that the individual experts missed some exposure but did not produce many false-positive assessments by using panel assessment as reference. However, this is not unexpected due to the dependence between the individual and the panel assessment methods. Benke et al. (1997) found sensitivity and specificity within the ranges of

0.48–0.79 and 0.91–0.98, respectively, when exposure in 49 jobs was compared with exposure data.

Experts with the strongest opinion might be expected to have a greater impact on the plenary discussions than others. However, considerable agreement on probable exposure in the individual assessments was obviously needed to obtain a consensus on exposure. In addition, the work experience of the expert was not systematically associated with the kappa value for the agreement between individual and panel assessments.

5.3 Limitations in exposure assessment

Potential misclassification of the exposure status of the workers within the Norwegian offshore cohort will result in information bias for the planned cohort study. Misclassification of exposure may mask the true risks of developing cancer due to occupational exposure (Kauppinen, 1996). Pearce et al. (2006) suggest that exposure assessment should be performed blinded: that is, without the assessors knowing health outcome, as we did in this study. When exposure assessment is blinded to health outcome, the misclassification will be nondifferential, that is, towards no difference between people with and without disease (Pearce et al., 2006).

Articles I and II document well the background information provided to the experts. Lacking such information would reduce the credibility of the study (Stewart et al., 1996) and limit the interpretation of epidemiological studies (Stewart, 1999).

Stewart et al. (1996) also suggest that the accuracy and reliability of the estimates should be evaluated, where possible, to quantify the likely degree of misclassification and its effect on the estimated risk of disease, which is in accordance with Article IV.

Misclassification of exposure due to limitations in historical quantitative monitoring data

Historical monitoring data are usually sparse (Stewart et al., 1996). They might have been collected in a non-random order to determine compliance with regulatory standards, to evaluate control measures or to assess exposure levels during unusual conditions (leaks, spills and process shut-downs). Such measurements focus on the people or departments most highly exposed and might thus be biased and not representative for the normal process conditions. According to the sampling reports on which Article I is based, the aim of most measurements was to cover worst-case conditions. The measurements presented in the models in Article I are all 2-hour samples and are not sampled subsequently to estimate full-shift exposure, although the conditions are constantly changing in the drilling areas. Thus, the 2-hour sampling strategy does not allow full-shift measurement assessment.

Estimates of exposure based on worst-case sampling will probably be higher than the exposure found for normal or average conditions. If these levels are used in epidemiological studies, the exposure estimated for an increased risk of a disease will be higher than the actual or true level of exposure at which an association with disease can be detected (Stewart, 1999).

The most frequently used exposure metric is 8-hour time-weighted averages (12 hours in the offshore industry), due to measurement of compliance with occupational exposure limits. However, both peak exposure and averages excluding peaks may be more appropriate for health outcome. Further, episodic events and time between events might be more important than daily average exposure (Stewart et al., 1999).

Misclassification due to limitations in qualitative information

The use and content of metal degreasers containing chlorinated hydrocarbons is uncertain. Some companies reported replacing trichloroethylene products as early as 1985. The informants seem to have applied the abbreviation TRI for both products containing trichloroethylene and products containing 1,1,1-trichloroethane, the latter being in IARC Group 3. The fact that these two solvents cannot be distinguished might lead to incorrect conclusions in the interpretation of any association between exposure to these compounds and any development of cancer in the planned cohort study.

Misclassification due to heterogeneous exposure within job categories

When we used job category as one of the exposure parameters we assumed equivalent exposure for everyone in this category. However, workers holding the same job may differ in exposure because of differences in individual work practices and microenvironments (Stewart et al., 1991). Exposure within a homogeneous exposure group may vary considerably, enough that the exposure–response relationship is impossible to find (Kauppinen, 1996). If more detailed work descriptions had been obtained, the relatively broad job categories presented in Article II could have been refined, probably resulting in reduced risk of misclassification.

The job categories were defined according to the information collected through the interviews. When exposure for different job titles was considered indistinguishable due to similarities in tasks they were grouped into the same job category, keeping in mind that, in the coming epidemiological studies, the specificity will be reduced when unexposed job titles are included in broader groups of exposed workers.

Exposure to a mix of agents

Many job categories in this study have been assessed as being exposed to several carcinogens (Article IV). For people exposed to a mix of agents, the agent causing the disease might not be clear (Stewart et al., 1996). The carcinogen category may also have several causative agents (Stewart et al., 1996). The group of chlorinated hydrocarbons in this study includes several compounds that might differ in cancer outcome, and workers' exposure will vary according to specific compounds and the intensity of exposure. Thus, results connected to this category might be misleading and difficult to interpret.

Lack of exposure information for lower-risk carcinogens

This study includes carcinogens with established risk as well as less well-recognised agents. The indications for exposure combinations (Articles II and IV) might not be sufficiently refined to reveal any exposure–response association for the carcinogens with lower risks and weaker established carcinogenic effect, such as the IARC Group 2B agents. Historically, many high-risk carcinogenic agents such as asbestos have been identified. Detection of lower-risk carcinogens requires more control of misclassification: valid design, reliable methods in exposure assessment and careful control of confounding factors (Kauppinen, 1996). Excess risks can be observed for diseases with large relative risk despite severe misclassification. The impact of misclassification can be reduced if the exposure information is improved for agents with less hazardous impact (Stewart et al., 1996).

IARC Group 3 carcinogens, however, are included in the study for the important role in exposure in the offshore petroleum industry, and the information concerning these agents might be used to generate hypotheses.

Quantitative estimates of exposure to benzene and mineral oil

Benzene and mineral oil were among the agents with the highest number of exposed job categories. These carcinogens have the best potential for being estimated quantitatively such as cumulative exposure for the planned cohort study. The benzene exposure we reported was similar to that of other studies (Glass et al., 2000; Health and Safety Executive, 2000b; Kirkeleit et al., 2006) and might be used for the relevant job categories to estimate cumulative exposure.

Estimating cumulative exposure to oil mist and oil vapour in the mud-handling areas during complete drilling of a well requires taking into account the variation in determinants of exposure in this time period. Every well drilled is continuously logged for parameters such as type of mud used, mud flow, section of well and mud temperature. A study of representative wells will yield a picture of the shifting process conditions associated with different sets of determinant values. These sets of determinant values could be used in the exposure models described here and serve as a basis for developing cumulative estimates for oil mist and oil vapour.

However, relying on estimates of cumulative exposure might be wrong if peak exposure or episodic events are more important for developing cancer than daily average exposure (Stewart et al., 1996).

The other sampling data are relatively fragmentary and should only be taken as indicating exposure for specific processes when the contaminant is present.

5.4 Further research

The results presented here can be used for classifying exposure in the planned cancer study of the cohort established. They might also form the basis for further development of exposure assessment, such as preparation of job-specific questionnaires for case–control studies. In nested case–control studies, more detailed information on companies, platforms and installations, job sites, job titles, processes, products and exposure levels can be collected through interviews or by reconstructing the work areas and subsequently measuring exposure.

We validated the assessments by comparing experts' individual answers with plenary assessments. A gold standard was not available, and the extent of misclassification should be studied further by smaller-scale validation studies, ideally in a subgroup of the cohort, as Pearce et al. (2006) suggested. In this study, the individual experts highly agreed with the panel. The results should be validated further by comparing objective measures such as new sampling data on specific work processes, observational studies of work practice or analogous studies performed in the offshore petroleum industry in other parts of the world.

Most occupations are exposed to more than one potential risk factor. Controlling for multiple types of exposure when the risk factors are highly correlated is difficult because separating their effects might be impossible. Pearce et al. (2006) suggest considering *a priori* the factors most likely to be associated with the health outcome of interest and limiting the analysis to the particular subset of relevant agents.

Seixas & Checkoway (1995) encourage validation of statistical exposure models. In the present study (Article I), we suggest to validate data on oil mist and oil vapour in drilling areas against new measurement data monitored after May 2004, newly found historical data or measurements in other countries.

Although the literature discusses the possible contribution of hydrocarbons and other agents from other sources such as drilling mud additives or drilled cuttings (Gardner, 2003; James et al., 2000) we did not consider this here. Further, the potential formation of hazardous substances such as polycyclic aromatic hydrocarbons in the drilling mud caused by the effect of high pressure and temperature in the wells needs to be investigated.

Research on these determinants of exposure in drilling areas is scarce, implying that further studies are needed on evaluation of technical control measures, the characteristics of oil-based mud and process conditions.

Benzene and mineral oil were among the agents with the highest number of exposed job categories. These carcinogens have the best potential for being estimated quantitatively such as cumulative exposure for the planned cohort study.

6. Study conclusions

To provide exposure information for a planned cohort study on cancer in Norway's offshore petroleum industry, this study identified and described exposure to known and suspected carcinogenic agents, mixtures or exposure circumstances for 27 defined job categories in 1970–2005 after interviewing key offshore workers and extracting information from collected documents (Article II). The following carcinogens were presented: benzene; mineral oil – inhalation exposure; mineral oil – skin exposure; crystalline silica; asbestos; refractory ceramic fibres; formaldehyde; tetrachloroethylene; trichloroethylene; welding; nickel compounds; chromium [VI]; lead; crude oil – skin exposure; diesel engine exhaust; dichloromethane; ionising radiation; and occupational exposure as a painter. Monitoring reports were obtained on seven agents: benzene, mineral oil mist and vapour, respirable and total dust, asbestos fibres, refractory ceramic fibres, formaldehyde and tetrachloroethylene. For the planned cohort study, exposure might be quantitatively estimated for benzene and mineral oil mist and vapour. The other sampling data are relatively fragmentary and should only be taken as indicating exposure for specific processes when the contaminant is present.

Article I described the historical, personal exposure to airborne hydrocarbon contaminants in the form of oil mist and oil vapour in the mud-handling areas of offshore drilling facilities operating in Norwegian waters when drilling with oil-based muds. Although the exposure to air pollutants declined from 1979 to 2004, some measurements still exceed Norway's occupational exposure limits.

Linear mixed-effects models were created to identify time trends and significant determinants of exposure between 1989 and 2004 when the glass fibre filter and charcoal tube sampling method was used. The models showed a declining time trend for both oil mist (6%) and oil vapour (8%) (Article I). The type of rig, the mud temperature, technical control measures, type of base oil, viscosity of the base oil, work area and season of sampling appear to be associated with the exposure levels. Drilling crews on movable drilling rigs experience concentrations of oil mist and oil vapour twice those of workers at fixed drilling facilities. The concentrations of hydrocarbon air contaminants increase as the mud temperature increases and reach high concentrations compared with Norway's occupational exposure limits, especially for oil mist.

In Article IV eight experts assessed 1157 (63%) of 1836 exposure combinations of carcinogens (*n* = 17), job categories (*n* = 27) and time periods (1970–1979, 1980–1989, 1990–1999 and 2000–2005), resulting in 265 (14%) agreed exposed combinations. Chlorinated hydrocarbons, benzene and inhalation of mineral oils had the highest number of exposed job categories (*n* = 14, 9 and 10, respectively). The job categories classified as exposed to the highest numbers of carcinogens were the mechanics (*n* = 10), derrick employees (*n* = 6) and process technicians (*n* = 5).

Interrater agreement was evaluated to study the method used for assessing exposure when using an expert group (Article III). The overall kappa and single score ICC indicate that the raters in this study agree on exposure estimates above the chance level. The interrater agreement is higher than that found in comparable studies. The average score ICC indicates very reliable mean estimates and implies that more than enough raters were used. The raters seemed to have been provided with enough documentation on which to base their estimates, but providing limited monitoring data leads to more incongruence among raters. Having real exposure data at hand with its inherent variability apparently makes estimating exposure in a rigid semiquantitative way more difficult.

We studied the agreement between the experts' individual ratings and the subsequent panel assessment and found this to be high (Article IV). The assessments of the three university experts and the five industry experts did not apparently differ.

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