Supplementary information to the Job Exposure Matrix for benzene, asbestos and oil mist/oil vapour among Norwegian offshore workers

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Preface

This report gives a summary of a project Occupational and Environmental Medicine, University of Bergen/Uni health carried out within the Programme "Chemical work environment in the oil- and gas industry" of the Norwegian oil- and gas industry. This report describes how we developed estimates for exposure burden related to selected components; benzene, asbestos and oil mist/vapour. The objective was to provide supplementary information to the original Job Exposure Matrix from 2005 on these components. The exposure burdens are estimated for typical workers within the respective job categories. Readers should be aware of the limitations of the applied models when interpreting the exposure estimates.

We would like to acknowledge the "Chemical work environment in the oil- and gas industry" Programme for funding and facilitating this project. We will also thank the advisory group and all our contacts in the oil- and gas industry for supplying information of relevance to this project.

Bergen, December 2011

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Summary

Background

In a previous project we developed a Job Exposure Matrix (JEM) for exposure to carcinogenic agents for 29 job categories in four time periods. The JEM was based on monitoring reports gathered from offshore oil companies and contractors. Information on task-specific determinants of exposure was obtained through visits to oil companies, drilling companies, chemical suppliers and to maintenance, modification and operation contractors. Interviews were made with key informants, generally long-term workers of different job categories. They were interviewed about work processes, chemical products used and relevant exposure. In the present study we also requested the petroleum industry to provide information on major technological changes that were likely to have affected exposure.

Objective

The objective of the present project was to provide supplementary information to the original JEM from 2005 on exposure to benzene, asbestos and oil mist/oil vapour.

Methods

Two strategies for refinement of the JEM were chosen for the three components; A semi-quantitative approach for benzene and asbestos and a quantitative strategy for oil mist/vapour. The rationale for this differentiation was the varying amount of available quantitative data. The semi-quantitative approach for assessing exposure included; Identification of relevant tasks, rating of exposure determinants for these tasks, estimation of frequency and duration of these tasks, and finally rating of exposure burden for each job category based on the set of tasks performed. For oil mist/vapour the amount of quantitative data was considered to be sufficient to develop quantitative estimates of exposure for operators in the mud handling areas of drilling installations.

Results

The semi-quantitative rating of job categories in terms of exposure burden to benzene and asbestos was categorized into four groups (low to high) in four and three time periods, respectively. In our estimates we did not incorporate any variability in exposure within job categories and across installations and fields.

Generally, the exposure burden declined with time period. Mechanics, industrial cleaners and process technicians had the highest rating of exposure burden to benzene in all time periods. Prior to 1985 the derrick men, machinists and insulators had the highest rating of exposure burden to asbestos. Due to maintenance work there was still some asbestos exposure after 1985. However, no asbestos exposure is assumed at installations built after 1985.

Estimated full-shift exposures to oil mist and oil vapour from drilling fluids were highest for mud handling operators and drill floor workers. For all job categories there were declines in personal exposure to oil mist/vapour with time. High exposure to diesel vapour was measured for mud handling operators when diesel was used as base oil up to about 1985. However, we have no information about the quantity and how frequently diesel was used as base oil.

Conclusions

The exposure burdens related to benzene, asbestos and oil mist/oil vapour are estimated for typical workers within the respective job categories. The estimated contrasts in exposure between job categories and time periods can be used in future analysis of the association between exposure and cancer. However, exposure varies with time, between and within job categories and across installations and fields. Thus, in this project several generalizations have been made when estimating exposure burden for typical workers within the respective job categories. The limitations of the applied models should be taken into account when interpreting the exposure estimates.

1. Introduction

Background

Occupational and Environmental Medicine, University of Bergen (UiB)/Uni health has, since 2002, carried out several projects with relevance to historical exposure in the Norwegian offshore petroleum industry (Bråtveit et al., 2010; Kirkeleit, 2007; Steinsvåg et al., 2005, 2007). Information gathered during these studies has been used as background information.

In one of the previous projects “Retrospective assessment of exposure to carcinogens in Norway’s offshore petroleum industry" (Steinsvåg, 2005, 2007) we developed a Job Exposure Matrix (JEM) for the possibility/probability of exposure to carcinogenic agents for 29 relevant job categories in four time periods, expected to be used in future analysis of the association between exposure and cancer in the The Cancer Registry of Norway’s Offshore Cohort (CRONOC). This cohort was established in 1999 including nearly 28 thousand workers who reported to have worked on drilling or production installations in the North Sea between 1965 and 1999 (Strand & Andersen, 2001; Aas et al. 2009). Development of the JEM was based on historical monitoring reports of chemical exposures gathered from offshore oil companies and contractors. Supplementary information on likely task-specific determinants of exposure was obtained through visits to oil companies, drilling companies, chemical suppliers and to maintenance, modification and operation contractors. Interviews were made with key informants, generally long-term workers, representing different job categories. They were interviewed about the work processes, chemical products used and relevant exposure.

In another project benzene exposure was monitored in different job categories when workers performed tasks assumed to represent relatively high benzene exposure; tank work, pipeline cleaning, work in the flotation package, etc. (Bråtveit et al., 2007; Kirkeleit, 2006, 2007).

Recently, we finalized the report “Historical exposure to chemicals in the Norwegian oil and gas-industry”, which summarizes available quantitative, historical documentation of chemical exposure at offshore installations (Bråtveit et al., 2010). Also in that project we made company visits and arranged meetings to collect quantitative and qualitative information, particularly for the years 2003-2007.

In December 2010 the Cancer Registry, UiB and the “Chemical exposure project” in the Norwegian oil industry arranged a workshop on chemical exposures to discuss the exposure assessment for the CRONOC. The Workshop was arranged in two parts: The first part included the project group, the advisory group and invited participants from the oil industry, the authorities and from employer and employees organizations. The aim was to invite for comments on the planned refinement of the JEM. The other part was between the project group and the advisory group where the aim was to discuss the strategies for the refinement of the JEM and to define the focus of the refinement. The workshop concluded that the JEM should be refined for asbestos, oil mist/vapor and benzene with regard to work tasks for selected job categories/work titles.

The objective of this project was to provide supplementary information to the original JEM from 2005 on exposure to benzene, asbestos and oil mist/oil vapour.

Methods

Details on materials and methods are given in the respective sub-reports on benzene, asbestos and oil mist/vapour.

Organization.

A University of Bergen research group comprising four researchers carried out the project between December 2010 and November 2011. The advisory group included Jakob Nærheim and Kjersti Steinsvåg representing oil companies, John Cherrie, IOM, Edinburgh and Tom G. Grimsrud, Jo Stenehjem and Tone Eggen from the Cancer Registry.

Strategies of JEM refinement

Two strategies for refinement of the JEM were chosen for the three components; A semi-quantitative approach for benzene and asbestos and a quantitative strategy for oil mist/vapour (see the respective sub-reports for details). The rationale for this differentiation was the varying amount of available quantitative exposure data.

For benzene, personal exposure data was available from 1990, but 75% of the measurements was performed after year 2000. However, few measurements were taken for individual job categories and during different tasks, and relatively few installations were included, making the representativity of the data questionable. For asbestos, quantitative data was scarce from offshore installations. However, information on asbestos exposure during analogous tasks onshore is available from published international literature. Consequently, for both benzene and asbestos, we decided to use a semi quantitative approach for assessing exposure burden which included the following steps; Identification of relevant tasks, rating of exposure determinants for these tasks, estimation of frequency and duration of these tasks, and finally rating of exposure burden for each job category based on the set of tasks performed (Hopf et al., 2010). The objective for this approach was to estimate contrast in exposure between job categories and between time periods.

For oil mist/vapour the amount of quantitative data was considered to be sufficient to develop quantitative estimates of exposure for operators in the mud handling areas of drilling installations. The estimates were based on a combination of values from exposure models and from mean exposures in the different mud handling areas, linked to assumptions of time spent in these areas by the different job categories.

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2. Rating of job categories according to their exposure burden to benzene

Objective

This part of the project was carried out to refine the JEM for benzene by using information on expert-based determinants of benzene exposure to rate the relevant job categories in respect to the exposure burden to benzene. This article presents the exposure assessment process, and the derived semi-quantitative exposure estimates for benzene for the different job categories used in the offshore cohort.

Introduction

Production process and the petroleum stream

On many offshore installations, the petroleum stream is first separated into gas, condensate, crude oil and produced water before transport to shore via pipelines or by tank ships. The separation and transport take place in closed processing equipment, but the workers are exposed through work on and inside the production vessels in the processing unit. Benzene is a natural component in the oil and gas produced from the reservoirs, and is present in all the four separation streams, with the highest concentration in condensate. Laboratory analysis at an onshore refinery between the years 1989-2011 showed that the benzene content of crude oil from 7 oil fields in the period ranged 0.01-0.49 weight%, while the benzene content in condensate from one field ranged 1.6-2.6 weight% (Figure 2.1) (Statoil, 2011, personal communication). Until 2009 the majority of condensate production (76%) has been at two oil fields/installations (Statistics Norway, 2011).

However, the benzene content of the oil blends analysed at the refineries will be affected by several factors. Crude oils with different origins are mixed through commingling operations and the contribution of crude oil from the different fields varies with production speed (Hwang et al. 2000). New wells with different benzene contents may have been added to production, while others have been taken out. The fields contributing to a specific blend have also changed over time. Hence, the information on the blends benzene content is probably more relevant for the onshore refinery workers than in the estimation of exposure to the offshore production workers included in the present study.

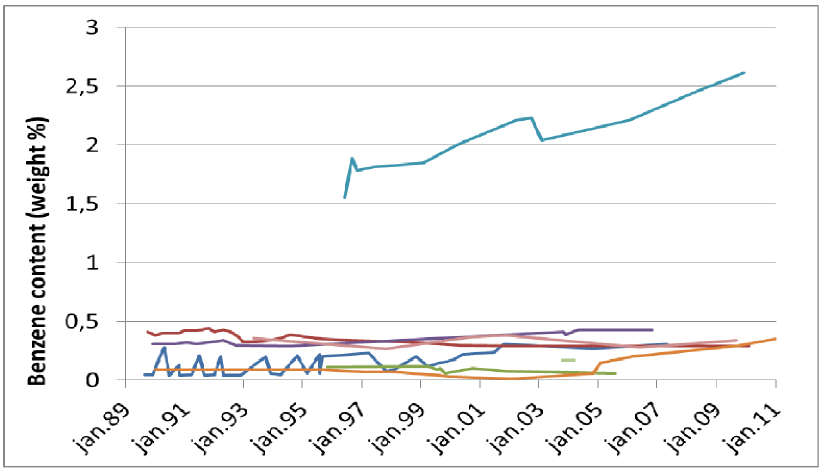

Figure 2.1. Results from laboratory analysis of benzene content of crude oil from seven oil fields (all below 0.5%) and in condensate from one field (1.6-2.6%) between the years 1989-2011 (Data from an oil refinery).

Benzene and leukaemia

Benzene is a leukemogenic agent causally associated with acute myelogenous leukaemia (Baan et al. 2009). Preliminary analysis of the retrospective cohort of workers in the Norwegian petroleum industry offshore suggest excess risk of leukaemia (Aas et al. 2009), while a historical cohort study of Norwegian offshore-workers have reported excess risk of both acute myelogenous leukaemia and multiple myeloma (Kirkeleit et al. 2008). In general the information regarding benzene exposure during production of crude oil and natural gas indicates that offshore workers full-shift exposures have been low (Glass et al. 2000; Kirkeleit et al. 2006; Steinsvåg et al. 2007; Bråtveit et al. 2007; Gaffney et al. 2010). Hence, the excess risk reported in this industry implies that the exposure levels have either been higher than published for this industry, or that the increased risk for these neoplasms can be found at lower levels of exposure than previously assumed. An alternative suggestion is that the pattern of exposure is important, i.e. the workers are likely to have low average exposure with occasional high peak exposures.

Material and methods

Background information from previous studies

As stated previously, background information for the present project was collected through several projects with relevance to historical exposure to carcinogenic agents in the offshore petroleum industry (Bråtveit et al., 2007, 2010; Kirkeleit, 2006; Steinsvåg et al., 2005, 2007).

Collection of supplementary information

Monitoring data and other information on benzene exposure prior to 2000 are scarce (Bråtveit et al., 2010). Hence, in the present study we requested the petroleum industry to provide supplementary information on major changes that were likely to have affected the workers exposure to benzene on selected oil fields on the Norwegian continental shelf. These factors included; 1) technological modifications on the water treatment system, pipeline cleaning, and sampling of petroleum stream, 2) installation of laboratory hoods (changes in local exhaust ventilation), 3) closing of open drains (enclosure of exposure), and 4) changes in work practices, implementation of new regulations, and out-sourcing of tasks with potentially high benzene exposure. A questionnaire on these topics was sent by e-mail to two of the largest operators on the Norwegian continental shelf. We received information on technical modifications for a total of 12 installations. This information was pooled to develop a time-line of major changes assumed to be representative for the offshore petroleum industry. Information on these changes was used when rating the intensity of benzene exposure for the various tasks across the four time periods.

Job categories offshore

In the original JEM, based on an expert assessment of occupational exposure (Steinsvåg et al. 2005), nine of totally 29 job categories were defined as “probably” exposed to benzene (industrial cleaners, process technicians, laboratory technician, electricians, electric instrument technicians, plumbers and piping engineers, mechanics, painters and insulators). Seven job categories were defined as not exposed (drill floor crew, welders, sheet metal workers, machinists, turbine operators and hydraulics technicians, deck crew (maintenance) and scaffold builders). The remaining jobs were defined as “possibly” exposed to benzene. The objective of the present study was to use information on determinants of benzene exposure to rate the job categories selected by Steinsvåg and co-workers (2007) in respect to exposure burden to benzene. Identification of contrasts in exposure between the groups could be used in evaluating the risk of hematopoietic malignancies in offshore workers. In our JEM the sheet metal workers and welders was pooled together. The same was true for chef and catering. The turbine operators and hydraulics technicians were separated into two job categories.

Strategy for rating of exposure burden of benzene

The strategy used for rating of exposure burden was based on the principles used by Hopf et al., (2010) for PCB-exposed workers. The following steps were included in our strategy for rating the job categories' exposure burden to benzene:

Step 1) Identification and description of the tasks assumed to have the highest potential for benzene exposure in the upstream petroleum industry offshore.

Step 2) Rating of the identified tasks in terms of intensity of benzene exposure. The rating was based on an evaluation of each task with respect to selected expert-based exposure determinants (source, transmission path and individual, see Table 2.1). Intensity rating for each task was calculated as the arithmetic mean score of the 10 determinants. The intensity rating was performed for four specific time periods; 1970-79, 1980-89, 1990-99, and 2000 onwards (Table 2.2).

Step 3) Each job category was rated according to their total exposure burden, defined as the sum of products of i) the intensity of benzene exposure for the individual tasks within the job category, ii) the frequency of the individual tasks within the job category, and iii) duration of the individual tasks within the job category. Thus, the total exposure burden for the respective job categories is the sum of the exposure burdens associated with the individual tasks they normally perform.

Step 4) The job categories were categorised into four groups based on their total exposure burden score (Table 2.3).

Rating of intensity based on determinants of exposure, the frequency of tasks performed, and their duration was done by four university/hospital occupational hygienists/researchers with a significant experience from research projects, field work and exposure assessments offshore.

STEL exceeding score

Exceedings of STEL (Short term exposure limit) was one of the exposure determinants included in the rating system (Table 2.1). Total STEL exceeding score by job category was calculated as the sum of product of Exceedings of STEL (0, 1 or 2 from step 2) and the Frequency of these respective tasks (0, 0.5, 1 or 2 from step 3) for the individual tasks performed by the respective job categories.

Results

Step 1: Tasks assumed to have the highest potential for benzene exposure

The tasks assumed to have highest potential for benzene exposure were selected based on results from pooled benzene exposure measurements, which mostly had been done after year 2000 (Bråtveit et al., 2010), and also according to descriptive information on tasks and exposure gathered from the industry.

Sampling of the petroleum stream (crude oil, condensate and water produced).

Operators (process technicians and laboratory engineers) sample crude oil either through an automated short-cut loop or manually in small bottles from taps in the production process. During manual sampling a valve/tap is opened, the crude oil, condensate or produced water

are flushed and collected into a bottle/beaker. The operation takes approximately one minute, but there might be several sampling points on one sampling round. According to information retrieved from the industry a sampling round lasts approximately 40 minutes, ranging between 5 to 90 minutes.
The frequency of sampling crude oil and condensate varies between the companies and installations, ranging between 2 and 6 times per day. The frequency of sampling produced water is mainly determined by amount produced and by the oil content of the produced water, i.e. the higher the oil content, the higher is the frequency.
Around 2000 and onwards some of the installations installed automated and closed sampling points. However, according to the collected information on technical modifications the majority of installations mainly have open, manual sampling points throughout the production period.

Laboratory work related to the analysis of the petroleum streams
In addition to taking samples of the petroleum stream, laboratory work includes bench work with quality control tests such as analysis of water content and specific weight of crude oil and condensate. The oil concentration of the water produced has to be determined before the water is discharged at sea or reinjected into the well.
Several of the analytical procedures in the 1970s and 1980s involved benzene until it was substituted in the end of the 1980s. Laboratory work was done without proper ventilation up to 1985 where after the companies began taking steps to limit worker exposures to benzene in the laboratories through installation of fume cupboards. Washing of glassware with products containing benzene may also have caused benzene exposure.

Opening, changing and closing blind flanges and valves
To allow work on the processing equipment (maintenance, entering processing equipment and tanks, etc) or to prevent cross contamination between fluids along the line, a segment of the hydrocarbon-leading system either has to be opened or isolated by placing or removing a blind flange (spade) in between two pipe flanges. Also, before a valve or segment can be disassembled from the processing equipment prior to maintenance, the petroleum stream has to be closed on both sides of the valve before the vessel is depressurized and flushed with inert gas or water. After removal the valve is cleaned with a degreasing agent, repaired and surface treated before it is put in place in the processing system. Maintenance of the valves on the wellhead is done on location. The degreasing agent might have included benzene. The mechanics mainly perform these tasks, but process operators occasionally open process equipment ahead of maintenance work.

Inspection and maintenance of the water treatment system (produced water)
The water produced contains dispersed oil, and has to be cleaned before it is discharged at sea or reinjected into the well. The installations varies in water cleaning technologies, and during the production period a broad range of water treatment systems have been and are still in use. The flotation package is an example of a technology with a significant potential for benzene exposure. This technology is still in use at installations that started production in the 1980s**.** In this system the oil is skimmed off the upper layer of the two-phase water–oil mixture. During inspection the operators might open the trap doors and, when necessary, adjust the separation level. At times they have to use a swab to push the oil phase over the separation edge. In the 1990s the use of closed hydrocyklons has increased. The process technicians and the mechanics are mainly responsible for the maintenance of the pumps, regulation systems and filters related to the water cleaning systems.

Pipeline cleaning operations

A cleaning pig is a device that is sent down a pipeline to remove solid or semisolid deposits or debris from the walls of the oil and gas pipelines. When inserting and launching the cleaning pig, the operators depressurize the launching station, open the trap door and install the pig into the launcher before locking and securing the door. The product in the pipeline is used to push the pig along the pipe until it reaches the receiving trap at another installation or at an onshore terminal. When the operators remove a cleaning pig from the receiver, they depressurize the system and open the trap closure. The pig is then pulled out of the receiver, often by hand or with mechanical assists, and thick oil and wax from the pig is either removed by manual shovelling or by immersion into a barrel with hot water. Before closing the trap, the trap closure seal is cleaned and lubricated. When the pig is removed from the receiver there is a high potential for hydrocarbon exposure due to evaporation caused by the high temperature in the pipeline. According to the information retrieved from the industry both receiving and sending of a cleaning pig lasts approximately 53 minutes (range 15-90 minutes).

Around 1998 and onwards some of the installations implemented a routine consisting of leaving the pig within the lock for about 24 before opening the trap closure. Also, the received pigs have usually been cleaned on site with water and a cleaning agent. However, after 2000 some of the installations have contracted this task out to specialized cleaning companies onshore.

Tank work

While crude oil is stored in production separators during the separation process on a production installation, crude oil might also be stored in large cargo tanks before offloading and transport onshore. Both separators and cargo tanks are prone to degradation by corrosion, and are periodically emptied for internal inspection of the walls to detect pitting, general corrosion and cracks. If such damage is found, the tank must be repaired to avoid leaks. Hence, work that includes entering a tank or a separator might be separated into cleaning, inspection and maintenance work. Tank work can also include work on waste oil tank, sand traps and various types of drain tanks.

a) Cleaning of tanks and separators including jetting of the systems

Before the tank or separator is cleaned, it must be isolated from the rest of the processing system. This is done by inserting blind flanges (spades) and closing of valves, and is described above (see “Opening, changing and closing blind flanges and valves”). Before entering the tank for cleaning, the tank or separator is first automatically cleaned with hot oil and water and purged with inert gases and fresh air, where after the tank bottoms and sludge is manually removed from the inside of the tank.

Also, during the separation process sand accumulates in the processing vessels, separators and tanks. To limit problems such as erosion, corrosion and interference due to sand accumulation, and to be able to recycle remaining oil from the separated sand, the process equipment is jetted. Although jetting does not include entering of tank and vessels, the task has been included under cleaning of tanks and separators.

b) Inspection and maintenance of tank and separators

After the tank or separator is cleaned, the structures and welding seams are inspected to detect pitting, general corrosion and cracks. The tank or separator is ventilated with fresh air as long as work is in progress. If weaknesses or damage are found, the tank must be repaired to avoid leaks. Maintenance work typically includes tasks such as removal and maintenance of pumps, scaffold building, sheet metal work and welding.

Testing, bleeding off pressure, disassembly/assembly of sampling devices, transmitters and flowmeters

Transmitters measuring the pressure, and by that volume, in a separator, tank, etc., must occasionally be recalibrated and/or tested. This operation causes a potential for exposure to hydrocarbons when the processing system is opened or flushed.

Cleaning, maintenance and changes of filters

Change of filters can be performed by dismantling the filter from the holder, then spraying the filter before cleaning the filter in an acid bath. There is a potential for exposure to hydrocarbons when manually handling the filter.

Other tasks with possible benzene exposure prior to 1990

There are other known tasks with a possible exposure to benzene that have not been included in the rating of exposure intensity, e.g. fuelling of diesel and jet fuel, handling of small quantities of oil-contaminated waste. Also, a background level of benzene might be expected for most workers due to small and diffuse leakages from the processing equipment, and ventilation from crude oil cargo tanks on crude oil production vessels and tankers.

Further, prior to the enforced regulation on the use of benzene around 1985, surface treatment with paint containing benzene, cleaning of metal, equipment, tools, and deck using benzene-based degreasing agents, as well as the use of drilling mud with a high aromatic content, most likely caused a significant exposure to benzene for the job categories a) drill floor crew, mud engineers and shale shaker operators, and b) painters.

Thus, prior to 1990 exposure to benzene is probable for these job categories. In addition, since the industrial cleaners have been reported to also have performed surface treatment tasks, the use of paint containing benzene was included in the rating of the exposure burden for this job category.

a*) Drill floor crew, mud engineers and shale shaker operators.*

Water-based drilling mud was predominantly used in Norway until 1979. In addition diesel mud was also used (1979-1985) on some installations for drilling of more complicated parts of oil wells. Diesel generally contained less than 0.02% benzene (IARC, 1989). Heated mud lead to the evaporation of diesel vapour, and benzene was reported in one of four reports from sampling of diesel vapour in the early 80'ties. The highest reported benzene exposure was 1.3 mg/m^3 benzene, while other measurements, under similar conditions, did not detect benzene (Steinsvåg et al., 2005, 2007). Two reports from the mud handling areas at one drilling installation in 2006 and 2008 show personal exposure to benzene of exposure to benzene in the range <lod-0.29 ppm (n=8), while two other reports from 2006 did not detect benzene during drilling. The origin of the measured benzene is not indicated, whether it is from the base oil or from the well.

Thus, exposure to benzene when drilling with diesel based mud is possible from 1979 to 1985, but the intensity, frequency and duration of such exposure is uncertain. After this period the benzene content in the drilling mud was very low. Intermittent benzene exposure could originate from the well structure, but also in this case the intensity, frequency and duration of any exposure is uncertain.

b) Surface treatment

Prior to 1989 painters employed in the Norwegian petroleum industry might have been exposed to benzene during mixing and application of solvent-based paint products containing benzene (Steinsvåg et al. 2007). However, over the years the benzene content in these products has been reduced or replaced following regulations and other initiatives in the 1980s and 90s. The information on benzene exposure for this exposure scenario in the scientific literature is scarce, but according to the evaluation of painters' occupational exposure in general the reported mean benzene exposure levels range from below level of detection and 55 ppm (IARC, 2010).

Step 2. Intensity of benzene exposure
Whether the workers will be exposed to benzene from a particular source depends on a set of factors called determinants of exposure. In the present study determinants of exposure are used to predict the intensity of exposure for the various benzene-related tasks. These determinants were chosen according to the source-receiver model (Gardiner, 2005). The determinants of exposure were defined on the basis of the information given in interviews of key personnel and collection of relevant documents from oil and contractor companies operating on the Norwegian continental shelf, as well as from descriptions given in the scientific literature. The selected determinants of exposure are given in Table 2.1.
The intensity of exposure for all tasks was assessed for the four distinct time periods; 1970-79, 1980-89, 1990-99, and 2000 and onwards.

Step 3. Frequency and duration of benzene-related tasks and final exposure burden
As for the rating of intensity of exposure (see step 2), we used the information pooled from the industry to decide on the frequency and duration of task for the various job categories. Each job category was given a score for the frequency (times per work week) of the tasks given in Table 2.2 (0= none, 0.5= more than 0, but less than 1 time per work week, 1= between 1 or 7 times per work week, or 2= more than 7 times per work week). Analogous scoring was done for duration of the tasks; 1= less than 15 minutes, 2=between 15 and 60 minutes, and 3=more than 60 minutes. The rating of frequency and duration was only performed for the time period 2000 onwards, and used in the rating of all four time periods. The next step was to estimate the exposure burden for each task by multiplying the scores for intensity, frequency and duration. Finally, to estimate the exposure burden for each job category, the exposure burden for each of the tasks normally performed by respective job categories were added and divided by 9 (the total number of benzene-related tasks).

Step 4. Rating of job categories in terms of exposure burden
Based on the exposure burden score, the job categories were categorised into four groups; 1) red (burden score above 1.0), 2) orange (>0.5 to ≤ 1.0), 3) yellow (> 0 and ≤ 0.5) and 4) green (-; very low) for each of the four specific time periods (Table 2.3).

Since the process technician normally will perform only a limited number of the tasks reported for this job category (normally task 3, 5, 6, 8 and 9 in Table 2.2), this job category are divided into two groups; "low exposed" who do not perform tasks such as "pipeline cleaning operations", "inspection and maintenance of water treatment systems" and "cleaning of tanks and separators containing residues of benzene-containing material". This "low exposed" group of process technicians is assumed to be representative for more than 50 % of the process technicians.

STEL exceeding score
The job categories were categorised into four groups; 1) red (STEL exceeding score above 5), 2) orange (2 to <5), 3) yellow (> 0 and ≤ 2) and 4) green (-;very low) for each of the four specific time periods (Table 2.4).

Limitations

Exposure varies with time, between and within job categories and across installations and fields. Thus, for benzene several generalizations have been made when estimating exposure burden for typical workers within the respective job categories.

Information on benzene exposure prior to 2000
Since monitoring data and other information on benzene exposure prior to 2000 were scarce, the petroleum industry provided information on some major changes that took place on selected oil fields on the Norwegian continental shelf that were likely to have affected the workers exposure to benzene. To be able to use this information in the rating of tasks in respect to the intensity of exposure for the four distinct time periods, we pooled the information to develop a time-line of major changes that was assumed to be representative for the whole industry and used this information when rating the intensity of exposure for the various tasks across the four time periods. However, these factors are not similar across the installations, oil fields or companies.

Job category versus the individual worker
This job exposure assessment is based on describing the exposure assumed to be representative for the respective job categories. However, individual workers belonging to one job category might have work that is better described by another job category. For example, a process technician will also perform tasks that are typical for other job categories, such as laboratory technician (sampling and analysis of the petroleum stream), operator of the central control room (assumed not to be exposed to benzene) and mechanics (opening and closing of blind flanges). Also, in the rating of the job categories, it is the exposure burden for the total job category that is assessed, not the individual worker. Hence, while a process technician normally will perform only a limited number of the tasks reported for this job category, the industrial cleaner will perform most of the tasks that are typical for this job category over a short period of time. Therefore, when rating the process operators' exposure burden we also created a second group of process technicians "low exposed" who do not perform tasks such as "pipeline cleaning operations", "inspection and maintenance of water treatment systems" and "cleaning of tanks and separators containing residues of benzene-containing material". This job category is assumed to be representative for more than 50 % of the process technicians.

Variations in exposure across oil fields and companies
The ranking of the exposure burden for the respective job categories does not take into account possible differences in benzene exposure between various oil fields and oil companies/contractors. Hence, ranking of the job categories in respect to exposure burden may not necessarily be similar across the oil fields and companies. Further, although relative ranks of job titles at one installation might be appropriate at other locations, the absolute exposure level may vary given that the actual exposure level for a category rated with a relatively high exposure (e.g. "process technicians") at one installation may be equivalent to a job category rated with a low exposure (e.g. "plumber") at another installation.

Determinants
The selected determinants (Table 2.1) have been used for all tasks, and they have not been weighted differently in the various tasks.

Semi-quantitative scores vs. quantitative estimates of exposure
Semi-quantitative rating was preferred to quantitative estimates since measurements of benzene exposure have mainly been done among process operators after year 2000. The lack of quantitative data for the other job categories, as well as on exposure levels in general prior to 2000, did not allow us to make quantitative estimates of historical benzene exposure.

Table 2.1. Selected determinants for intensity rating of benzene exposure when performing the respective tasks in Table 2.2 (e.g. pipeline cleaning operations, cleaning of tanks, sampling of crude oil, condensate and produced water).

Determinants		**Score**		
		2	**1**	**0**
Source	Spill of benzene-source	Common	Sometimes	Seldom
	Quantity handled	Large	Moderate	Small
	Temperature	50 to 80 °C	Ambient to <50°C	Ambient temp
Transmission path	Process/task	Manual	Partly automated	Automated
	Drain	Open	Partly closed	Closed
	Exceedings of STEL	Often	Sometimes	Never
	Potential for dermal exposure	Extensive	Some	None
	Ventilation	Indoor	Outdoor, confined	Outdoor, open
Individual	Level of physical activity	High	Moderate	Low
	PPE use	No	Likely	Yes

Table 2.2 Example of exposure intensity rating of the different tasks performed by a process technician, based on the exposure determinants given in Table 2.1.

#	Tasks with a potential for benzene exposure	Exposure intensity rating according to exposure determinants			
		1970-79	1980-89	1990-99	2000 →
1	Cleaning and jetting of tanks and separators (crude oil, slop, etc.)	1.8	1.8	1.7	1.7
2	Pipeline cleaning operations	1.6	1.6	1.6	1.2
3	Sampling of crude oil, condensate and produced water	1.5	1.5	1.1	1.0
4	Maintenance of tanks and separators (e.g.crude oil, slop)	1.4	1.4	1.2	1.2
5	Opening, changing and closing blind flanges and valves	1.4	1.4	1.1	0.8
6	Testing, bleeding off pressure, cleaning and disassembly/assembly of sampling devices, transmitters and flowmeters etc.	1.4	1.4	1.1	0.8
7	Inspection and maintenance of water treatment system	1.4	1.3	1.2	1.1
8	Cleaning, maintenance and changes of filters	1.3	1.3	1.2	1.2
9	Analysis of benzene-containing material	0.9	0.9	0.7	0.4

Table 2.3 Rating of the job categories relative to each other according to exposure burden (exposure intensity x duration x frequency) of performed tasks in four time periods.

Job category	**Exposure burden (intensity x frequency x duration)**			
	1970-79	**1980-89**	**1990-99**	**2000 →**
Process technicians[a]	2.4	2.4	2.1	1.8
Mechanics	1.9	1.9	1.6	1.4
Industrial cleaners	1.4	1.4	1.3	1.3
Process technicians[b]	1.4	1.4	1.1	0.9
Laboratory engineers	1.3	1.3	1.0	0.7
Deck crew	0.8	0.8	0.7	0.7
Plumbers and piping engineers	0.6	0.6	0.5	0.4
Non-destructive testing	0.5	0.5	0.4	0.4
Machinists	0.4	0.4	0.4	0.4
Electric instrument technicians	0.3	0.3	0.2	0.2
Scaffold crew	0.2	0.2	0.2	0.2
Sheet metal workers and welders	0.2	0.2	0.2	0.2
Insulators	0.2	0.2	0.1	0.1
Mud engineers and shale shaker operations*	*	*	-	-
Drill floor crew*	*	*	-	-
Surface treatment (painters)*	*	*	-	-
Drillers	-	-	-	-
MWD and mud loggers	-	-	-	-
Derrick employees	-	-	-	
Well service crew	-	-	-	-
Control room operators	-	-	-	-
Electricians	-	-	-	-
Radio employees	-	-	-	-
Turbine operators	-	-	-	-
Hydraulics technicians	-	-	-	-
Chef and catering	-	-	-	-
Health, office and administration personnel	-	-	-	-

[a] : Subgroup of process technicians who perform all tasks in Table 2.2

[b] : Main group of process technicians who perform the most common tasks (task 3, 5, 6, 8 and 9 in Table 2), presumably representing more than 50 % of the process technicians

*: Job categories assumed to have been exposed to benzene prior to 1985, but available exposure information is inadequate to use the rating system

- : Job category estimated to have very low (close to background) exposure to benzene

Table 2.4. Total score for exceedings of STEL by job category calculated as the sum of products of Exceedings of STEL and Frequency of these respective tasks performed.

Job category	**STEL exceeding score (exceedings of STEL x frequency of the tasks)**			
	1970-79	**1980-89**	**1990-99**	**2000-**
Process technicians[a]	9	9	8	8
Mechanics	6.5	6.5	6.5	6.5
Industrial cleaners	5.5	5.5	5.5	5.5
Process technicians[b]	4.5	4.5	4	4
Laboratory engineers and technicians	4	4	2	2
Deck crew	2.5	2.5	2.5	2.5
Plumbers and piping engineers	2	2	2	2
Non-destructive testing	1	1	1	1
Machinists	1	1	1	1
Scaffold crew	0.5	0.5	0.5	0.5
Sheet metal workers	0.5	0.5	0.5	0.5
Welders	0.5	0.5	0.5	0.5
Insulators	0.5	0.5	0.5	0.5
Electric instrument technicians	-	-	-	-
Derrick employees	-	-	-	-
Drill floor crew	-	-	-	-
Drillers	-	-	-	-
MWD and mud loggers	-	-	-	-
Mud engineers and shale shaker operations	-	-	-	-
Well service crew	-	-	-	-
Control room operators	-	-	-	-
Electricians	-	-	-	-
Surface treatment (painters)	-	-	-	-
Radio employees	-	-	-	-
Turbine operators	-	-	-	-
Hydraulics technicians	-	-	-	-
Catering	-	-	-	-
Chef	-	-	-	-
Health, office and administartion personnel	-	-	-	-

[a] : Subgroup of process technicians who perform all tasks in Table 2.2

[b] : Main group of process technicians who perform the most common tasks (task 3, 5, 6, 8 and 9 in Table 2.2), presumably representing more than 50 % of the process technicians

- : Job category estimated to have very low probabilities of exceeding the STEL value

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3. Rating of job categories according to their exposure burden to asbestos

Objective

The objective of this part of the project was to use available exposure monitoring data and information on expert-based determinants of asbestos exposure in the upstream offshore industry to refine the original job-exposure matrix for asbestos. This article presents the exposure assessment process, and the derived semi-quantitative exposure estimates for asbestos for the relevant job categories used in the offshore cohort.

Introduction

Asbestos and mesothelioma

Asbestos is a class of fibrous minerals associated with a variety of cancers; mesothelioma, lung cancer and may cause ovarian and other cancers (Straif et al., 2009). In Western countries, past exposures to asbestos still results in considerable burden of disease each year (Driscoll et al, 2005; Segura et al., 2003). The offshore cohort is relatively young and an extended observation period would be important for in-depth analyses. The suggested excess of cancer of the pleura in this cohort may be linked to occupational exposure during employment offshore (Aas et al., 2009). The information about exposure sources and exposure levels are not well documented (Steinsvåg et al., 2007).

Asbestos exposure offshore

During the 1960s to mid-1980s the oil and gas industry offshore commonly used asbestos and asbestos-related products. Many workers exposed to asbestos products at that time did not know about the associated health risk.
The risk of asbestos is linked to the minute fibres produced by the asbestos minerals. Over the years the fire resistant property of these minerals as well as their cohesiveness was recognised as beneficial in the production of several products. Unfortunately, when these products broke apart or were otherwise disintegrated, they produced asbestos fibres which could be inhaled and cause serious health problems. Use of asbestos was generally banned in Norway in 1983. The offshore industry started to use asbestos products during the 1960s and continued until it was banned. Asbestos had heat resistant as well as a cohesive properties, or was used as a bonding agent, which was very beneficial when mixed with drilling mud. Several of the asbestos-related products were actually pure asbestos fibres which workers mixed directly into the drilling mud (Steinsvåg et al 2007). Asbestos brake bands were used in the drilling draw works on some installations until 1991, and asbestos fibres were detected in air samples from the drilling floor in 1988 (Steinsvåg et al 2007). At installations built before 1985, asbestos was used as fire protection, both in the living accommodations and in gaskets and as insulation material in other parts of the installations. Later removal of gaskets and insulation probably caused exposure to asbestos, especially for the insulators, and also for the process operators and the other categories comprising the maintenance, inspection, deck and construction sections.

Material and methods

Background information from previous studies

As stated previously, background information for the present project was collected through several projects with relevance to historical exposure to carcinogenic agents in the offshore petroleum industry (Bråtveit et al., 2007, 2010; Kirkeleit, 2006; Steinsvåg et al., 2005, 2007).

Job categories offshore

In the original JEM, based on an expert assessment of occupational exposure (Steinsvåg et al. 2005), nine of totally 29 job categories were defined as “probably” exposed to asbestos (industrial cleaners, process technicians, laboratory technician, electricians, electric instrument technicians, plumbers and piping engineers, mechanics, painters and insulators). Eight job categories were defined as not exposed (welders, sheet metal workers, scaffold builders, mud-operator, laboratory engineers and technicians, non-destructive testing, control-room operators, catering and health, office and administration personnel). The remaining jobs were defined as “possibly” exposed to benzene.

The objective of the present study was to use information on determinants of asbestos exposure to rate the job categories in respect to exposure burden to asbestos. Identification of contrasts in exposure between the groups could be used in evaluating the risk of malignancies associated with asbestos exposure in offshore workers.

Strategy for rating of exposure burden of asbestos

This article describes the exposure assessment process used and the derived semi-quantitative estimates for asbestos for the relevant job categories used in the offshore cohort. The strategy used for rating of exposure burden to asbestos was based on the principles used by Hopf et al., (2010) for PCB-exposed workers.

The following steps were included in the exposure assessment process:

Step 1): Identification and description of the tasks assumed to have the highest potential for benzene exposure in the upstream petroleum industry offshore.

Step 2): Rating of the identified tasks in terms of intensity of asbestos exposure. The rating was based on an evaluation of each task with respect to selected expert-based exposure determinants (source, transmission path and individual, see Table 3.1). Intensity rating for each task was calculated as the arithmetic mean score of the 8 determinants. The rating was performed for three time periods; before 1985, 1985-1999, and after 2000 (Table 3.2).

Step 3): Each job category was rated according to their total exposure burden defined as the sum of products of i) the intensity of asbestos exposure for the individual tasks performed within the job category, ii) the frequency of the individual tasks within the job category, and iii) duration of the individual tasks within the job category.

Thus, the total exposure burden for the respective job categories is the sum of the exposure burdens associated with the individual tasks they normally perform.

Step 4): The job categories were categorised into four groups based on their total exposure burden score (Table 3.3)

Rating of intensity based on determinants of exposure, the frequency of tasks performed, and their duration was done by four university/hospital occupational hygienists/researchers with a significant experience from research projects, field work and exposure assessments offshore.

Results

Step 1: Task with potential asbestos exposure

The tasks assumed to have highest potential for asbestos exposure were selected based on information on tasks and exposure gathered from the industry and on published literature on asbestos exposure during analogous tasks onshore.

Cutting sacks containing asbestos
Asbestos was used until 1983 as an additive in drilling mud. The derrick employee used knives to cut sacks containing asbestos, and fed it manually into a hopper. High concentrations of asbestos have been measured at analogous processes onshore (Esmen & Corn, 1998).

Near-field operators to cutting sacks containing asbestos
In addition to the operator cutting sacks containing asbestos, also other drilling crew employees in the surrounding areas could be exposed until 1983 when asbestos was prohibited.

Work on drill floor
Asbestos brake bands were used in the drilling draw works etc. on some installations until 1991, and asbestos fibres were detected in air samples from the drilling floor in 1988, (Steinsvåg et al., 2007). Spencer et al (1999) also found asbestos fiber release from the brake pads of overhead industrial cranes.
From the middle of the 1980's there was less manual handling of pipes at the drill floor, and drillers cabins were built.

Work on pipes and tubes
At installations built before 1985, asbestos was used as fire protection both in the living accommodations and in other parts of the installations, in gaskets and as insulation material (Steinsvåg et al., 2007). It has been assumed that at installations built before 1985 asbestos has been present in these components until at least 1995 (Steinsvåg et al., 2005).
Insulation; Before 1985 asbestos was used also in re-insulation work.
Removing and maintenance; Later removal and maintenance of gaskets and insulation probably caused exposure to asbestos, especially for the insulators, and also for the process job category and the other categories comprising the maintenance, inspection, deck and construction sections (Steinsvåg et al., 2007). Asbestos exposure during analogous work onshore is reviewed by Madl et al. (2007).

Work in machine rooms
Because of its thermal resistant qualities characteristics and qualities, asbestos was used widely until about 1985, also in machine rooms. Also for machine rooms it has been assumed that at installations built before 1985 asbestos was present in gaskets and insulation until at least 1995 (Steinsvåg et al., 2005). Airborne asbestos concentrations in machine rooms on maritime shipping vessels, when insulation-handling activities were not actively being performed, were reported to be relatively low (Murbach et al 2008).

General work on installation
The general exposure to asbestos in the processing areas was presumably low and estimated as a background exposure. At installations built before 1985, asbestos was used as fire protection also in the living accommodations. Documentation of dust/fibres samples from this areas show asbestos levels below the detection limit.

Step 2: Intensity of asbestos exposure in different tasks
Whether the workers will be exposed to asbestos from a particular source depends on a set of factors called determinants of exposure. In the present study determinants of exposure are

used to predict the intensity of exposure for the various asbestos-related tasks, and these determinants were chosen according to the source-receiver model (Gardiner, 2005). The determinants of exposure was defined on the basis of the information given in interviews of key personnel and collection of relevant documents from oil and contractor companies, as well as from descriptions given in the scientific literature. The selected determinants of exposure are given in Table 3.1.
The intensity of exposure for all tasks was assessed three time periods; before 1985, 1985-99, and 2000 and onwards.

Step 3. The frequency and duration of asbestos-related tasks
As for the rating of intensity of exposure (see step 2), we used the information pooled from the industry to decide on the frequency and duration of task for the various job categories. Each job category was given a score for the frequency (times per work week) of the tasks given in Table 3.2 (0= none, 0.5= more than 0, but less than 1 per work week, 1= between 1 or 7 times per work week, or 2= more than 7 times per work week). Analogous scoring was done for duration of the respective tasks; 1= less than 4 hours, 2=between 4-8 hours, and 3=more than 8 hours.

The next step was to estimate the exposure burden for each task by multiplying the scores for intensity, frequency and duration. Finally, to estimate the total asbestos exposure burden for each job category, the exposure burden for each of the tasks normally performed by the respective job category were added and divided by 8 (the total number of asbestos-related tasks). The rating of frequency and duration was only performed for the time period before 1985, and used in the rating of all three time periods.

Step 4. Rating of each job category in terms of exposure burden
Based on the exposure burden score, the job categories were categorised into four groups; 1) red (above 5.0), 2) orange (>1.0 to ≤ 5.0), 3) yellow (> 0 and ≤1.0) and 4) green (-; very low) for each of the three specific time periods (Table 3.3).'

The exposure burden was highest before 1985, due to the use of asbestos in the drilling mud, and as fire protection, in gaskets and as insulation material in different parts of the process areas, and also.in the living accommodations. After 1985 the exposure of asbestos is based on maintenance and repair of machineries and installation. Documentation from exposure samples offshore indicates that the exposure level was highest in closed room with poor ventilation (Bråtveit et al 2010). No asbestos exposure is assumed at installations built after 1985.

Limitations
Exposure varies with time, between and within job categories and across installations and fields. Thus, for asbestos several generalizations have been made when estimating exposure burden for typical workers within the respective job categories. In general the limitations discussed in chapter 2 (benzene) of this report also apply to the exposure rating for asbestos. In short;

- This job exposure assessment is based on describing exposures assumed to be representative for the respective job categories. However, individual workers belonging to one job category might have worked in a way that is better described by another job category.

- The ranking of the exposure burden for the respective job categories does not take into account possible differences in asbestos exposure between various installations and oil companies/contractors. Differences in work practices and by which job category a given task is performed might vary across oil installations and companies.
- The selected determinants (Table 3.1) have been used for all tasks, and they have not been weighted differently in the various tasks.

Table 3.1 Selected determinants for intensity rating of asbestos exposure when performing the respective tasks in Table 3.2.

Determinant		**2**	**1**	**0**
Source	Asbestos-source	Drilling mud additive	Fire protection, isolation of bands	Brake bands
	Quantity handled	Large	Moderate	Small
Transmission path	Process	Manual	Partly automated	Automated
	Proximity to asbestos source	Close	Near	Far
	Frequency of peaks above STEL	Often	Sometimes	Never
	Ventilation	Indoor	Outdoor, confined	Outdoor, open
Individual	Level of physical activity	High	Moderate	Low
	PPE use	No	Likely	Yes

Table 3.2 Example of exposure intensity rating of the different tasks for the derrick man, based on the exposure determinants given in Table 3.1.

Task #	**Tasks with a potential for asbestos exposure**	**1970-85**	**1985-2000**	**2000 -**
1	Working on drill floor	1.0	1.0	**0.6**
2	Cutting sack with asbestos	2.0	0	0
3	Nearby operator cutting sack with asbestos	1.7	0	0
4	Maintenance of pipes/tubes	1.3	1.3	0.7
5	Isolation pipes / tubes	1.9	0	0
6	Removing pipes / tubes	1.7	1.3	0.9
7	Working in machine room	1.3	1.03	1.0

Table 3.3 Rating of the relevant job categories relative to each other in respect to exposure burden (exposure intensity x duration x frequency) of performed tasks according to the three specific time periods.

Job category	**Exposure burden (Intensity x frequency x duration)**		
	1970-85	**1985-99**[a]	**2000-**[a]
Derrick man	9.8	*	-
Machinists	8.3	3.7	2.9
Insulators	6.0	2.8	1.7
Plumbers and piping engineers	4.3	3.7	2.2
Drill floor crew	4.1	*	-
Driller	2.9	*	-
Mechanics	1.8	*	*
Well service crew	1.4	-	-
Turbine operators	0.9	0.9	0.5
Hydraulics technicians	0.9	0.9	0.5
Deck crew	0.9	0.9	0.5
Electric instrument technicians	0.9	0.9	0.5
Mud engineers and shale shaker operations	0.9	0.9	0.5
Welders	0.9	0.9	0.5
Electricians	0.9	0.9	-
Process technicians	0.9	0.9	-
Scaffold crew	0.9	0.9	-
Sheet metal workers	0.9	0.9	-
Surface treatment (painters)	0.9	0.9	-
Industrial cleaners	0.9	-	-
Non-destructive testing	-	-	-
MWD and mud loggers	-	-	-
Control room operators	-	-	-
Radio employees	-	-	-
Laboratory engineers and technicians	-	-	-
Catering/chef	-	-	-
Health, office and administration personnel	-	-	-

[a]: For installations built before 1985. No asbestos exposure is assumed at installations built after 1985

*: Exposure assumed to be low, but there might have been some fibres from the brake band on the drill floor

- : Job category estimated to have very low (close to background) exposure to asbestos

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4. Exposure estimates for oil mist and oil vapour in the mud handling areas

Objective

The objective of this part of the project was to develop exposure estimates for the job categories in the cancer cohort that have been exposed to oil mist and oil vapour from the drilling mud.

Introduction

Operators in the mud handling areas of drilling installations are exposed to oil mist and oil vapour emitted from the mud flow lines including the shale shakers where solids and liquids separate. A schematic drawing of the mud handling areas can be found in Steinsvåg et al., (2006). In the original JEM from 2005 the following job categories were considered as probably exposed to oil mist and oil vapour during drilling with oil based mud (Steinsvåg et al., 2005, 2007);

- Drill floor crew
- Mud handling operators/shale shaker operators
- Derrick workers
- Measure while drilling (MWD) operators/mud-loggers

In the Cancer Cohort there are 2252 and 3680 workers with first and last position, respectively in the Drilling and Well Service section (Table 4.1). The number of mud handling operators is few, indicating a considerable overlap between Drill floor workers and Mud handling operators.

Table 4.1. *Drilling and Well Service workers in the Cancer Cohort distributed according to their first and last position offshore (Data from the Cancer Registry).*

	First position offshore (n)	Last position offshore (n)
Drilling and well service (not specified)	125	245
Drill floor workers	1460	894
Mud handling operators	13	48
Derrick workers	20	315
Driller	97	910
Well service workers	264	832
MWD/Mud-operator	273	436

The oil based drilling fluids used on offshore drilling installations consists of base oils and a number of additives such as weighting material, emulsifiers, brines and viscosifiers (OGP, 2009). The characteristics of the hydrocarbon base oils in the drilling fluids have changed through time. Three main generations of hydrocarbon base oils have been used; Diesel (1979-1984), low-aromatic mineral oils (1985-1997) and non-aromatic mineral oils (1998-2009) (Steinsvåg et al., 2006).

Figure 4.1 shows that use of oil based drilling mud has increased from 1997 to 2004. In the period 2005-2009 it has varied between 182 000- 220 000 m^3 (OLF 2011). We have not obtained statistical information about the use of oil based drilling fluids prior to 1997. Figure 4.2 illustrates the increasing number of wells drilled per year in the period 1966-2003.

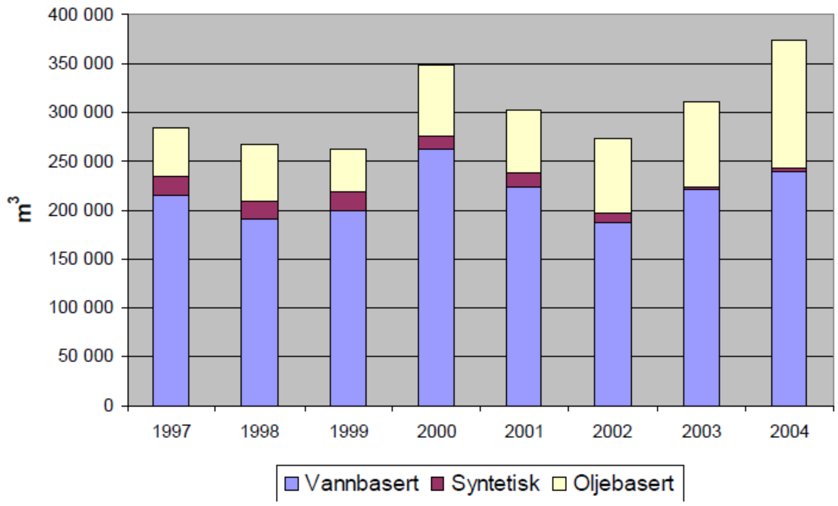

Figure 4.1. Use of drilling fluids in 1997-2004 (blue; water based, red; synthetic and yellow; oil based drilling fluids) (Figure from OLF, 2005)

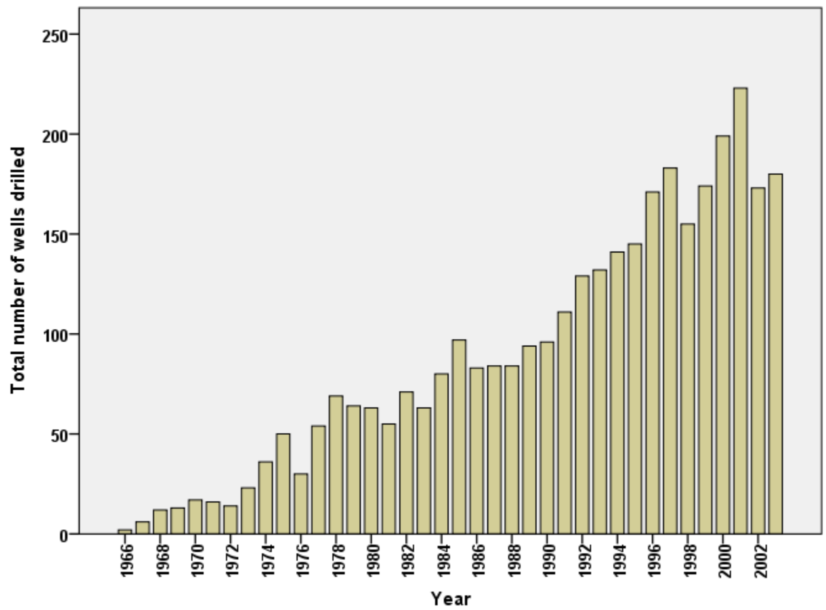

Figure 4.2. Total number of wells drilled per year from 1966 to 2003 (data from annual reports of the Norwegian Petroleum Directorate).

We have previously reported a decline in personal exposure to oil mist and oil vapour over time for workers in the mud-handling areas on offshore drilling facilities (Steinsvåg et al., 2006, Bråtveit et al., 2010). Stationary measurements showed a similar trend. The decline in measured concentrations corresponds with the changes in type of base oil. Furthermore, personal exposure levels as well as stationary concentrations were generally higher on movable than on fixed installations.

The normal work shift on offshore installations is 12 hours. However, most measurements of oil mist and oil vapour are of 2 hours duration. The measurements are mainly taken to assess exposure levels in the different mud handling areas, and not to systematically assess full-shift exposure for individuals or for job categories in the drilling crew.

In this study we estimate twelve-hour time-weighted average (TWA) for relevant job categories as a function of time spent in the different mud handling areas and the exposure level in that particular areas. Thus, we have used measurement data from 1979 to 2009 from the mud handling areas and made assumptions about the amount of time spent in the different areas to estimate 12 hours exposures to oil mist and oil vapour for the job categories in the drilling crew in different time periods.

Material and methods

Data collection

Collection of monitoring reports of oil mist and oil vapour in the mud handling areas of offshore drilling installations was done in two phases; in 2003/2004 during visits to 8 oil companies and 5 drilling contractors (Steinsvåg et al. 2006) and in 2009 by an e-mail request to 4 oil companies and 6 drilling contractors (Bråtveit et al., 2010).

During the company/contractor visits in the first data collection period we also interviewed 18 key informants from the drilling and well maintenance section, most of them long-term workers, representing different job categories. They were interviewed about the work processes, chemical products used and relevant exposure on offshore facilities. A questionnaire was sent to the owners of all drilling installations represented in the collected monitoring reports, requesting information about technical design and function of the shaker room/area. In the present study we also requested the petroleum industry to provide supplementary information on time spent by the operators in the different mud handling areas.

Final database.

The collected monitoring reports covered the period 1979-2009 and included 767 personal and 2074 stationary measurements of oil mist and oil vapour from the mud handling areas of 16 movable and 18 fixed drilling installations during drilling with oil based mud. Number of samples per installation varied between 6 and 92 for stationary samples and 1-59 for personal samples. Most samples are of 2 hours duration. Prior to 1985 dosimeters were mainly used for sampling of oil/diesel vapour. Otherwise most samples have been taken by an active method consisting of a series coupling of a glass fibre filter with a charcoal tube backup. This method is used for sampling oil mist and vapour simultaneously for 2 h. The measured values are 2 hours for work in specified areas, and are not linked to specific work tasks or to the time fraction of the total 12 hour shift they actually spend in the different mud handling areas.

Figure 4.3 shows that relatively few samples of oil vapour/mist in the shaker area have been taken before year 2000.

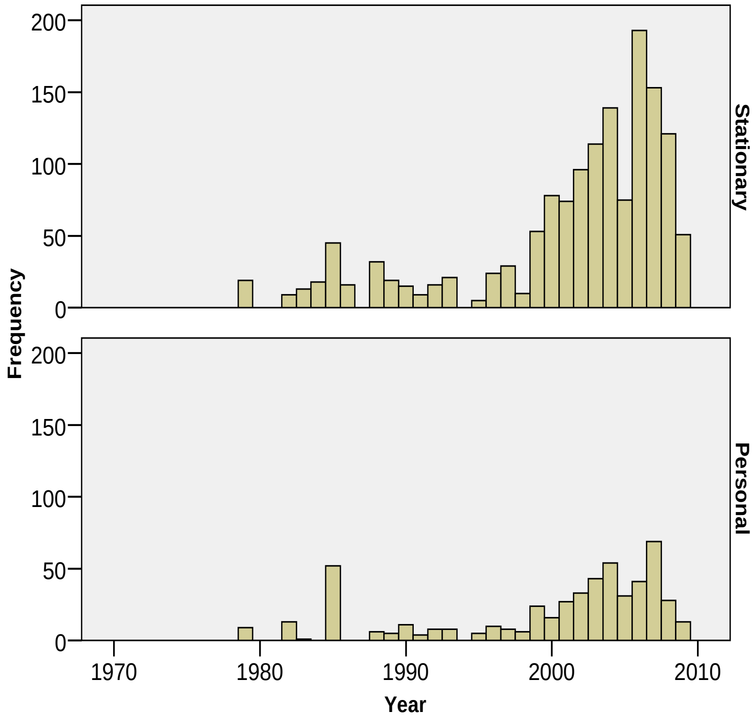

Figure 4.3. *Number stationary and personal measurements of oil vapour/mist in the shaker area by year of measurement.*

Estimation of concentrations of oil mist and oil vapour

Development of regression models

Separate linear mixed-effects models were developed for exposure in the shaker area, mud pit, slurryfication and the pump room. Independent models were made for personal and stationary measurements. The frequency distribution of both oil mist and oil vapour was skewed. Thus, both these data were $\log_e$ transformed before the statistical analysis. The $\log_e$-transformed concentrations of oil mist or oil vapour were used as dependent variables and type of drilling installation (fixed vs. movable) and time period (1985-1997 vs. 1998-2009) as fixed effects. To account for repeated measurements from the same drilling rig, the individual rig was used as a random effect. Personal samples were in most reports not linked to person identification, thus variability within and between workers could not be accounted for.

Areas with few measurements

Less than 10 measurements (personal + stationary) were available from the mud lab, sack storage, drill floor and the driller cabin, respectively. For these areas we have assumed exposure levels based on results from the few measurements in those particular areas, from measurements in adjacent or similar rooms/areas and on information collected through interviews.

Estimation of full-shift exposure (12 h)

Time-weighted 12-hour exposures (TWA) for the respective job categories are calculated as the sum of the products of estimated exposure level in the different mud handling area times assumed time spent in the respective areas divided by 12 hours;

$TWA = (C_1T_1+C_2\ T_2+C_nT_n)/12h$

C= exposure to the contaminant in the respective areas

T= time spent in the respective areas

Results

Generations of hydrocarbon base oils

Three main generations of hydrocarbon base oils has been used in three time periods (Table 4.3) (Steinsvåg et al., 2006). These differences need to be taken into account when assigning exposure levels to drill crew members in different time periods.

Figure 4.4 shows that most personal and stationary measurements have been taken when drilling with non-aromatic base oils in the last period (1998-2009). Only few measurements are available from the first period when diesel was used.

Table 4.3. *Main generations of base oils used when drilling with oil based mud.*

	Years used	Aromatic content	Boiling point range
Diesel	1979-1984	>15%,	150-370^{o}C
Low-aromatic mineral oils	1985-1997	1-10%	220-325^{o}C
Non-aromatic mineral oils	1998-2009	<0.01%,	230-320^{o}C (normal viscosity) 210-260^{o}C (low viscosity)

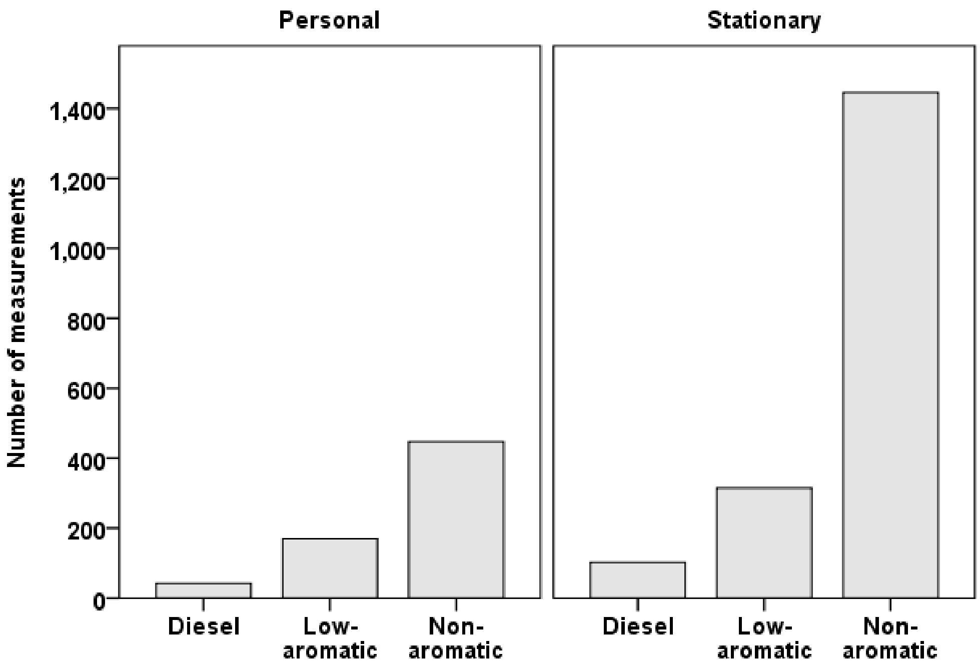

Figure 4.4. *Number of personal and stationary measurements of oil vapour in the mud handling areas when drilling with different generations of base oils.*

Exposure data in different mud handling areas

Table 4.2 shows that the majority (about 70%) of both personal and stationary measurements are from the shale shaker area (see schematic drawing of the mud handling areas in Steinsvåg et al., 2006).

Table 4.2. *Number (%) of personal and stationary measurements from different areas when drilling with oil based mud (1985-2009).*

	Personal samples (%)	Stationary samples (%)
Shaker area	525 (68.4)	1447 (69.8)
Shaker cabin	0	73 (3.5)
Mud pit	99 (12.9)	272 (13.1)
Mud lab	5 (0.5)	10 (0.5)
Pump room	53 (6.9)	79 (3.8)
Slurrification unit	84 (11.0)	175 (8.4)
Drilling floor	2 (0.3)	1 (0.05)
Drilling cabin	0	5 (0.2)
Sackroom	0	3 (0.1)

Figure 4.5 indicates a decline in median personal exposure to oil vapour in the mud handling areas between the two time periods when low-aromatic and non-aromatic base oils were used, respectively. Stationary measurements show a similar trend.

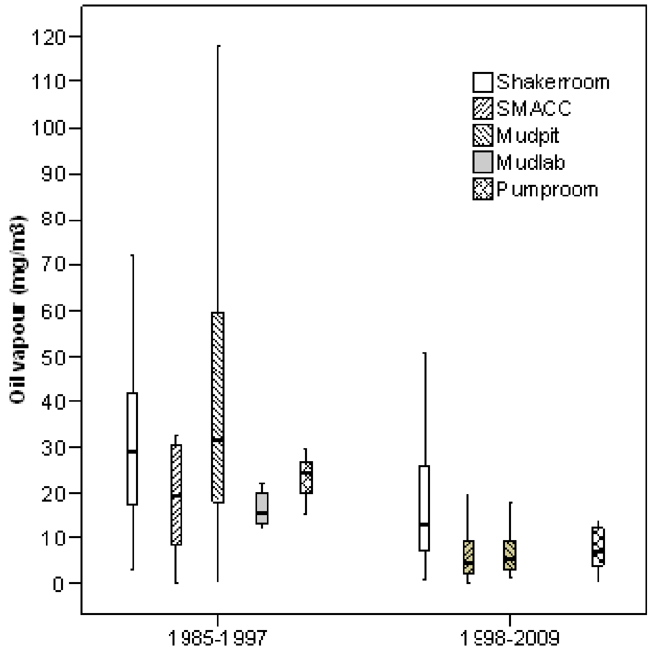

Figure 4.5. *Personal measurements of oil vapour in different mud handling areas (Bråtveit et al., 2010). Medians are indicated by solid lines within the boxes, while the length of the box corresponds to the interquartile range (25th to 75th percentile).*

Estimation of personal exposure in different mud handling areas

During the 12-hour shift the members of the drilling crew normally rotate between different mud handling areas.

Based on information from the monitoring reports the 2 hours personal measurements in the shaker area (including the shaker cabin) and in the slurrification units are in most cases taken when the operator actually is located in those areas. Thus, the respective 2 hour personal measurements are considered representative for personal exposure in these areas.

For the mud pit it is less certain from the reports that the operators have stayed in this area for the full sampling period. The personal measurements linked to the pump room and mud lab also cover time spent in other areas that have not been specified in the monitoring reports. In the other areas the number of measurements is very low (Table 4.2), which is presumably due to expected low exposures in these areas.

Consequently, we have used different approaches to estimate personal exposure in the different mud handling areas (Table 4.3). We have preferably used personal measurements in our exposure estimation. However, due to small number of personal measurements and the intermittent, shorter lasting work in the pump room, mud lab, drill floor and sack room, we have also used stationary measurements from these areas, in combination with assumptions based on results from measurements in adjacent or similar rooms/areas.

Use of stationary measurements might have biased the outcome. However, the data presented in Table 4.4a and b indicates that personal and stationary measurements, even though few in numbers, are comparable in these areas.

Table 4.3. *Summary of selected methods for estimating exposures in the respective mud handling areas*

Mud handling area	**Estimated levels based on**	**Rationale for method of estimating exposures**
Shaker area	P	Continuously in shaker area (+cabin) during sampling period
Mud pit	P	Mainly in mud pit during sampling period
Slurrification	P	Continuously in slurryfication during sampling period
Pump room	S	Shorter periods (< 2h) in area
Mud lab	S+A	Few stationary measurements, shorter periods in area
Drilling floor	S+P+A	Few measurements, shorter periods in area
Drilling cabin	S+A	Few stationary measurements, mainly driller
Sack room	S+A	Few stationary measurements, shorter periods in area

P=Personal samples; S=Stationary samples; A=Assumptions based on results from measurements in adjacent or similar rooms/areas

Table 4.4 shows estimated concentrations of oil mist and oil vapour from the different mud handling areas on fixed and movable installations, as well as for fixed+movable installations combined for the two time periods 1985-1997 and 1998-2009. For the shaker area and the mud pit we have stratified on type of installations (fixed and movable), but not for the other areas due to the low number of measurements. Assumed exposures are rough estimates where few measurements have been taken (in sack storage, drill floor and drillercabin; Figure 4.4a and b).

When calculating time weighed 12 hours exposure for fixed and movable installations combined, we have used the estimated levels in **bold** in Table 4.4a and Table 4.4b.

Table 4.4a. *Estimated oil mist concentration based on personal (P) or stationary (S) measurements and on assumptions (A). (See Table 4.5 for measured exposure before 1985)*

			Estimated oil mist concentrations (mg/m^3)		
	Type	**n**	**1985-1997**	**1998-2010**	
Shaker area (fixed+movable)[1]	P	425	**0.61**	**0.33**	
Fixed installations	P	283	0.54	0.29	
Movable installations	P	142	0.78	0.43	
Mud pit (fixed+movable)[1]	P	58	**0.57**	**0.18**	
Fixed installations	P	36	0.41	0.13	
Movable installations	P	22	0,91	0,30	
			1985-2010		
Slurryfication[1]					
Fixed installations	P	77	**0.25**[2]		
	S	166	0.23[2]		
Pump room	P	16	0.32[2]		
	S	50	**0.43**[2]		
Mudlab	S	4	**0.05** (GM)[3]		
Sack storage	S+A	3	0.06 (GM)[3]		**0.20/0.11**[4]; 1/3 of shaker
Drill floor	S+P+A	3	0.34 (GM)[3]		**0.20/0.11**[4]; 1/3 of shaker
Drillercabin	S+A	4	0.09 (GM)[3]		**0.07/0.04**[4]; 1/3 drill floor

[1]Estimated by linear mixed effects models; [2]No sign. difference between year groups; [3]Geometric mean of measurements; [4]Assumed exposure levels for the periods 1985-1997/1998-2009; sack storage and drill floor: 1/3 of estimated concentration in shaker; drillercabin: 1/3 of estimated concentration on drill floor.
Bold values have been used when calculating time weighed 12 hours exposure for fixed and movable installations combined (Table 4.7)

Table 4.4b. *Estimated oil vapour concentration based on personal (P) or stationary (S) measurements and on assumptions (A).*

			Estimated oil vapour concentrations (mg/m3)		
		n	**1985-1997**	**1998-2010**	
Shakerarea(fixed+movable)[1]	P	440	**26.8**	**12.0**	
Fixed installations	P	299	22.1	9.9	
Movable installations	P	141	39.9	17.8	
Mudpit(fixed+movable)[1]	P	72	**34.9**	**4,5**	
Fixed installations	P	49	26.4	3.4	
Movable installations	P	23	53.6	7.0	
			1985-2010		
Slurryfication[1]					
Fixed installations	P	81	**5.7**[2]		
	S	169	6.8[2]		
Pump room[1]	P	5 3	10.2[2]		
	S	7 9	**8.9**[2]		
Mudlab	S	1 0	**7.0** (GM)[3]		
Sack storage	S+A	3	0.8 (GM)[3]		**9.0/4.0**[4]; 1/3 of shaker
Drill floor	S+P+A	3	6.8 (GM)[3]		**8.9/4.0**[4]; 1/3 of shaker
Drillercabin	S+A	5	5.0 (GM)[3]		**3.0/1.4**[4]; 1/3 drill floor

[1]Estimated by linear mixed effects models; [2]No sign. difference between year groups; [3]Geometric mean of measurements; [4]Assumed exposure levels for the periods 1985-1997/1998-2009; sack storage and drill floor: 1/3 of estimated concentration in shaker; drillercabin: 1/3 of estimated concentration on drill floor.
Bold values have been used when calculating time weighed 12 hours exposure for fixed and movable installations combined (Table 4.7)

Exposure data from before 1985

Water-based mud systems were mainly used before 1985. However, diesel was also used from the last part of the 70-ties up to about 1985. We have not been able to find information about how much or how frequently diesel was used as base oil.

Three monitoring reports from 1979, 1982 and 1983 describe dosimeter-measurements of diesel vapour from three fixed installations (Table 4.5). We have not included this exposure/the period before 1985 in the following estimation of full-shift exposure for the job categories.

Table 4.5. *Results from measurement of diesel vapour in mud handling areas (1979-1985)*

			Diesel vapour concentration (mg/m^3)	
	n	**R**	**GM**	**range**
Shaker area				
-personal	23	3	1257	298-2650
-stationary	40	3	1663	172-9520
Mud pit				
-personal	17	2	620	73-1775
-stationary	31	2	694	34-5049

R=number of rigs

Time spent in mud handling areas

Table 4.6 indicates assumed, representative number of hours spent in the different areas for the job categories in the drilling crew. For the individual job category the number of hours adds up to 12 hours. "Other" location refers to areas/meeting rooms with background exposure (assumed not exposed). We have not sufficient information to differentiate fraction of time between the two main time periods (1985-1997 and 1998-2010). Two scenarios are indicated for the drill floor worker to illustrate its impact on estimated full shift exposure.

Table 4.6. *Assumed distribution of hours spent (x) in different mud handling areas for the respective job categories over a representative 12 h shift*

	Hours per 12 h shift								
	Shaker-area	**Mud-pit**	**Slurry-fication**	**Mud lab**	**Pump-room**	**Drill floor**	**Sack room**	**Driller cabin**	**Other**
Drill floor worker[a]	xxxx	x	x		x	xx	x		xx
Drill floor worker[b]	xxxxxx	x	x		x	xx			x
Mud handling op.	xxxxxx		x		x	x	x		xx
Derrick		xx			xx		xxxx		xxxx
Driller						xx		xxxx	xxxxxx
Well service									
MWD	x	x	x	xxxx					xxxxx

[a] First scenario for drill floor worker; 4 hours in the shaker area
[b] Second scenario for drill floor worker; 6 hours in the shaker area

Estimated full-shift exposure (12 h)

According to Table 4.7 the job categories in the drilling crew might be assigned into three main exposure groups;

The estimated 12 hours exposures to oil mist and oil vapour were highest for the drill floor workers and the mud handling operators. The estimated exposure was medium for the derrick and the MWD/Mud-operators, and the lowest exposure was estimated for the driller. For all job categories the exposure decreases from the first to the second time period.

Table 4.7. Estimated time weighed average exposure over 12 h for the different job categories.

	OIL MIST (mg/m^3)		**OIL VAPOUR (mg/m^3)**	
	1985-1997	1998-2010	1985-1997	1998-2010
Drill floor worker[a]				
fixed&movable installations	0.4	0.2	15	7
fixed installations	0.3	0.2	13	6
movable installations	0.4	0.3	21	9
Drill floor worker[b]				
fixed&movable installations	0.5	0.3	20	9
fixed installations	0.4	0.2	17	8
movable installations	0.6	0.3	28	12
Mud handling operator				
fixed&movable installations	0.4	0.2	16	8
fixed installations	0.4	0.2	14	7
movable installations	0.5	0.3	23	11
Derrick				
fixed&movable installations	0.2	0.1	10	4
fixed installations	0.2	0.1	9	3
movable installations	0.3	0.2	13	4
Driller	0.06	0.03	3	1
MWD/Mud-operator				
fixed&movable installations	0.1	0.1	8	4
fixed installations	0.1	0.1	7	4
movable installations	0.2	0.1	11	5

Estimated exposures are somewhat higher on movable than on fixed installations (Table 4.7). We expect that the first analysis of the cancer cohort with respect to this type of exposure will be done on fixed and movable installations taken together. However, we also report the estimated exposures also when stratifying by type of installation.

Annual drilling days.
We sent a questionnaire to the operators to collect information on the average drilling days per year using oil based mud. We got a response from 10 drilling installations. From year 2000 onwards the average number of days of drilling with oil-based mud was 119 days (range 75-250 days). For the period 1985-2000 only one installation responded (100 days per year).

Limitations

Although the estimated exposure levels are based on about 750 personal measurements from 34 drilling installations, there are still several uncertainties in the estimated concentrations. The number of measurements was relatively low before year 2000, particularly in some of the mud handling areas. Rough assumptions on exposure levels were made in some areas where the number of measurements was particularly low.
Even though exposures may vary between rigs, we have only stratified by type of installation being fixed or movable, and did not attempt to estimate exposure at a rig-specific level.

Sampling has traditionally been aimed at covering the expected worst-case conditions indicated by process parameters such as mud temperature and section of the well (Steinsvåg et al., 2007). Thus, the exposure data presented might be higher than would be expected from representative sampling. However, the drilling conditions might have changed before the occupational hygienist arrived on the platform. This might have led to measurements during conditions deviating from the planned worst-case strategy (Steinsvåg et al., 2006), thus reflecting conditions closer to representative sampling.

The exposure measurements were mainly taken to assess exposure levels in the different mud handling areas, and not to systematically assess full-shift exposure for workers. We have made assumptions on the average number of hours the respective job categories have spent in the different areas. However, estimated hours spent in different mud handling areas vary both between rigs and from day to day. We did not have enough information to differentiate between time periods in number of hours spent in different areas.

We have chosen not to estimate the decreasing trend in exposure in more detail than by the time-dependent substitution of base oil. Our previous studies have shown decreasing trends also within the time period 1998-2004 (Steinsvåg et al., 2005; Bråtveit et al., 2009). A more detailed analysis (by year) would have required considerably more resources to bring into the cohort analysis.

The yearly exposure to oil mist and vapour is also dependent on the number of drilling days with oil based mud. We have not taken this factor into account when estimating the exposure levels.

The difference in aromatic hydrocarbon content between the two generations of base oils used after 1985 should be taken into account when analysing the cohort. We have not weighed the exposure in the two time periods according to type of base oils.

Diesel was used from the last part of the 70-ties up to about 1985 on some installations. However, we have not been able to find information about how much/how frequently diesel was used as base oil in this period. The data we present for diesel exposure is based on only three reports from 1979, 1982 and 1983.

In a previous study of exposure during offshore drilling we found indications that oil mist concentration was underestimated, presumably due to evaporation from the sampling filter (Bråtveit et al., 2009). This underestimation is probably even more pronounced for the newer generation of more volatile, low viscosity base oils than for base oils with normal viscosity. There are problems with the sampling methods for oil mist/vapour, both inter-laboratory differences and possible bias in the mist assessment (Galea et al., 2010). The oil mist sampling and analytical method has been developed for relatively non-volatile machine oils. Although it is desirable to separate aerosol and vapour components of the oil mist in air, it is likely that when relatively volatile oils are sampled, the aerosol component is typically substantially underestimated because of vapour losses from filter (Galea et al., 2010). Thus, the estimated oil mist exposure levels in the present study are probably underestimated. The extent of underestimation is, however, uncertain.

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