ORIGINAL ARTICLE

Exposure to carcinogens for defined job categories in Norway's offshore petroleum industry, 1970 to 2005

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Objectives: To identify and describe the exposure to selected known and suspected carcinogenic agents, mixtures and exposure circumstances for defined job categories in Norway's offshore petroleum industry from 1970 to 2005, in order to provide exposure information for a planned cohort study on cancer.

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 ($n = 329$). On the basis of a previous questionnaire administered to present and former offshore employees in 1998, 27 job categories were defined.

Results: This study indicated possible exposure to 18 known and suspected carcinogenic agents, mixtures or exposure circumstances. 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 mean exposure level of 367 personal samples of benzene was 0.037 ppm (range: less than the limit of detection to 2.6 ppm). Asbestos fibres were detected (0.03 fibres/cm³) 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/m³. Descriptions of products containing known and suspected carcinogens, exposure sources and processes were extracted from the collected documentation and the interviews of key personnel.

Conclusions: This study described exposure to 18 known and suspected carcinogenic agents, mixtures and exposure circumstances for 27 job categories in Norway's offshore petroleum industry. For a planned cohort study on cancer, quantitative estimates of exposure to benzene, and mineral oil mist and vapour might be developed. For the other agents, information in the present study can be used for further assessment of exposure, for instance, by expert judgement. More systematic exposure surveillance is needed in this industry. For future studies, new monitoring programmes need to be implemented.

In December 1969, a significant oil field was discovered on Norway's continental shelf. In the subsequent years, several 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.¹

About 6000 people are employed full time in offshore production and drilling operations at 48 oil and gas fields in Norway.² In addition, several thousand workers have short-term engagements every year in maintaining, modifying and demolishing offshore installations.

Offshore oil and gas production platforms usually consist of three main sections: the drilling area, the process area and living accommodation. 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 the deck crew, health personnel and helicopter assistants.

In response to the increasing concern about cancer in Norway's oil industry, Lærum *et al*³ 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 a continuous control of hazardous substances are needed. The concern was pursued by Eide,⁴ who questioned the possible long-term effects of exposure to low-aromatic oil-based drilling fluids. The call for more research was further strengthened by the recent media focus on chemical exposures offshore and by a subsequent report from Norway's Ministry of Labour and Social Inclusion on chemical exposures on Norway's continental shelf in December 2005.⁵

Published results from systematic sampling of hazardous agents on offshore installations are scarce. A few studies have

reported data on benzene exposure in the process area,^{6–8} dust levels in a shale shaker room,⁹ and exposure to oil mist and oil vapour when drilling with oil-based muds.^{10–12} Gardner¹³ reviewed various types of occupational exposures on offshore oil and gas installations, and other reports^{14–16} have provided overviews of chemicals used offshore.

In 1998, the Cancer Registry of Norway (CRN) established a Norwegian offshore cohort comprising 27 986 former and present offshore workers who completed a questionnaire on job history, lifestyle and demographics.¹⁷ Cancer development in the Norwegian offshore 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 for 2010.

The objective of this study was to identify and describe the exposure to selected known and suspected carcinogenic agents, mixtures and exposure circumstances for defined job categories in Norway's offshore petroleum industry from 1970 to 2005, in order to provide exposure information for a planned cohort study on cancer.

MATERIALS AND METHODS

Organisation

A University of Bergen research group comprising three researchers, two secretaries and a research fellow carried out the project between December 2002 and November 2005. An

Abbreviations: CRN, Cancer Registry of Norway; IARC, International Agency of Research on Cancer; NDT, non-destructive testing; RCF, refractory ceramic fibre

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, Stavanger.

Preparation for the data collection

In the CRN questionnaire issued in 1998, the 27 986 replying offshore workers stated their entire work history including job titles, the respective installation and work section, and their leisure time activities.¹⁷ The inclusion criteria for that cohort were they had to have a Norwegian personal identification number and had to have worked full time or part time on an offshore oil or gas producing or drilling installation for at least 20 days within a 4-month period. It is estimated that about 60% of these offshore workers answered the study. Printouts of every possible version of the first and last job titles yielded lists of thousands of occupations. Before our study, a researcher from the CRN 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 International Agency of Research on Cancer (IARC),¹⁸ the report of Strand and Andersen,¹⁷ and from published literature on chemical exposure offshore (see the Introduction).

This study defined known carcinogens as agents, mixtures or occupational circumstances classified in IARC groups 1, 2A and 2B. Suspected carcinogens were selected from IARC group 3.¹⁸

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.¹⁷ 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 the companies to let a university research group of 2–4 people visit the company to carry out interviews and to collect data on radiation and chemical exposures, 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 similarly visited. Everyone contacted accepted the visits and interviews.

The companies selected key informants, generally long-term workers, representing different job categories, who were interviewed about 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 CRN questionnaire and processes with associated possible exposure to carcinogens formed the checklists used in the interviews of the key

personnel. The informants were also given the opportunity to outline issues of probable significance to the project.

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

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, 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.

Extraction of key information and selection of carcinogens to present in this study

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 collected data. Based on the available information, the 18 carcinogenic agents, mixtures or exposure situations assumed to be of greatest importance for personal exposure were selected for presentation in this study: benzene, mineral oil–inhalation exposure, mineral oil–skin exposure, crystalline silica, asbestos, refractory ceramic fibres (RCFs), 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 as skin exposure might occur even when exposure through inhalation is neglectable.

Job categories

Based on the information given by the key informants and the collected data, the 294 job titles from the offshore cohort were grouped by the researchers into 27 job categories in five work sections according to similarities in job tasks and expected type of carcinogen exposure.

Statistics

We analysed data by descriptive statistics using SPSS V.13.0.

RESULTS

Job categories

Table 1 shows the 27 job categories grouped by work section.

Carcinogens

Monitoring reports were found for seven agents (table 2).

Table 3 links the selected 18 carcinogenic agents, mixtures or exposure circumstances with their associated products, exposure sources or situations, and possibly exposed job categories.

Benzene

Benzene is a natural component in the oil and gas produced from the reservoirs. 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. Benzene is a light component, present in all the

Table 1 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	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
Non-destructive testing inspector	Non-destructive 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

four separation streams, with the highest concentration in condensate. The separation and transport take place in closed processing equipment, but the workers are exposed through work on and inside equipment in the process areas. The benzene results were grouped by job categories. The deck category had the highest exposure level (geometric mean = 0.010 ppm; table 2). Although the average exposure to benzene was rather low for all categories compared with the recommended Norwegian limit value of 0.6 ppm,²⁰ the ranges for the process (less than the limit of detection to 0.97 ppm) and deck (less than the limit of detection to 2.6 ppm) categories indicate that at times some workers experience relatively high levels during a 12-h work shift. Only 55 of 367 samples had a description of the tasks performed during sampling. For the process category, the work tasks included; sampling of oil and produced water; well start-up; bleeding off pressure; gravity check; laboratory work; and work on waste oil tank, sand trap and drain tank. The laboratory and mechanic categories collected samples, and mechanics did in addition work on valves. The deck and electrician categories are probably exposed when maintaining and repairing processing equipment, but the sampling reports did not describe any tasks.

Water-based drilling mud was predominantly used in Norway until 1979, when diesel mud was also used on some installations for drilling of more complicated parts of oil wells. The mud-handling areas were originally designed for water-based mud, with open flow lines and mud pits. Heated mud lead to the evaporation of diesel vapour, and benzene was

reported in one of four reports from sampling of diesel vapour. It was not stated or discussed whether the source of benzene was the drilling mud or the diesel equipment that was probably used. Although most mud-handling systems nowadays are enclosed, some older installations might still have partly open flow lines.

Mineral oil

In the drilling sections, exposure measurements have focused on the oil mist and oil vapour caused by mineral oil-based drilling mud, which was introduced in 1985 to replace the use of diesel mud in the deeper parts of wells. Personal exposure to these contaminants is described elsewhere,¹² but the sampling data are briefly stated in table 2 in order to give an overview.

Oil mist and oil vapour from mineral oil are also present in other parts of offshore installations, such as turbine or generator rooms, but the mean levels are rather low (table 2). However, the range of exposure indicates that high levels might occur in these areas at times.

Before automatic pipe-handling systems were installed on the drill floor (1985–95), the workers could literally be soaked in mud during drilling operations. All operators handling the mud systems still have some skin exposure to mud (table 3).

Increased automation has led to more hydraulic systems. In hydraulic systems, turbines and other machinery, mineral oil circulates in closed systems, but leakage and maintenance and repair may lead to skin exposure. Use of mineral oil for lubrication of machines is also associated with skin exposure (table 3).

Crystalline silica

When mixing drilling mud, the derrick employee is exposed to dust from various dry additives such as barite and bentonite, which contain crystalline silica. During the 1990s, the dust concentrations when mixing mud probably declined due to installation of automatic sack-cutting units. Table 2, however, indicates relatively high dust exposure in the mud mixing area even when the process was automated.

The well service group was probably also exposed to crystalline silica during cementing, and the painters during sandblasting, but no measurements were found. From 1970 to 1979, the sand for sandblasting contained 2–5% silica. In 1979, a limit of maximum of 1% was set. Because sandblasting was replaced by water jetting as the preferred technique for removing paint and rust in about 1995, painters probably had minor silica exposure after 1995. According to the informants, sandblasting is currently carried out inside some tanks and on the platform jacket.

Asbestos

Asbestos was used as a drilling mud additive until it was prohibited in 1980. Sacks containing asbestos were cut with a knife and fed manually into a hopper, most likely by the derrick employee.

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 (table 2). On some installations, the design of the drilling area might have led to migration of fibres from the brake bands into the drilling cabin or down one floor to the shale shaker area. Use of asbestos was generally banned in Norway in late 1984.

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. Later removal of gaskets and insulation probably caused exposure to asbestos, especially for the insulators, and also for the process category and the other categories comprising the

Table 2 Measured data from various Norwegian offshore installations on benzene (ppm), mineral oil mist and oil vapour (mg/m³), dust (mg/m³), asbestos (fibres/cm³), refractory ceramic fibres (fibres/cm³), tetrachloroethylene (mg/m³) and formaldehyde (mg/m³)

Agent	Sample type	Comment	n (b)	AM (SD)	GM (GSD)	Range	Description
Benzene	P	Deck	29 (10)	0.17 (0.51)	0.010 (14)	<LOD-2.6	Sampling in process and drilling sections of 12 installations representing four oil companies in 1994 (n = 123), 1995 (n = 14), 1996 (n = 9), 2002 (n = 48) and 2003 (n = 173). Sampling method: 3M dosimeter 3500 (n = 344, 23 samples were missing information), 12 h sampling time. Analysis: GC. Measurements below detection limit were set to LOD/ $\sqrt{2}$ ¹⁹
	P	Process	204 (101)	0.036 (0.097)	0.008 (5.3)	<LOD-0.97	
	P	Laboratory	40 (13)	0.012 (0.019)	0.006 (3.7)	<LOD-0.11	
	P	Mechanic	78 (37)	0.006 (0.011)	0.002 (4.5)	<LOD-0.08	
	P	Electrician	16 (4)	0.015 (0.017)	0.006 (5.9)	<LOD-0.05	
		Total	367 (165)	0.037 (0.099)	0.007 (5.7)	<LOD-2.6	
Mineral oil	S/P	Oil mist, turbine rooms	24	0.21 (0.29)	0.095 (4.2)	0.010-1.3	Turbine rooms at three installations (1992-3 and 2002). Two personal samples, the rest are stationary. Sampling method: filter/coal tar tube in series. Analysis: FTIR/GC
	S/P	Oil vapour, turbine rooms	51 (13)	4.7 (20)	0.41 (5.3)	<LOD-120	
	P*	Oil mist, low-aromatic mud	90 (5)	4.3 (9.8)	0.65 (6.3)	<LOD-48	
	P*	Oil mist, non-aromatic mud	228 (5)	0.54 (0.68)	0.39 (2.1)	<LOD-8.0	
	P*	Oil vapour, low-aromatic mud	94 (2)	36 (33)	21 (4.0)	<LOD-164	
	P*	Oil vapour, non-aromatic mud	233	16 (17)	9.8 (3.0)	0.30-122	Previously published ¹² personal samples of exposure to oil mist and oil vapour in mud-handling areas on Norwegian offshore drilling facilities. The low-aromatic mineral oil samples have been taken in 1989-97 and in 2000, while the non-aromatic mineral oil samples were in 1998-2004. Sampling method: Filter/coal tar tube in series, 2 h sampling time. Analysis: FTIR/GC. Measurements below detection limit: LOD/ $\sqrt{2}$ ¹⁹
Dust	S	Total dust	19	1.6 (2.3)	0.74 (3.2)	0.18-9.6	Dust sampling when mixing dry drilling mud chemicals at the mud mixing areas of four offshore installations with a sack-cutting machine (1999, 2002 and 2004). Sampling method: dust track (direct measurements) (n = 5) or personal air monitoring pumps with 0.8 µm cellulose acetate filter (n = 23). Analysis: gravimetric
	P	Total dust	5	12 (9.4)	8.9 (2.4)	2.8-27	
	P	Respirable dust	4	0.20 (0.091)	0.18 (1.6)	0.10-0.32	
Asbestos	S	Above brake drum	U	0.03			Stationary samples of asbestos fibres on the drilling floor at one installation in 1988. Exposure caused by asbestos-containing brake bands. Analysis by electron microscope proved that the samples contained asbestos fibres. The composition of the brake lining was: 41% asbestos, 28% rayon and cotton, 21% binding agent, 9% brass chip
	S	Other samples, brake dust	U	0.02			
	S	Clearing	23 (16)	1.8 × 10 ⁻⁴ (1.9 × 10 ⁻⁴)	1.3 × 10 ⁻⁴ (2.11)	<LOD-8.0 × 10 ⁻⁴	
RCFs	P	Pipe	6	0.86 (0.25)	0.82 (1.4)	0.43-1.2	Clearing of asbestos on an installation in 1995. Sampling method: personal air monitoring pumps with 0.8 µm cellulose acetate filter. Analysis: manual fibre counts. Measurements below detection limit: LOD/ $\sqrt{2}$ ¹⁹
	P	Gas cooler	4	0.18 (0.15)	0.12 (3.0)	0.03-0.38	
	P	Removal	4	0.093 (0.045)	0.08 (2.0)	0.003-0.12	
Formaldehyde	P		6	0.13 (0.09)	0.10 (3.8)	0.06-0.29	A sampling report from an installation in 1991 reports personal exposure levels when working with a RCFs product. Firstly, installing pipe insulation; secondly, installing insulation on a gas cooler's cooling tube and, thirdly, removal of insulation. Sampling method: personal air monitoring pumps with filter. Analysis: manually fibre count
	S		10	0.21 (0.15)	0.25 (0.15)	0.05-0.53	
Tetrachloroethylene	P	Long term (360 min)	13	6.7 (1.9)	6.9 (1.3)	4.2-11	Merged results from two reports. One from 1999 where sampling was done when filling biocide during water injection on an installation and a second report sampling work at a biocide unit on another installation (2000). Sampling method: GMD Systems dosimeters. Analysis: HPLC
	P	Short term (10 min)	4	69 (63)	50 (2.1)	28-177	

AM, arithmetic mean; b, number of measurements below limit of detection; FTIR, Fourier transform infrared spectroscopy; GC, gas chromatography; GM, geometric mean; GSD, geometric standard deviation; HPLC, high-performance liquid chromatography; LOD, limit of detection; n, number of measurements; P, personal samples; RCFs, refractory ceramic fibres; S, stationary samples; SD, standard deviation; U, unknown number of measurements.

*Previously published results.¹²

maintenance, inspection, deck and construction sections (table 3).

Refractory ceramic fibres

RCFs replaced asbestos as an insulation material in the mid-1980s. Insulators have probably been exposed when installing and removing RCF (table 3); measurement data support this (table 2).

Formaldehyde

Formaldehyde has mainly been used as a biocide in the oil processing systems, and samples taken during water injection and work carried out at a biocide unit range from 0.06 to

0.29 mg/m³ for personal samples and from 0.05 to 0.53 mg/m³ for stationary samples (table 2). Maintaining chemical stores, opening pumps, calibrating injection pumps, filling biocide tanks from transport tanks, and injecting biocide into water injection systems may have caused exposure to the process, deck, instrument, mechanic and electrician categories (table 3). Formaldehyde use probably declined during the time period studied. Formaldehyde seems to have been replaced by other biocides, and gradually phased out before 2002.

Chlorinated hydrocarbons

As indicated by the results from sampling of tetrachloroethylene at a dry-cleaning unit of a drilling rig in 1990, the catering

Table 3 Carcinogenic agents, mixtures and exposure circumstances with the respective IARC group linked to products, exposure sources or situations and job categories where this exposure might occur in Norway's offshore petroleum industry, 1970 to 2005

Carcinogenic agent, mixture or exposure circumstance	IARC group	Products	Exposure sources or situations	Job categories where this exposure might occur
Benzene	1	Component in the petroleum stream Laboratory chemical Diesel-based drilling mud*	Work in process area Work inside crude oil tanks and separators Diesel-based drilling mud*	Process, laboratory, electrician, instrument, piping, welder, mechanic, insulator, scaffold, industrial cleaner Industrial cleaner, process, deck, scaffold, welder Drill floor, mud, derrick, driller Drill floor, mud, derrick Turbine/hydraulics, machinist, process
Mineral oil-inhalation exposure	3	Mineral oil-based drilling mud Hydraulic oils Turbine oils Cylinder oils Lubrication oils	Drilling with mineral oil-based mud Turbine/machine rooms	Drill floor, mud Turbine/hydraulics, mechanic, machinist, process, deck
Mineral oil-skin exposure	3	Mineral oil-based drilling mud Hydraulic oils Turbine oils Cylinder oils Lubrication oils	Drilling with mineral oil-based mud Hydraulic, turbine, cylinder and lubrication oils	Drill floor, mud Turbine/hydraulics, mechanic, machinist, process, deck
Crystalline silica	1	Barite Bentonite Viscosifier in water-based muds Filter material Cement Cement chemicals Sand Various construction materials Fire-extinguisher Fire-retarding paints	Dust in mud-mixing area Cementing Sandblasting Silica in paint products	Derrick Well service Painter, sheet metal Painter
Asbestos	1	Drilling mud additive Brake bands Passive fire protection Gaskets Insulation	Drilling mud additive Brake bands in drilling draw works Fire protection Removal of gaskets and insulation	Drilling and well maintenance section As above Painter, electrician, piping Insulator, process, job categories comprising the maintenance, inspection, deck and construction section Insulator†
RCFs	2B	Insulation	Dust when installing or removing insulation	Insulator†
Formaldehyde	1	Biocide Disinfection agent Developer Corrosion inhibitor for hydrochloric and hydrofluoric acids Paints	Operation and maintenance of biocide tank/unit	Process, deck, instrument, mechanic, electrician
Tetrachloroethylene	2A	Degreasing spray Laboratory chemical Glue Moist stabiliser	Dry-cleaning unit Degreaser	Catering Electrician, instrument, turbine/hydraulics, process, laboratory, machinist, deck, catering
Trichloroethylene	2A	Metal degreaser Laboratory chemical Glue Surface products	Metal degreasing: spray Washing/degreasing of machine parts	As above Mechanic, drill floor, mud, process, industrial cleaner, turbine/hydraulics, machinist, deck
Welding	2B		Fume of heavy metals such as nickel and chromium [VI] Welding and grinding stainless steel	Welder Welder, sheet metal, painter†
Nickel compounds, selected Chromium [VI]	1/2B			
	1	Stainless steel Lead chromate pigments in paint (also zinc chromate) Laboratory chemicals Drilling mud additive: chrome lignite	Welding on stainless steel Mechanical work on stainless steel (turning, grinding, etc) Painting with chromate-containing paints Removal of surfaces containing chromate pigments	Welder† Welder, mechanic, sheet metal Painter, deck Sheet metal, painter†
Lead and inorganic lead	2A	Lead chromate pigment in paints Other paint products Leaded grease/dope	Painting with lead chromate paint Removal of lead chromate coating Leaded thread compound	Painter, deck Sheet metal, painter† Drill floor, deck
Crude oil-skin exposure	3	Crude oil	Sampling and laboratory analysis Operation and maintenance in process area Cleaning inside tanks and production equipment, particularly during shut-down of process area Diesel machines Diesel generators Diesel fork lift trucks in mud-mixing area	Process, laboratory Process, electrician, instrument, piping, welding, mechanic, insulator, deck Industrial cleaner, scaffold, welder Deck, well service† Deck Derrick, deck, drill floor, mud
Diesel engine exhaust	2A		Surface treatment Use of anti-friction coating spray	Painter Mechanic
Dichloromethane	2B	Surface products Glue spray Paint and lack remover Laboratory chemical Antifriction coating spray		

Table 3 Continued

Carcinogenic agent, mixture or exposure circumstance	IARC group	Products	Exposure sources or situations	Job categories where this exposure might occur
Ionising radiation	1		Non-destructive testing Well logging Low-radioactive sediments	Non-destructive testing Measure-while-drilling and logger, driller Process, industrial cleaner, deck Painter, deck, machinist, mechanic
Occupational exposure as a painter	1	Complex mix of hazardous chemicals in paints and surface treatments	Painting and other surface treatment	

*This product/source is uncertain; please see text in the section Results.

†Border zone personnel: other process and maintenance categories might also be exposed.

category might have been exposed to chlorinated hydrocarbons. However, few installations had dry-cleaning units.

Chlorinated hydrocarbons in sprays and fluids for metal degreasing were used extensively until the early 1990s (table 3).

Other carcinogens

Stainless steel is a preferred construction material on offshore installations because of its anticorrosive quality. Welding, turning and grinding stainless steel may lead to exposure to airborne components such as nickel and chromium (VI). The fire hazard associated with production of petroleum products implies restriction of hot work to a minimum, especially in the production areas, and welding is normally enclosed within welding tents. Every 2–3 years, the process area is shut down for 14 days and processing equipment is opened and cleaned, before extensive maintenance work, including welding, is carried out.

Originally, the top paint layers on offshore steel constructions contained chromate pigments, especially lead. According to the interviews, lead chromate pigments in paints were phased out in 1984–9, but search of a product database indicated that such paints are still in use, although probably to a lesser extent. Painted surfaces offshore may contain up to 10% lead. Paint removal by sandblasting, water jetting, grinding or other techniques might have caused high exposure to lead, in addition to chromium (VI), but no monitoring reports were obtained for such processes.

Leaded grease has been extensively used by drill floor workers to grease drilling and casing pipe threads. This operation caused skin exposure, and, owing to health concerns, the leaded dope was substituted in 1995 by less hazardous petroleum-based grease without heavy metals.

Skin may be exposed to crude oil when oil samples are collected and analysed, which is usually carried out by the employees in the process or the laboratory categories, and during operation and maintenance work in process areas. The highest exposure probably occurs when cleaning the inside of tanks and production equipment, particularly during shut-downs. Specialised industrial cleaners often travel from one shut-down to another during the summer season.

Diesel-driven machines and generators have their exhaust outlet to the open air, probably not causing significant exposure to diesel exhaust for the deck category and other outdoor personnel on platforms. Diesel forklift trucks have been used indoors in the sack rooms of drilling installations, and might have caused relatively high exposure to diesel exhaust for the derrick and deck categories. The drill floor and mud categories may have shorter stays in this area. Electric forklift trucks have gradually replaced diesel trucks, and to our knowledge the last installation replaced these trucks in 2001.

From about 1980 to about 1994, painters applied dichloromethane to epoxy-based passive fire protection on steel to smooth the surface. The mechanic category probably used

anti-friction coating sprays that contained 30–60% dichloromethane on metal mating surfaces for lubrication and anticorrosive purposes.

The increasing number of platforms during the first three decades of Norway's offshore petroleum industry has led to increasing non-destructive testing (NDT) of welding seams using x rays and gamma sources. Furthermore, well logging by radioactive isotopes carried out by measure-while-drilling operators has increased. Sediments emitting low-level ionising (α , β and γ) radiation from minor amounts of radium sulphate inside processing equipment²¹ may imply a risk of inhaling radioactive dust for the process, cleaner and deck categories. Measure-while-drilling or logger operators, NDT operators and drillers wear thermoluminescence dosimeters that are analysed after 1–2 months of use. The annual mean dose for all the NDT operators in Norway ($n = 766$) in 2005 was 0.14 mSv, whereas for the loggers ($n = 17$) no radiation was detected.²² The recommended annual limit value is 1 mSv.²²

Painters have had a complex mixture of carcinogens in their work environment, such as asbestos in passive fire protection, crystalline silica when sandblasting, lead chromate, trichloroethylene, dichloromethane and formaldehyde.

DISCUSSION

To support a planned cohort study on cancer, this study presents possible exposure to 18 known and suspected carcinogenic agents, mixtures or exposure circumstances for 27 defined job categories in Norway's offshore petroleum industry from 1970 to 2005.

Processes and tasks involving carcinogens were identified through interviews and collected documentation. Despite the recommendations of Lærum *et al.*,³ little effort seems to have been made in systematically sampling toxic agents, and few exposure measurements had apparently been carried out. The research group obtained access to sampling data for only seven relevant agents, indicating a more ad hoc sampling regime.

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. In epidemiological studies, these data can be used for development of quantitative estimates of exposure for specific job categories. The other sampling data are relatively fragmentary, and should only be taken as indications of exposure levels for specific processes when the contaminant is present.

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 epidemiological studies specificity is reduced when unexposed job titles are included in broader groups of exposed workers.

The benzene samples in this study showed low geometric mean levels, in accordance with published data from this industry.⁶⁻⁸ On the other hand, the range for the process and deck categories indicates that some workers are at times exposed to benzene levels exceeding Norway's occupational exposure limit. Owing 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.¹² On the basis of exposure data and job histories, individual exposure to oil mist and oil vapour might be quantitatively estimated in the planned cohort study. In another study, personal exposure to total hydrocarbon compounds has been reported to be up to 450 mg/m³ during work at the shale shakers when drilling with oil-based mud.¹⁰ At an installation with a higher level of enclosure of the mud systems, James *et al.*¹¹ reported the results from two personal samples of workers comprising the mud category operating in the shale shaker room to be 0.06 and 0.40 mg/m³ for oil mist and 3.2 and 35.0 mg/m³ for oil vapour, which were in accordance with the findings presented in Steinsvåg *et al.*¹²

Within Norway's offshore industry, the most striking exposure situation involving asbestos was when asbestos was a constituent in dry powder used as a drilling mud additive before 1980. Esmen and Corn²³ measured high levels of asbestos (range 0.39–1.9 fibres/cm³) during analogous processes involving cutting sacks and pouring the asbestos-containing content into a container.

Spencer *et al.*²⁴ found asbestos fibre release from the brake pads of overhead industrial cranes in the range <0.005–0.011 fibres/cm³, which is lower than the results presented in this study on asbestos fibres from brakes in drilling draw works.

Two studies^{25, 26} report migration of fibres within the same range as we found when RCFs are installed or removed by insulators, whereas van den Bergen *et al.*²⁷ report higher levels (range 9–50 fibres/cm³).

Although the association between exposure to crude oil or mineral oil and the development of cancer has not yet been established,^{28, 29} these components were included due to the expected high prevalence of exposure.

In the period 1990–2000, all drilling facilities in Norwegian waters installed automatic sack-cutting machines for dry additives, which has 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 have not been published on platforms in Norway. Hansen *et al.*⁹ 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/m³, with barium and silicon being the two most abundant elements.

There is uncertainty regarding the use and content of metal degreasers containing chlorinated hydrocarbons. Some companies reported substituting trichloroethylene products as early as 1985. The informants seem to have applied the abbreviation TRI to both products containing trichloroethylene and products containing 1,1,1-trichloroethane, the latter being in IARC group 3. The indistinguishability of the two solvents might lead to incorrect conclusions in the interpretation of the association between exposure and cancer development in the planned cohort study.

The petroleum industry has improved in replacing and reducing the number of products containing carcinogens from the 1980s to the present. One example is leaded grease used on drilling and casing pipe threads. The number of such products

has 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 skin uptake might be expected from leaded grease.^{30, 31}

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. This method is often used in retrospective exposure assessment studies where the industry locations are still present.³² Instead, the research group had to rely on close contact with key people in the industry.

A drawback in this study was that the informants were often assisted by a person representing the leadership of the company, which might sometimes have led the interviewees to hold back information. Furthermore, the companies themselves selected participants for these meetings. However, an independent set of interviewees was difficult to achieve due both to logistic constraints and to the need for a close relationship with and overview of 20 companies. The interviews were semistructured, free-flowing, with a basis in checklists of job titles and carcinogens. Stewart *et al.*³² 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 before interviewing. Tielemans *et al.*³³ suggest that this strategy might provide a more complete understanding of occupational exposure than self-administered job-specific questionnaires.

During the data collection, many companies claimed that retrospective data were filed in complicated archive systems or incompatible computer systems. This might have influenced

Main messages

- The job categories with respective exposure to carcinogens are identified in Norway's offshore petroleum industry, 1970 to 2005.
- Exposure data on benzene, mineral oil mist and oil vapour, respirable and total dust, asbestos fibres, refractory ceramic fibres, formaldehyde and tetrachloroethylene are presented.
- Exposure sources and situations are described.
- The lack of measured data for most of the described exposure sources and situations means that this industry needs to implement a more systematic strategy for exposure assessments, including quantitative measurements of carcinogens.
- For a planned cohort study on cancer, a quantitative estimation of exposure to benzene, and mineral oil mist and vapour might be applied. For the other agents, the information in this study might be used for further exposure assessment, for instance, by expert judgement.

Policy implication

- The scarce documentation on exposure to carcinogens in Norway's offshore petroleum industry means that more systematic surveillance of exposure to carcinogens is needed in order to comply with Norwegian regulations and to allow more rigorous future studies in this industry.

the results presented in tables 2 and 3. 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 sufficient resources to do complete archive searches. Although we expect not to have a complete set of existing documentation from the industry, the provided documents on carcinogens are considered representative for the industry.

The high number of processes and tasks that involve carcinogens in Norway's offshore petroleum industry and the scarcity of measured data described in this study make quantifying exposure unfeasible for most offshore exposure sources and situations. For a planned cohort study on cancer, a quantitative estimation of exposure to benzene, and mineral oil mist and vapour might be applied. For the other agents, the information in this study might be used for further exposure assessment, for instance, by expert judgement.

CONCLUSION

To provide exposure information for a planned cohort study on cancer in Norway's offshore petroleum industry, this study identified and described exposure to 18 known and suspected carcinogenic agents, mixtures or exposure circumstances for 27 defined job categories in 1970 to 2005 after interviewing key offshore workers and extracting information from collected documents. The following carcinogens were presented: benzene; mineral oil—inhalation exposure; mineral oil—skin exposure; crystalline silica; asbestos; RCFs; 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 the planned cohort study, a quantitative estimation of exposure to benzene, and mineral oil mist and vapour might be applied. For the other agents, the information in this study might be used for further exposure assessment, for instance, by expert judgement. A more systematic exposure surveillance is needed in this industry. For future studies, new monitoring programmes need to be implemented.

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