Article IV

Expert assessment of exposure to carcinogens in Norway's offshore petroleum industry

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Objectives: This study presents and evaluates an expert group's assessment of exposure to carcinogens for defined job categories in Norway's offshore petroleum industry, 1970-2005, to provide exposure information for a planned cohort study on cancer.

Methods: Three university and five industry experts in occupational hygiene individually assessed the likelihood of exposure to 1836 combinations of carcinogens (n = 17), job categories (n = 27) and time periods (n = 4). In subsequent plenary discussions, the experts agreed on exposed combinations. Agreement between the individual and the panel assessments was calculated by Cohen's kappa index. Using the panel assessment as reference, sensitivity and specificity were estimated.

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

Conclusion: The resulting 265 of 1836 possible exposure combinations convened as "exposed" by expert assessment is presented in this study. The experts' individual ratings highly agreed with the succeeding panel assessment. The university experts and the industry experts' assessments had no apparent differences. Further validation of the exposure assessment is suggested, such as by new sampling data or observational studies.

INTRODUCTION

Several countries produce oil and gas offshore; among others, Canada, the United States, Venezuela, Brazil, Norway, the United Kingdom, Nigeria, Angola, Azerbaijan, Iran, China and Australia (The International Association of Oil & Gas Producers, 2006).

With the discovery of the oil field Ekofisk in 1969, Norway started to exploit oil and gas offshore, and today 50 oil and gas fields in Norway are being operated (Ministry of Petroleum and Energy, 2005). In 2004, 5721 people were employed full time in offshore production and drilling operations in Norway (Statistics Norway, 2006). In addition, several thousand workers have short-term assignments every year in maintaining, modifying and demolishing offshore installations.

Offshore oil and gas production platforms usually have three main sections: the drilling area, the process area and living accommodations, operated 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 1998 the Cancer Registry of Norway established a Norwegian offshore cohort including 27,986 former and present offshore workers who completed a questionnaire on job history, lifestyle and demographics (Strand and Andersen, 2001). The development of cancer in this cohort will be analyzed in the years to come.

To support the planned cohort study with exposure information, qualitative and quantitative data for known and suspected carcinogens were obtained through company visits comprising interviews of key workers and collection of written documentation, including sampling reports. This background information, published elsewhere (Steinsvåg et al., 2006a; Steinsvåg et al., 2006b), shows that the measured data are scarce, especially for the 1970s and 1980s. Visits to all offshore platforms were not feasible, thus strengthening the need for close cooperation with experts in occupational hygiene in the offshore petroleum industry in order to assess exposure.

Collecting reliable and valid retrospective exposure data is a challenge for many cohort studies and essentially all case–control studies. To compensate for this, several methods have been used to estimate historical exposure such as job-exposure matrices, self-reported exposure or expert judgment. Some studies combine elements from different methods (Teschke, 2003).

The use of expert assessment has generally increased in recent decades. Occupational hygienists, chemists, engineers and other professionals are regarded to have a better understanding of occupational exposure than workers. However, experts may not be familiar with the specific jobs, workplaces and industries to be considered (Teschke et al., 2002), and their background may influence how they assess exposure (Teschke et al., 1989). Hawkins & Evans (1989) and Post et al. (1991) showed that, without measurement data, experts tended to overestimate exposure.

In this study, an expert group comprising three university researchers and five occupational hygienists representing the offshore petroleum industry was established to individually assess the likelihood of exposure to 17 carcinogens for 27 defined job categories in four time periods, totally 1836 combinations. Subsequently, consensus on exposure was reached by plenary discussions between the eight raters. Prior to the assessments, the experts were provided with all available information (Steinsvåg et al., 2006a; Steinsvåg et al., 2006b).

This study aimed at presenting and evaluating an expert group's assessment of exposure to carcinogens for defined job categories in Norway's offshore petroleum industry from 1970 to 2005 to provide exposure information for a planned cohort study on cancer. The expert assessments were evaluated by calculating the agreement between the eight experts' individual ratings and the subsequent panel assessment and by illustrating the effects of potential misclassification.

MATERIAL AND METHODS

Background material

Background information on possible exposure in the offshore industry was obtained through company visits, including interviews of key personnel representing different job categories (*n* = 83) and collection of monitoring reports (*n* = 118) and other relevant documentation (*n* = 329). The visited companies comprised eight oil companies, five drilling companies, three chemical suppliers, three maintenance, modification and operation contractors and one catering service supplier. Monitoring reports were obtained for seven agents (benzene, mineral oil mist and oil vapour, dust, asbestos fibers, refractory ceramic fibers, formaldehyde and tetrachloroethylene). The results of personal exposure measurements of oil mist and oil vapour during drilling were extracted from 65 reports and published elsewhere (Steinsvåg et al., 2006a). Selection of known (classified in IARC group 1, 2A and 2B) and suspected (classified in IARC group 3) carcinogens (IARC, 2006) and job categories together with descriptions of products containing carcinogens, exposure sources and processes extracted from the collected documentation and interviews of key personnel is described in Steinsvåg et al. (2006b).

Expert assessment

The expert group comprised 3 occupational hygienists from the industry, 2 occupational hygienists from consulting companies affiliated with the offshore industry and 3 university researchers with experience from offshore projects. The industry experts were to represent experience from both drilling contractors and oil companies.

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

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

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

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

Time was divided into four periods (1970–1979, 1980–1989, 1990–1999 and 2000–2005), but the experts were given the opportunity to choose other time periods when specific milestones were known for technical changes or substitutions of chemicals. In cases (n=17) where a time period was divided the highest exposure rating was used in the statistical analysis.

During a two-day meeting, the eight experts first assessed individually the likelihood of exposure (unlikely, possible, probable) for totally 1836 combinations of carcinogens (n = 17), job categories (n = 27) and time periods (n = 4) based on the written background information for each carcinogen and their own competence and experience. For about every third carcinogen, the expert group had a brief discussion to eliminate any misunderstandings concerning how to complete the form.

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

Statistics

The data was analyzed using SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA).

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

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

Based on the total number of workers in the cancer cohort ($n = 27{,}986$) presented by Strand and Andersen (2001), it was roughly estimated that each of the 27 currently defined job categories had 1000 workers in the time period 1970–2005. For instance, the 9 job categories assessed as probably being exposed to benzene comprise 9000 workers, which constitute about 30% of the total cancer cohort.

RESULTS

Exposed combinations of carcinogen, time period and job category

Table 1 shows the combinations of carcinogens, time periods and job categories for which the experts' panel assessment indicated exposure. In IARC group 1, benzene had the highest number of exposed job categories ($n = 9$). For IARC groups 2A and 2B, chlorinated hydrocarbons had 14 and welding 3 exposed job categories. In IARC group 3, 10 job categories were classified as being exposed to inhalation of mineral oil. The job categories classified as exposed to the highest numbers of carcinogens were the mechanics ($n = 10$), derrick workers ($n = 6$) and process technicians ($n = 5$). Several job categories in this study were exposed to a mix of lung carcinogens (Siemiatycki et al., 2004; Rousseau et al., 2005): derrick (asbestos, silica and diesel engine exhaust), drill floor crew (asbestos and lead), mechanics (asbestos, chromium [VI] and nickel), painters (silica, chromium [VI], occupational exposure as a painter, nickel and lead) and sheet metal workers and welders (chromium [VI] and nickel).

Agreement between individual expert ratings and panel assessment

In the plenary discussions the expert group evaluated 63% of the possible combinations ($n = 1836$) of carcinogen, time period and job category. In this panel assessment, 265 (14%) of the total number of combinations were eventually scored as "exposed". For each combination of carcinogen, time period and job category, the number of raters ($n = 0$–8) who agreed on probable exposure during the individual rating was cross-tabled with the number of corresponding combinations during individual ratings and exposed combinations during panel assessment, respectively (Table 2). For increasing number of raters who individually agreed on exposure, the number of combinations scoring "exposed" in the panel assessment also increased.

The overall agreement between the individual and the consensus methods ($\kappa = 0.64$) was close to the corresponding kappa value for the university experts ($\kappa = 0.63$) and the industry raters ($\kappa = 0.65$), separately (Table 3). Raters 8 and 5 had the highest agreement with the panel ($\kappa = 0.74$), and rater 4 agreed least with the panel ($\kappa = 0.53$).

The sensitivity was moderate (0.55–0.86), and the specificity was high (0.91–0.97).

There were no apparent differences between the agreement measures of the university versus industry experts.

Effect of misclassification on the relative risk

Given the individual sensitivity and specificity of each rater, with panel assessment as reference, the hypothetical observed ranges of relative risk were assessed under varying assumptions of the true relative risk and prevalence of exposure (Table 4). Attenuation of relative risk due to individual misclassification will be greater for carcinogens with low prevalence of exposure, and more cases are needed when the prevalence of exposure is low (Table 4).

DISCUSSION

To provide exposure information for an ongoing cohort study on cancer, this study presents and evaluates an expert group's assessment of exposure to carcinogens for defined job categories in Norway's offshore petroleum industry, 1970-2005.

Benzene and mineral oil were among the agents with the highest number of exposed job categories. These carcinogens have the best potential for developing quantitative estimates for the planned cohort study (Steinsvåg et al., 2006b). Exposure to benzene and mineral oil during offshore work is also described elsewhere (Steinsvåg et al., 2006a; Glass et al., 2000; Health and Safety Executive, 2000a; Kirkeleit et al., 2006; Eide, 1990; Davidson et al., 1988; James et al., 2000). On the other hand, chlorinated hydrocarbons had the highest number of exposed job categories due to the use of metal degreasers, but very few measurements have been done (Steinsvåg et al, 2006b). Most job categories in this study are exposed to several carcinogens. This is in accordance with other descriptions of occupational exposure in the offshore petroleum industry (Cottle and Guidotti, 1990; Gardner, 2003; Health and Safety Executive, 2000b; Hudgins, 1991; Grieve, 1988; Elliott and Grieve, 1987). The process job category is assessed to be exposed to both benzene and formaldehyde and thus might be expected to have an increased risk of developing leukaemia (Siemiatycki et al., 2004; Rousseau et al., 2005) compared to an internal reference group or the general population. According to rough estimates in this study, 30% of the workers in the offshore cohort have been exposed to benzene. To exemplify the effect of misclassification in the individual assessments, assumptions of a "true" relative risk of 2.0 for benzene-exposed workers might reveal an observed relative risk in the range of 1.6–1.7. Given this attenuated relative risk, this study indicates that minimum 20–33 cases of leukaemia are needed to detect a significantly increased risk.

Although several job categories have been exposed to a mix of lung carcinogens (Siemiatycki et al., 2004; Rousseau et al., 2005), an increased risk of lung cancer in the offshore cohort will not necessarily be detected since all the members of the cohort have passed a pre-employment health examination, which may result in possible healthy hiring effects. A study in the petroleum industry in Australia found lung cancer incidence below unity (standardized incidence rate 0.69, 95% confidence interval 0.57–0.83) (Gun et al., 2006).

The agreement between the individual and the panel assessments in this study (κ = 0.53–0.74) is considered to be acceptably above chance. When van Tongeren *et al.* (2002) assessed the likelihood of exposure in three categories (unlikely (0), possible (1) and probable (2)), they found an overall kappa between three raters of 0.36 for 0 versus 1 or 2 and 0.31 for 0 or 1 versus 2. In the present study, the high specificity (0.91–0.97) and moderate sensitivity (0.55–0.86) indicate that the individual experts missed some exposure but did not produce many false-positive assessments by using panel assessment as reference. However, this is not unexpected due to the dependency between the individual and the panel assessments. Benke *et al.* (1997) found sensitivities and specificities within the ranges of 0.48–0.79 and 0.91 to 0.98, respectively, when exposure in 49 jobs was compared with exposure data.

Experts with the strongest opinion might be expected to have a greater impact on the plenary discussions than others. However, considerable agreement on probable exposure in the individual assessments was obviously needed to obtain a consensus on exposure. In addition, there was no systematic relationship between the work experience of the expert and the kappa value for the agreement between individual and panel assessments.

The common goal of retrospective exposure assessment is to develop the most accurate and unbiased estimates of exposure within the limitations of the resources. Quantitative approaches are useful for developing exposure–response relationships (Smith et al., 2005). This study identified processes and tasks involving carcinogens through interviews and collected documents, showing that little exposure measurement had apparently been performed for most carcinogens (Steinsvåg et al., 2006b). Due to lack of sampling data for most agents, expert assessment of the likelihood of exposure was considered the best option for classifying exposure. Case-by-case expert assessments in Dutch cancer cohort studies (van Loon et al., 1997; Zeegers et al., 2001; Boers et al., 2005) also used probability categories for assessing occupational exposure.

In this study, dichotomizing exposure categories by including "possible exposure" in the "unexposed" group might be considered a stringent exposure classification for the offshore cohort. However, such reclassification will presumably reduce the risk of assigning false-positive exposure.

The intention of the plenary discussions was to provide valid information of exposure to carcinogens for the offshore petroleum workers. Benke *et al.* (2001) used a panel of three industrial hygienists who independently assessed exposures but suggest that a group approach could have improved the classification of exposure. However, panel judgments are also likely to be subjected to misclassification, and the validity of the panel assessment is difficult to justify when sufficient sampling data or work practice descriptions are not extensive. If more detailed work descriptions had been obtained, the relatively broad job categories in this study could possibly have been refined; this might have reduced the risk of any misclassification of exposure.

Few sampling reports and other relevant documentation were found from the 1970s. Fifteen of the 83 people interviewed had offshore experience from this decade, but detailed knowledge on exposure to carcinogens was scarce. Hence, the assessments made for this decade might be less valid.

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

In this study the individual experts highly agreed with the panel. The results should be validated further by comparing objective measures such as new sampling data on specific work processes, observational studies of work practice or analogous studies performed in the offshore petroleum industry in other parts of the world.

CONCLUSION

This study presents and evaluates an expert group's assessment of exposure to carcinogens for defined job categories in Norway's offshore petroleum industry, 1970-2005, to provide exposure information for a planned cohort study on cancer. The eight experts assessed 63% of the 1836 combinations in plenary, resulting in 265 (14%) convened exposed combinations. Chlorinated hydrocarbons, benzene and inhalation of mineral oils had the highest number of exposed job categories (n=14, 9 and 10, respectively). The job categories classified as exposed to the highest numbers of carcinogens were the mechanics (n=10), derrick workers (n=6) and process technicians (n=5). The experts' individual ratings agreed highly with the subsequent panel assessment. There were no apparent differences between the three university experts and the five industry experts' assessments.

Further validation of the exposure assessment is suggested, such as by new sampling data or observational studies.

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Table 1. Combinations of carcinogens, time periods and job categories which eight experts by plenary discussions agreed upon as “exposed”

Carcinogen IARC group	Time period	Job categories exposed
Asbestos 1	1970–1980	Derrick workers
	1970–1988	Drill floor crew
	1970–1989	Piping engineers and inspectors Mechanics Machinists Insulators
Benzene 1	1970–1989	Painters
	1970–2005	Process technicians Laboratory engineers and technicians Electricians Electric instrument technicians Piping engineers and inspectors Mechanics Insulators Industrial cleaners
Formaldehyde 1	1970–2005	Deck crew Process technicians
Silica 1	1970–1989	Well service crew
	1970–1995	Painters
	1970–1999	Derrick workers
Chromium[VI] 1	1970–1999	Painters
	1970–2005	Mechanics Sheet metal workers Welders
Ionising radiation 1	1970–2005	Measure while drilling (MWD) operators/mud-loggers Non-destructive testing (NDT) inspectors
Occupational exposure as a painter 1	1970–2005	Deck crew Painters

Nickel compounds 1 (includes some 2B compounds)	1970–2005	Sheet metal workers Mechanics Painters Welders
Lead 2A	1970–1995	Drill floor crew
	1970–1999	Painters
Chlorinated hydrocarbons 2A	1970–1989	Drill floor crew Mud engineers/shale shaker operators Derrick workers Drillers Well service crew Measure while drilling (MWD) operators/mud-loggers Process technicians
	1970–1992	Deck crew Industrial cleaners Machinists Turbine operators/hydraulics technicians Electricians Electric instrument technicians Mechanics
Diesel engine exhaust 2A	1970–1999	Derrick workers
Refractory ceramic fibers 2B	1985–2005	Insulators
Dichloromethane 2B	1970–2005	Mechanics
	1980–1989	Painters
Welding 2B	1970–2005	Sheet metal workers Mechanics Welders
Mineral oil – inhalation 3	1970–2005	Industrial cleaners Process technicians Deck crew Mechanics Machinists Turbine operators/hydraulics technicians
	1985–2005	Drill floor crew Derrick workers Measure while drilling (MWD) operators/mud-loggers Mud engineers/shale shaker operators

Mineral oil – skin 3	1970–2005	Drill floor crew Mud engineers/shale shaker operators Derrick workers Process technicians Deck crew Industrial cleaners Mechanics Machinists Turbine-operators/hydraulics technicians
	1985–2005	Measure while drilling (MWD) operators/mud-loggers
Crude oil – skin exposure 3	1970–2005	Mechanics Process operators Laboratory engineers and technicians Industrial cleaners

Table 2. Number of raters who individually agreed on "exposed combination", number of corresponding exposure combinations during individual assessments, and number of exposure combinations assessed "exposed" during panel assessment

Number of raters who individually agreed on "exposed combination"	Number of corresponding exposure combinations during individual assessments (% of 1836 combinations)	Number of corresponding exposure combinations during panel assessment (% of 1836 combinations)
0	675 (37)	0 (0)
1	398 (22)	0 (0)
2	230 (13)	4 (0.2)
3	135 (7.3)	12 (0.7)
4	75 (4.0)	17 (0.9)
5	87 (4.8)	30 (1.6)
6	69 (3.8)	45 (2.5)
7	69 (3.8)	59 (3.2)
8	98 (5.3)	98 (5.3)
Total	1836 (100)	265 (14)

Table 3. Results from expert assessment by eight raters with years of experience in occupational hygiene, offshore experience, number of exposure combinations individually assessed "probable exposure", agreement between individual and panel assessments of exposure (Cohen's kappa index) and sensitivity and specificity using panel assessment as reference: each expert completed 1836 cells (17 carcinogens * 4 time periods * 27 job categories)

Rater number	Years of relevant experience (offshore experience)	Number of "probable exposure" combinations	Kappa of individual versus panel assessment	Sensitivity	Specificity
1[a]	25 (3)	249	0.62	0.65	0.95
2[a]	15 (3)	256	0.70	0.73	0.96
3[a]	3 (3)	198	0.58	0.55	0.97
4[b]	19 (3)	251	0.53	0.58	0.94
5[b]	23 (3)	235	0.74	0.73	0.97
6[c]	15 (15)	379	0.65	0.86	0.91
7[c]	13 (8)	210	0.59	0.57	0.96
8[c]	6 (4)	248	0.74	0.76	0.97
Mean individual		253			
Panel		265	0.64	0.68	0.95

[a]University rater.

[b]Industry rater from contracting company.

[c]Industry rater from an oil company.

Table 4. Observed range of relative risk and minimum range of cancer cases needed to attain the observed relative risk, under varying assumptions of "true" relative risks and prevalence of exposure given the individually estimated sensitivity and specificity [a]

"True" relative risk	Prevalence of exposure (%)	Observed relative risk range	Minimum cancer cases needed – range
2	30	1.6–1.7	20–33
	10	1.4–1.7	22–50
	1	1.1–1.2	196–1244
4	30	2.3–2.9	5–8
	10	2.2–3.0	4–9
	1	1.2–1.6	26–152

[a] Sensitivity and specificity from Table 3.