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Review

Overview and Characteristics of Some Occupational Exposures and Health Risks on Offshore Oil and Gas Installations

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This review considers the nature, and recognition and control, of health risks in the offshore oil and gas industry from the occupational hygiene point of view. Particular attention is given to the changes in the nature of exposure and control of inhalation risks from substances hazardous to health in the UK sector, but other risks (e.g. dermatitis, noise and vibration) are also considered. The amount of published information on exposure to these hazards in the sector, or indeed on long-term health outcomes of working offshore, is limited. The approach taken to occupational health and hygiene in the sector has to be set in the context of the challenge of working in a remote and hostile environment where attention to safety and the need for emergency response to acute, rather than chronic, medical events are vital. However, changes in attitudes towards occupational health in the sector, legislation, the impact of environmental protection requirements and technology have all contributed to increasing the attention given to assessment and control of chemical and physical hazards. The health risks and benefits associated with the abandonment of installations, the application of new technologies, recovery of oil from ever deeper waters, lower staffing levels, environmental changes, the ageing workforce and the recognition of exposure patterns needing further attention/control (sequential multiple exposures, smaller workforce, peak/short-term exposures, etc.) are other current and future occupational hygiene challenges.

Keywords: offshore review; benzene; drilling muds; hazardous substances; noise; HAV

INTRODUCTION

The international oil and gas industry is a truly global enterprise—for example, in the USA the oil industry is second only to the military in terms of having personnel in remote locations (Boultinghouse, 1999). Among the most demanding of these remote workplaces, for both technology and the workforce, is the offshore sector. Offshore oil and gas exploration and production can be found in environmental conditions ranging from Arctic to tropical; and in situations ranging from inshore shallow waters to remote deep-water locations.

With respect to UK waters, exploration and production of gas started in the southern North Sea in the early 1960s and expanded rapidly in the 1970s when oil was discovered in the northern North Sea. There are currently ~20000 people working offshore in the UK sector, compared with an historic high of around 34000 in 1992/93 (HSE, 2000a). There are over 200 fixed installations, ~130 of which are permanently crewed by 12–200 people. In any one year, 40–50 mobile drilling rigs will work in the sector and other vessels (pipe-laying barges, heavy lift vessels, service vessels, standby vessels, diving support vessels, etc.) will be coming and going.

HEALTH HAZARDS IN THE OFFSHORE ENVIRONMENT

Virtually all the health hazards common to industry are present offshore (HSC, 1996). They include: chemical hazards (toxic, corrosive, irritant and sensitizing substances and possible carcinogens); physical hazards (noise, vibration, various forms of radiation, thermal extremes); biological hazards (legionella, food poisoning); ergonomic hazards (manual handling activities, workstations, VDUs); and psychosocial hazards associated with either the work (overload, underload, hours of work, tour patterns, work relationships, etc.) or the location (travel, being away from home, living on the job, etc.), all of which can contribute to psychological stress

Although details, such as the chemicals used, have changed, and some new hazards have emerged (e.g. legionella and VDUs), offshore hazards are much the same as those recognized by the International Labour Office more than 20 yr ago (ILO, 1978, 1980). Thus, the ILO reports mentioned: various chemical hazards (hydrogen sulphide, crude, various mud components, welding/cutting fumes, acids, coatings, etc.); physical hazards (noise and vibration, various forms of radiation and thermal extremes); mechanical hazards (e.g. handling heavy objects); psychological stresses (isolation, hours of work, tours, shifts, work load and content, fatigue, etc.).

WHAT ARE THE RISKS TO HEALTH?

There is a range of reports on the general health of offshore workers (for a short summary, see Gardner and Wiig, 1999) and there are data (e.g. HSE, 2000a; NPD, 2000) relating to acute accident and ill-health events collected through statutory reporting schemes and from studies of medical evacuation from offshore installations (Norman *et al.*, 1988; HSE, 1998b).

The risk of chronic long-term ill-health associated with offshore work is, however, difficult to judge. There is some information on chronic work-related ill-health in offshore workers in Norwegian Petroleum Directorate (NPD) annual reports (Wiige, 1996; NPD, 2000), which is broadly in-line with onshore findings in the UK (HSC, 2000). Thus, the main concerns raised by both the NPD and the HSC relate to musculoskeletal disorders and stress. However, there appear to be no published epidemiological studies of the mortality or morbidity associated with working offshore, though there is an ongoing Norwegian prospective study of cancer among offshore workers (Anda, 1998). There are a few studies of upstream onshore oil and gas production workers, including in some cases drilling and pipeline workers (Divine and Barron, 1987; Yang and Zhang, 1991; Schnatter *et al.*, 1992; Sathiakumar *et al.*, 1995; Divine and Hartman, 2000). The most consistent finding from these has been an excess of leukaemia. Thus a Chinese study (Yang and Zhang, 1991) reported a significantly higher increased incidence of leukaemia in 'oil fields' [standardized incidence rate (SIR) = 1.46; $P < 0.01$] and 'polluted areas' (SIR = 1.40; $P < 0.01$) workers; compared with other areas in China. Similarly, a cohort study (Divine and Barron, 1987; Divine and Hartman, 2000) and a case-control study (Sathiakumar *et al.*, 1995) of crude oil and gas production workers have found statistically significant excesses of acute myelogenous leukaemia [standardized mortality ratio (SMR) = 192 in the cohort study (SMR for roustabouts of 276), using the US population as the control, and odds ratio (OR) = 2.0 in the case-control study]. Both studies suggested increasing risk with longer and earlier employment: first employment pre-1940 had the highest risk in the case-control study and this was the only group with elevated risk in the cohort study. There is no published information on the exposure experience of these higher-risk groups, but Sathiakumar *et al.* (1995) noted anecdotal reports that personal hygiene was poor and that some onshore oilfield workers had received heavy exposure to crude oil.

An excess of malignant melanoma (SMR = 6) was found in a cohort of upstream workers (Schnatter *et al.*, 1992), but this finding has not been supported in other studies. Other cohorts have, though, worked at different latitudes and may have had lower UV exposure, which could influence their melanoma risk.

In the absence of good risk data, the HSE, as an enforcement agency, has approached the management of health risks offshore by 'reading across' from known onshore risks and monitoring the assessment and management of these by offshore duty holders (Gardner, 2001).

SOME SPECIAL FEATURES OF WORKING OFFSHORE

There are several features of offshore work that have an impact on the way occupational health and hygiene has been practised in the sector.

Physical isolation

Installations are isolated, the workforce travels to work by helicopter and then 'lives over the shop' while they are there. The medical aspects of this lifestyle were recognized early in the development of the North Sea (Anon., 1975a,b; IP, 1976). As well as medical care and first aid on the installation, and planning for medical emergencies and medical evacuations, there was a need to ensure the initial and continuing 'fitness to work' of the workforce. Although occupational hygiene matters were not overlooked (Cumming and Taylor, 1973; ILO, 1978, 1980), they did not have the urgency of the person-orientated medical aspects of the work. Even in the 1990s, the HSE's initial experience was that the assessment and control of health risks were less well managed than the person-orientated aspects of health (Gardner, 1997).

Major hazard potential

The Piper Alpha disaster in 1988 tragically illustrates why safety is a primary concern of offshore managers. In comparison, it has been recognized that there has been less focus on health. Line managers have responsibility for safety as part of their role, safety targets in plans, and safety performance indicators against which to measure progress. Until recently, this was rare for health. Gardner and Wiig (1999) have discussed the reasons for the 'Cinderella' status of health in the sector. They include the fact that work-related ill-health may only appear years after an individual's exposure to the causative agent(s) and these may not have been recognized as hazards at the time. As a result, line managers do not see obvious cases of work-related ill-health among their current workforce. The self-selecting nature of offshore work, and the medical fitness to work requirements (UKOOA, 2000) probably also contribute to the fact that obvious illness among offshore workers is relatively rare. For instance, in a study of 768 individuals taking return medicals, only five were refused a medical certificate (HSE, 1997). [A large number were only given interim certificates, but these were either because they had not got a dental certificate (459) or because further information was awaited from their GPs, and they were likely to have been given full certificates once these questions had been addressed.] The end result has been that health was often seen as a difficult topic best left specialists, so even if cases of ill-health occurred, managers would not get involved in their investigation in the same way that they do with accidents.

Shift and tour patterns

Offshore workers work 12 h shifts each day to a variety of patterns, over a two or three week 'tour', with varying periods of leave between tours. Where limits have been set for chronic exposure to hazardous substances, they are usually defined in terms of the traditional 8 h working day. Eide (1990a) has reviewed general methods for adjusting 8 h occupational exposure limits to offshore work schedules. He recommended that the 'worst case' adjustment factor of 0.60 found from the toxicokinetic models should be used because of its simplicity compared with 'accurate' calculations of adjustment factors. Also for simplicity, HSE (1994) suggested that occupational exposure limits (OELs) for 12 h shifts offshore should be adjusted on a pro rata basis, i.e. a correction factor of 0.67.

Ageing workforce

Many workers have worked offshore for over 20 yr and on some installations the average age of the workforce is in the late forties. The effect of ageing on an individual's ability to work in offshore conditions and his/her changing vulnerability to health stresses in the working environment has hardly been examined, though Norwegian data shows that the sick leave rate increases with age (Bjerkeboek *et al.*, 2001).

Multiple exposures

Work offshore can involve exposure to a range of hazards sequentially or simultaneously (e.g. hazardous substances, noise, vibration, hot or cold conditions, heavy manual handling activity are all present on the drill floor). Again, potential interactions between different stressors such as these have hardly been explored.

Environmental concerns

Worker exposure to hazardous substances offshore can be affected in various ways by environmental concerns. Thus, the substitution of less environmentally hazardous materials can introduce materials that are potentially more hazardous to them. For instance, removal of various ozone-depleting chemicals under the Montreal Protocol led in some cases to changes to more toxic, or asphyxiating, fire-fighting gases (such as carbon dioxide and nitrogen), and following further recent restrictions, tetrachloroethylene has been suggested as a replacement for Arklone for oil-in-water analysis. In this context, it is notable that the Guidelines for the Revised Offshore Chemical Notification Scheme on the classification of the hazards associated with chemicals used offshore consider only environmental risk (CEFAS, 2002). On the other hand, the OSPAR (Oslo–Paris) Convention for the Protection of the Marine Environment of the North-east Atlantic (OSPAR, 2002), has led to removal of substances directly toxic to workers, as well to the environment, from materials used offshore (e.g. cadmium, lead, polychlorinated biphenols). Perhaps the greatest impact of environmental concerns has, however, been on the nature and use of chemicals in drilling (see under Drilling below).

The following section reviews some aspects of the history, culture and current status of the assessment and control of hazardous substances, noise and hand–arm vibration syndrome (HAVS) offshore.

HAZARDOUS SUBSTANCES

Background

Several hundred substances with a range of uses and toxicities are, or have, been used offshore (Hudgins, 1991). Additionally, there are the products (crude oil, hydrocarbon and other gases, and hydrogen sulphide) and other substances used and produced in general workplace processes (e.g. welding, application of coatings and resins, shot blasting).

In the UK, the Control of Substances Hazardous to Health Regulations (COSHH) were first introduced in 1988, but not applied offshore until 1995. However, many offshore companies had already applied the essential philosophy of COSHH, i.e. assessment, prevention or control of exposure, and 'monitoring', including of equipment by maintenance, and by air monitoring and health surveillance, as necessary. The approach can be recognized in Codes of Practice for the safe use of drilling fluids published in the early 1990s (UKOOA, 1990; IP, 1991). In a survey (Gardner, 2001) during 1997–98, the HSE found that, in practice, assessments sometimes used only the information in the Material Safety Data Sheets (MSDS), so they were hazard-based, rather than risk-based. In the worst cases, process-generated substances (e.g. hot cutting fume) might not be assessed because they had no MSDS. It is still often the case that electronic assessment systems emphasize the hazard from the substance rather than the risk from its manner of use. This hazard-based approach tends to drive control to the provision of personal protective equipment (PPE) rather than considering other more effective methods and there is a heavy reliance on PPE offshore (Gardner, 2001). Similar flaws in risk assessments for chemicals have been noted in the Norwegian sector (Myhvrold *et al.*, 2001); this is not, of course, a problem peculiar to the offshore environment.

Exposure to hazardous substances offshore

Production and ancillary processes. Most offshore production processes are similar to those encountered onshore (e.g. sampling, addition of process chemicals, pigging) or during general factory work (e.g. welding, painting, cleaning), and therefore open to the same controls. It is probably for this reason that although individual companies have measured personal exposures during many activities, the only published exposure data found during the preparation of this review were on benzene and related aromatics. Thus, an HSE survey (HSE, 1999a) of 11 installations found that of 241 personal samples, 93.8% were <0.1 p.p.m. (8 h TWA basis) and 91% were <0.05 p.p.m. Only one sample approached 1 p.p.m. and this was suspect; the next highest exposure result was 0.64 p.p.m. While this is quite reassuring in relation to long-term exposures, there remains the question of what peak and high short-term exposures to benzene occur during maintenance, sampling, pigging and similar processes, and hence what opportunities arise for further reduction of exposure by 'peak shaving'.

Drilling. The drilling fluid, or 'mud' system has been described many times; descriptions most accessible and useful to occupational hygienists are those in Davidson *et al.* (1988)) and the IP Code of Practice (IP, 1991). The composition and use of drilling fluids in the UK sector has been recently reviewed (HSE, 1999b).

Briefly, drilling mud is a complex oil- or water-based mixture that is pumped from tanks down the inside of the drill pipe and exits into the borehole from the rotating drill bit. It returns to the surface in the annular space around the drill pipe, is cleaned by passing over shale shakers and desanding, and then recirculated via mud tanks. Mud has many functions, including removing rock cuttings from the hole, cooling and lubricating the bit, maintaining a pressure in the hole to prevent influx of gas and crude oil, and carrying various materials downhole to serve needs such as stabilizing the hole wall. The uses of muds are such that their physical characteristics (e.g. density and viscosity) tend to be more important than their chemical make up, except in so far as they have any propensity to react with the strata being drilled.

In the past, mud components had considerable toxicity for both humans and the environment. For example, an ILO report (ILO, 1980) listed some of the materials used in drilling mud as: 'bentonite or polymer suspension with such additives as caustic soda, soda phosphate, hydrated lime, sump oil, diesel, phenol and phenol derivatives or barium sulphate and is consequently often strongly caustic and highly poisonous'. However, the composition of muds has changed considerably over the years, with a general trend to materials of lower toxicity. Thus, chromium lignosulphate additives and attapulgite were phased out in the early 1980s, mainly for health and safety reasons. Similarly, diesel as a base-oil for drilling was replaced by low-toxicity mineral oils (LTMOs) with low aromatic content. During the 1980s, environmental concerns led to a steady reduction of the limits on the amount of oil, including LTMOs, allowed on cuttings discharged into the sea, which in turn led to changes in the nature of the base-oils used—e.g. long-chain esters and ethers, dodecyl benzenes, and other materials were used for a while. Also, developments in water-based muds have allowed them to be used more widely (HSE, 1999b). Currently a 'zero discharge' regimen is in place and the most common methods used to meet this requirement are the collection of the cuttings for subsequent onshore thermal processing to recover base-oil and disposal of the cuttings, or reinjection into the well.

Inhalation risks. Special attention is given here to the inhalation risks from mud because the topic has not been reviewed recently and work on potential chemical changes in mud during use and recycling is not well known outside specialist petroleum engineering publications. Also, the formulation of oil-based muds has much in common with the formulation of metalworking fluids and hence there are similar difficulties in respect of sampling and setting appropriate exposure limits (HSE, 2000b, 2002). Mud systems on many old installations were designed for water-based muds that do not produce vapours. For example, mud pits, fluid flow lines, shale shaker troughs, cutting ditches, etc., were open and control of aerosols usually relied on general ventilation. This reflected practice in onshore drilling, where the equipment is in the open air and control of aerosols and vapours successfully relied on natural ventilation. Structural constraints offshore also mean that much of the mud system is confined, exacerbating the potential for exposure.

Eide (1990b) reviewed possible health effects associated with aerosol and vapour from low-aromatic, oil-based drilling fluids and the published exposure data from both the UK and Norwegian sectors. He quotes from referenced Norwegian sources, personal TWA exposures to total hydrocarbons (aerosol and vapour by sampling onto charcoal tubes) of up to 300 mg/m^3 during work in the mud-handling areas (with the highest levels at shale shakers) and on the drill floor. Using sampling onto Tenax tubes and analysis by gas–liquid chromatography (GLC), Davidson *et al.* (1988) measured personal TWA exposures of up to 200 mg/m^3 on the drill floor and up to 450 mg/m^3 at shale shakers. At the time these samples were taken, TWA exposure limits for total hydrocarbons were in the range 100–350 mg/m^3. Eide notes that on installations where control measures were in place, personal exposures to total hydrocarbons were <100 mg/m^3. Eide (1990b) also reported Norwegian data on oil mist, showing TWAs of 0.7–20 mg/m^3, but the method used (sampling onto glassfibre filters) would have underestimated the concentration of oil mist because of evaporation (e.g. Simpson *et al.*, 2000). More recently, airborne oil mist and hydrocarbon vapour concentrations in a shale shaker house during drilling have been measured using a double glassfibre filter with a jumbo charcoal tube backup (James *et al.*, 2000). There was a good level of enclosure (e.g. the three shale shakers were enclosed by a ventilation canopy that covered all sides) and other parts of the system (e.g. fluid flow lines, cuttings ditch, shaker trough) were covered or part-covered. The results varied from 0.03 to 5.52 mg/m^3 for oil mist and from 3.2 mg/m^3 (personal sample) to 96.4 mg/m^3 for oil vapour. I have found no other recent published reports of sampling for exposure to oil-based aerosols and vapours, but surveys by individual companies (various personal communications) support Eide's summary. Conditions have thus improved considerably and, because of the environmental changes noted above, water-based muds are currently used as frequently as possible; LTMOs being the base-oil of choice where they have to be used. However, some current formulations of base oil are much 'lighter' (lower viscosity and lower molecular weight) than many used in the past, so vapour formation is potentially higher than in the past.

Although base-oils have attracted the most attention, workers are potentially exposed to a range of particulates, especially during powder handling in the sack room (various additives, especially barium sulphate) and at the shale shaker (aerosols from mud and the strata being drilled). With respect to the sack room, few exposure data have been published, though many companies have carried out surveys. In practice, the potential problems of exposure and the opportunities for control are much the same as in comparable situations onshore. For instance, over the working period, exposures to barium sulphate during the manual emptying of sacks can be easily reach 5–10 times the OEL, but control by application of LEV at the hopper, good sack-handling techniques, bulk handling, etc., can keep exposures well below the OEL. Hansen *et al.* (1991) published detailed elemental analyses of airborne dust from 16 static samples from a shale shaker room during drilling using a water-based mud. Total airborne dust concentrations at the working area were in the range 0.05–0.7 mg/m^3. Barium sulphate was the major component of the mud and, not surprisingly, the element found in highest concentration in the dust samples was barium. The concentrations of barium found were equivalent to 0.4–0.5 mg/m^3 of barium sulphate, which could account for up to half of the total amount collected. Current barium sulphate UK 8 h TWA OELs for respirable and total inhalable dust are 4 and 10 mg/m^3 respectively (HSE, 1998a, 2002). Although Hansen *et al.* (1991) give few workplace details, the shale shakers are referred to as 'open', implying no more than control by general ventilation.

Potential chemical changes in muds during use and recycling. Since muds are subjected to elevated temperatures and increased pressures, there has been a concern that organic components might break down, or chemical reactions might occur, to form more toxic substances. There was a particular concern that base-oil high in aromatics might contain, or form polycyclic aromatic hydrocarbons (PAHs), while muds based on alkyl benzenes might break down to yield free benzene. There is no evidence in the literature of either of these having been reported, though the current Guidelines for the UK Revised Offshore Chemical Notification Scheme (CEFAS, 2002) do require a full declaration of PAH content using methods that can achieve a limit of detection of ~0.1 p.p.m.

James *et al.* (2000) have carried out a series of chromatographic analyses of the headspace above various oils used in drilling muds and compared them with field drilling fluids at temperatures up to 80°C. The field samples produced higher total headspace hydrocarbon concentrations than any of the laboratory-produced samples and all of the field samples contained light hydrocarbon substances that were not seen in any of the individual additives, or in any of the laboratory-prepared drilling fluids. James *et al.* (2000) suggest that these results may have been because of the presence of diluents used to carry various additives added in the field, but not included in the laboratory-prepared samples, or to contamination from the formation through which they were drilling, or interference in the analysis. In the laboratory, James *et al.* (2000) also found that some clays had a marked effect on the concentration of vapour in the headspace of drilling fluid systems. They suggest that the effect could be due to the clay itself, some kind of catalytic effect, or a reaction with one or more of the additives. From the point of view of controlling exposures in practice, an important finding was that using base oils rather than the more volatile solvents currently employed as diluents for additives could reduce total emissions.

A different perspective on the question of the possible breakdown/reactivity of muds arises when recycling processes are considered. As noted, cuttings are now commonly collected in closed systems and taken onshore for cleaning and disposal. The most common cleaning methods use thermal desorption systems that allow recovery and hence reuse of the base oils. The question of whether the base-oil changes in composition during the process has recently been addressed. Thus, Jones *et al.* (2002) have used GLC–mass spectrometry for both liquid and headspace analysis of recovered mineral oils, synthetic linear paraffin oils and, for comparison, diesel. Diesel showed no significant change in its non-volatile composition after going through the thermal desorption process, though a number of new volatile components were present in the headspace, including pentadienes, benzene and 1-octene. With respect to the other oils examined, the hydrocarbon distributions did not appear to be changed significantly by the thermal process, i.e. there was no fractionation of these components during recovery. However, a range of non-volatile and volatile contaminants was found. In the liquid, for example, Jones *et al.* (2002) found anthracene in one mineral oil base and 1-tetradecene in another. The former may have come from contamination with crude oil (previously observed by Churan *et al.*, 1997) and the latter from contamination with a synthetic base oil of linear alphaolefines. Also, all the thermally recovered oils were discoloured (light yellow) and the intensity of their UV/visible spectrum in the range 240–340 nm increased. However, the identified aromatics observed by GLC did not fully account for this increase. Headspace volatiles included dimethyl suphide (DMS), which gave the recovered oil a pungent odour, and a range of oxygenated components, including butyraldehyde, 2-ethyhexenal and 2-butoxyethanol. The DMS may have been from crude oil contamination, and the oxygenated products due to partial oxidation of the oil or additives. Some of these contaminants could at the very least produce unpleasant working conditions when using recovered base oils; the odour threshold of DMS has been reported in the range 0.0001–0.35 mg/m^3 (Ruth, 1986) and isobutyraldehyde is particularly pungent.

Dermatitis. Although most published occupational hygiene work in the offshore sector has concentrated on inhalation risks, dermatitis from skin contact with muds is a recognized risk (Davidson *et al.*, 1988; Ormerod *et al.*, 1989, 1998; IP, 1991; Ormerod, 1997). On the drill floor, in particular, skin contamination can be extensive, but occasionally dermatitis also occurs in divers who make contact with discarded cuttings on the sea bed (Ormerod *et al.*, 1989, 1998; Ormerod, 1997). The only detailed published study of the control of dermatitis in the offshore sector seems to be an HSE inspection project carried out in 1996–97. This found that most companies assessed dermatitis risks as part of the COSHH assessment (Gardner, 2001). However, the assessments were often hazard-based, using the MSDS simply as a prompt for the use of PPE and/or barrier creams. Those companies that had carried out specific skin-related risk assessments had benefited by developing more effective methods to prevent and control exposure, including some examples of substitution (e.g. the replacement of zinc bromide with less corrosive/toxic caesium formate brines.). Training and awareness of employees to skin disorders was usually on an *ad hoc* basis, but some companies had well-developed skin care programmes.

The overall conclusions from the project were (Gardner, 2001):

1. Companies that had carried out specific skin-related risk assessments had benefited by developing more effective methods to prevent and control the risk.
2. Duty holders needed to consider risk reduction methods other than PPE such as substitution, closed systems, mechanical aids and better housekeeping.
3. The use of barrier creams required careful monitoring since, in some cases, they were regarded as a form of PPE, hence giving a false sense of security.
4. Work-related dermatitis seems to occur more often than it is reported to the Regulator.

Noise

Background. There are two important potential health problems arising from exposure to noise offshore: noise-induced hearing loss and the potential for sleep disturbance with resultant fatigue and stress. Recognition and discussion of the problems (Taylor, 1973), and reporting of area noise levels for different locations on drilling installations (Melling, 1975), appeared early in the history of exploration in the North Sea. At that time there was no specific legislation on noise at work, but the HMSO Code of Practice for reducing the exposure of employed persons to noise was used with a recommended maximum level of 88dB(A) for general work areas on offshore installations based on a daily 12 h shift. Department of Energy/HSE design guidance recommended area-based limits for specific areas on installations, e.g. 70 dB(A) in workshops and 45 dB(A) in sleeping areas. The UK Noise at Work Regulations (NAWR) were applied offshore in 1997, which resulted in a round of reassessment.

Assessment and monitoring of noise exposure. The NAWR specifically require an assessment of personal noise exposure, and this has had considerable impact on the assessment and monitoring of noise offshore. Historically, the emphasis offshore had been on measuring area noise. Indeed the Certifying Authorities (CAs) required area measurements as part of the certification process, and the design guides on noise levels were necessarily area based. Hence, many measurements have been made of noise associated with particular equipment or areas on drilling rigs and fixed installations. In many areas, there is little difference in the noise levels measured in the 1970s (e.g. Melling, 1975) and more recently (HSE, 1999c). For example, on the drill floor during drilling, Melling quoted levels in the range 92–98 dB(A) and similar levels are still to be found today. However, if installations are considered by 'generation' (first generation 1967–80; second generation 1980–90; third generation 1990–2001), then there is evidence that the average noise levels on second- and third-generation installations is lower than on first-generation installations (Graham Cowling Acoustic Technology Ltd, personal communication). However, there is no significant correlation between average noise levels in different areas of installations and their year of construction (HSE, 1999c).

The HSE has carried out inspection projects examining the assessment and control of noise offshore both before and after the NAWR were applied. Results from these have been published elsewhere (Gardner, 2001), but a summary of the findings gives an insight into the impact of the regulations and a useful context against which to set changing approaches to noise control offshore.

The first project (1994–95) was carried out before the NAWR were applied and most of the organization on noise matters related to the requirements of the then CAs. Thus, only about a third of the installations investigated had a specific noise policy, but virtually all of them had regular noise surveys and half had other area surveys beyond the CAs requirements. The CAs compared the results to the noise standards given in Den/HSE guidance on design, construction and certification of offshore installations. Most companies also used the 'action levels' of the then onshore NAWR with the noise surveys to identify areas where hearing protection had to be worn.

There were some marked differences between these findings and those found in 1999–2000, i.e. 2 yr after the application of the NAWR offshore. The percentage of duty holders with policies and procedures on noise had doubled and others were developing policies; all but one had completed noise assessments and included personal exposure assessments; around 20% had identified further potential noise control measures; and 65% had appointed a 'responsible person' for noise matters. However, this person was not necessarily a 'competent person' and often had limited authority. Some companies also had targets for assessment and training, and it was evident that workforce awareness was higher than before.

Control of exposure to noise. Part of the noise control problem offshore lies in the design of installations. They are very compact, so there is limited space for noise enclosures and similar control approaches; they are largely constructed of steel; and they have a high density of noisy equipment in enclosed modules. In the long term, noise reduction can be managed by designing out noisy sources, fitting noise controls at the design and commissioning stage of new or refurbished installations, and having policies to purchase less noisy equipment. Noise is assessed in design and, as noted, more recent generations of installations do seem to have lower average noise levels than their predecessors. However, although virtually all companies have purchasing policies covering noise, these are not always well used. For instance, a company may see the purchase of a piece of noise-suppressed equipment as unnecessary if it is to be installed in a module where hearing protection will anyway have to be worn because of existing noise levels.

The basic control measure offshore has been, and remains, the provision of hearing protection for use in designated hazardous areas based on the action levels in the NAWR. It is now common in the UK sector for duty holders to have policies agreed with the workforce to wear hearing protection everywhere outside the installation accommodation. It is argued that the risk of hearing loss will be minimized if hearing protectors become accepted as part of everyday PPE offshore. The analogy is made with eye protection, the general wearing of which has indeed successfully reduced the incidence of eye accidents, but the situations are not comparable. Noise can in principal be engineered out or controlled at source, but many potential causes of eye injuries cannot. It is also said that it is easier to enforce and supervise the general wearing of hearing protection than it is to enforce and supervise its use only in noisy areas. But, if supervising and ensuring the wearing of hearing protection was difficult in obviously high-risk areas, why is it expected to be easier if it has to be worn everywhere? The underlying theme seems to be to change behaviour rather than improving control of noise at source, or improving monitoring and supervision.

The use of hearing protection in this way goes against the general philosophy of using PPE as a control of last resort. Non-selective use of hearing protection might also degrade its real significance in controlling risk and bring about a change in risk perception leading to poor practices, such as 'lifting' of muffs to hear conversation in noisy areas, and hence increasing the risk of over-exposure. Extended wearing of muffs can also lead to hygiene problems and be uncomfortable. Anecdotal evidence suggests that these factors may also increase the tendency to occasionally 'lift' them; hence the policy may increase the risk rather than reduce it. Such policies also have difficulty when there are areas on an installation where it is necessary to wear double-protection (i.e. plugs and muffs) and if there are areas/situations where it may pose a threat to good communication.

Hand–arm vibration (HAV)

Details of an inspection initiative made by HSE during 1998–99 on the offshore industry's approach to the assessment and control of HAV risks have been published (Gardner, 2001). A somewhat unexpected conclusion from the initiative was that the use of hand-held vibrating tools was more widespread than had been previously thought. Among the companies surveyed, including contractors, ~1800 workers were reported as using hand-held vibrating equipment. Scaling this up across the sector would suggest 2000–3000 workers are regularly exposed to the risk of HAV. The most frequently used equipment known to have high vibration levels were grinders, needle guns, impact wrenches, air drills and chipping hammers. Also reported, but less commonly used, were nibblers, scrabblers, air drills, jigsaws, a floor-polishing machine and an engraving pen. Early in the work it became apparent that that exposures during the use of hand-held vibrating tools offshore were likely to be much the same as onshore and are open to the same controls. However, it was also apparent that this was an area where assessment and control of the risk, and training of operatives, needed improving offshore. It was also found that guidance from the HSE was not penetrating the sector. Only 15% of the companies asked, said they had seen at least one of HSE's publications on HAV and it seemed that industry-developed guidance might be more successful. A meeting was held with industry representatives and the industry reacted rapidly to improve the situation. By the end of 1999, better systems to assess the risks (including measuring or otherwise assessing the vibration levels of equipment), and the purchase of lower-vibration tools and controls (such as limiting and recording the time spent using vibrating tools), were becoming widespread and the development of guidance by the industry was under way (Campell, 2001; McIlroy, 2001; OCA, 2002).

OCCUPATIONAL HYGIENE CHALLENGES OFFSHORE

Some challenges for occupational hygienists offshore have already been mentioned (i.e. mixed exposure scenarios and the ageing workforce), together with areas requiring further consideration (e.g. the significance of peak and short-term exposures), but there are many others. The factors that bring about changes in drilling and production in the North Sea are varied, develop and change over time, and have different potential impacts on the occupational hygiene needs of the workforce. Changes to legislation is one such factor, and in the relatively short term there will be challenges in following up changes to COSHH, stemming from the Chemical Agents Directive (HSE, 2001) and the proposals for change agreed in the common position reached by member-states on a European Directive on the minimum health and safety requirements regarding exposure of workers to the risks arising from noise (HSE: www.hse.gov.uk/hthdir/noframes/noise.htm) and vibration (HSE: www.hse.gov.uk/hthdir/noframes/vibrat.htm).

Technological advances, such as those that have made it economic to develop smaller, or part worked-out fields, may have a positive or negative impact on occupational health and hygiene aspects of the work. Thus, changes to drilling techniques, such as slim-hole, coiled tubing, through tubular and horizontal drilling, can reduce the amount of mud needed and the time taken, both of which result in less worker exposure, as well as reducing the quantity of cuttings produced. Also, the greater automation of the drill floor has removed workers from the associated health risks. On the other hand, underbalanced drilling and gas injection systems, which have become more common offshore in the last few years, introduce new high noise sources and risks from asphyxiant/toxic gases. Similarly, the introduction of floating production storage and offloading systems (FPSOs) for use in deep water have introduced increased or new exposure opportunities—they are often compact and add opportunities for exposure during offloading of crude oil to the tankers servicing them—and introduced stressors such as seasickness and the uncertainties of bad weather at sea.

A drive for efficiency has led to fewer people working offshore. In some cases new technology (such as subsea installations) have contributed to this without increasing health risks to workers. Where savings have been achieved by reducing staff, this may first lead to stress over job security and in the longer term to changed patterns of exposure in multi-skilled individuals or teams. Thus, when exposures to traditional hygiene factors, such as chemicals and noise, are spread over a number of people, an individual's total exposure is, to some degree, controlled. However, multi-skilling and team approaches can 'concentrate' exposure opportunities on one or a few people.

The North Sea sector is now a mature part of the industry and this can bring its own challenges. For example, the quantity of normally radioactive material in the form of low specific activity scale produced tends to increase with the age of the field and this has to be managed. As installations meet the end of their working lives, decommissioning is necessary and this brings all the occupational hygiene problems associated with the demolition of any complex plant (residues, hot cutting of coated surfaces, etc.) and associated buildings (asbestos and other lagging materials, etc.). If any of this is done offshore the environment increases the difficulties. There also remains a question over what should, or can be done to treat or remove discarded drill cuttings lying on the sea-bed; some of the possible solutions could involve exposure risks to those carrying out the work.

The global nature of the industry has already brought problems of managing health in ever more isolated areas and under the threat of quite exotic diseases. With worldwide environmental changes produced by 'global warming', a global industry like oil and gas exploration, drilling and production is likely to experience some effects. Not least are possible changes in the distribution of diseases. However, the nature of occupational hygiene controls may also need to be modified if weather and temperature conditions change in the sometimes quite extreme and unpredictable way that some models suggest.

Note that views expressed in this review are those of the author and do not necessarily reflect HSE's current policy, priorities and interests.

NOTE ADDED IN PROOF

Since this paper was written, COSHH 2002 has come into force.

REFERENCES

Note that all the HSE Offshore Safety Reports (OTOs and OTHs) referred to below are available on the HSE website (www.hse.gov.uk/) and are freely down loadable. Other publications referred to are available through the usual library systems or directly from the Society of Petroleum Engineers (www.spe.org/).

Anda I. (1998) Health cares out of the shadows. NPD Diary; no. 2; 16–17.

Anon. (1975a) Medical implications of oil related industry. Br Med J; 2 (5961): 5–6.

Anon. (1975b) Medical aspects of North Sea Oil. Br Med J; 3 (5983): 576–80.

Bjerkeboek E, Wiig H, Heber H. (2001) Ageing of the offshore workforce in the Norwegian offshore industry: implications for safety and health. Proceedings of the occupational health offshore conference. Aberdeen, 27–29 March 2001. HSE Offshore Technology Report OTO 2001 041. pp. 255–61. ISBN 0-7176-2260-6.

Boultinghouse O. (1999) Emergency telemedicine services. Health care and trauma at remote locations conference. Quoted by Aalund A. (associate editor) in a report on the conference Disease, trauma spur health-care push for oil travelers, expats. Oil Gas J; OGJ Special 29 Nov; 31–40.

Campell I. (2001) Report on hand arm vibration syndrome. Proceedings of the occupational health offshore conference. Aberdeen, 27–29 March 2001. HSE Offshore Technology Report OTO 2001 041. pp. 173–6. ISBN 0-7176-2260-6.

CEFAS. (2002) www.cefas.co.uk/ocns.

Churan M, Candler JE, Freeman M. (1997) Onsite and offsite monitoring of synthetic-based drilling fluids for oil contamination. SPE/EPA exploration and production conference. Dallas, 3–5 Mar. SPE 37906.

Cumming RP, Taylor W (editors). (1973) Aspects of health and safety in oil development. Proceedings of a symposium held in Lerwick, 17–18 March 1973. Lerwick: The Shetland Times Ltd.

Davidson RG, Evans MJ, Hamlin JW, Saunders KJ. (1988) Occupational hygiene aspects of the use of oil-based drilling fluids. Ann Occup Hyg; 12: 325–32.

Divine BJ, Barron V. (1987) Texaco mortality study III. A cohort study of producing and pipeline workers. Am J Ind Med; 11: 189–202.

Divine BJ, Hartman CM. (2000) Update of a study of crude oil workers 1946–1994. Occup Environ Med; 57: 411–7.

Eide I. (1990a) The application of 8-hour occupational exposure limits to non standard work schedules offshore. Ann Occup Hyg; 34: 13–7.

Eide I. (1990b) A review of exposure conditions and possible health effects associated with aerosol and vapour from low-aromatic oil-based drilling fluids. Ann Occup Hyg; 34: 149–57.

Gardner RJ. (1997) Occupational health: OSD's inspection experience. Proceedings of the occupational health offshore conference. Aberdeen, 26–28 March 1996. HSE Offshore Technology Report OTO 531. pp. 35–40. ISBN 0-7176-1423-9.

Gardner RJ. (2001) Offshore safety division national inspection projects: findings and lessons on occupational health management in the offshore sector. Proceedings of the occupational health offshore conference. Aberdeen, 27–29 March 2001. HSE Offshore Technology Report OTO 2001 041. pp. 47–60. ISBN 0-7176-2260-6.

Gardner RJ, Wiig H. (1999) Management of occupational health offshore: still a challenge for the industry? Offshore Europe Conference, Aberdeen 1999. SPE 56987.

Hansen AB, Larson E, Hansen LB, Lynsaae M, Kunze H. (1991) Elemental composition of airborne dust in the shale shaker house during an offshore drilling operation. Ann Occup Hyg; 35: 651–7.

HSC. (1996) Management of occupational health risks in the offshore oil and gas industry. Oil Industry Advisory Committee. London: HSE Books. ISBN 0-7176-0886-7.

HSC. (2000) Health and safety statistics 1999/2000. London: HSE Books. ISBN 0-7176-1867-6.
HSE. (1994) A brief guide on COSHH for the offshore oil and gas industry. The control of substances hazardous to health regulations 1994. London: HSE Books. HS (G)125.
HSE. (1997) Medical status of the offshore population offshore technology report OTO 97 057.
HSE. (1998a) Barium sulphate: risk assessment document. EH72/9. ISBN 0-7176-1527-8.
HSE. (1998b) Study of medical evacuations from offshore installations. Five year report 1987–1992. Offshore Technology Report 1999 OTO 098 171.
HSE. (1999a) Occupational exposure to benzene, toluene and xylene and ethylbenzene during routine offshore oil and gas production. HSE Offshore Technology Report OTO 1999 088.
HSE. (1999b) Drilling fluids: composition and use within the UK offshore drilling industry. HSE Offshore Technology Report OTO 1999 089.
HSE. (1999c) Collection and analysis of offshore noise data. Offshore Technology Report 1999 OTO 099 012.
HSE. (2000a) Offshore injury, ill health and incident statistics report 1999/2000. HSE Offshore Technology Report OTO 2000 111.
HSE. (2000b) Metal working fluids (MWFs) exposure assessment document. HSE, EH74/4. ISBN 0-7176-1797-1.
HSE. (2001) Proposals for implementing the Chemical Agents Directive (98/24/EC) with new Control of Substance Hazardous to Health Regulations and Control of Lead at Work regulations.
HSE. (2002) EH40/2002: occupational exposure limits 2002. London: HSE Books. ISBN 0-7176-2083-2.
Hudgins CM. (1991) Chemical usage in North Sea oil and production and exploration. Report for the Norwegian Oil Industry Environmental Committee.
ILO. (1978) Safety problems in the offshore petroleum industry. Geneva: International Labour Office. ISBN 9221019896.
ILO. (1980) Working conditions and working environment in the petroleum industry, including offshore activities. Report 3, Petroleum Committee of the International Labour Organization, 9th session. Geneva: International Labour Office. ISBN 92-2-102217-X.
IP. (1976) Health and safety in the oil industry. Proceedings of the Institute of Petroleum 1976 annual conference, Eastbourne, England. London: Heyden and Son Ltd. ISBN 0-85501-308-7.
IP. (1991) Code of practice for the safe handling of drilling fluids. Chichester: John Wiley and Sons. ISBN 0-477-93461-5.
James TGJ, Schel T, Navestad B, Geddes TA, Nelson MG, Webster D. (2000) Improving the working environment and drilling economics through better understanding of oil-based drilling fluid chemistry. SPE Drill Completion; 15(4) Dec; 1–7.
Jones RW, Sanders MW, Chambers BD. (2002) Improvements in the analysis of thermally recovered drilling fluid base oils from drilled cuttings. SPE conference on health, safety and the environment in oil and gas exploration and production, Kuala Lumpur, Malaysia, 20–22 March 2002. SPE 74166.
McIlroy S. (2001) Tackling bad vibes in the oil and gas industry—a case study on hand arm vibration syndrome (HAVS). Proceedings of the occupational health offshore conference. Aberdeen, 27–29 March 2001. HSE Offshore Technology. Report OTO 2001 041. pp. 169–71. ISBN 0-7176-2260-6.
Melling TH. (1975) Noise on offshore platforms. Noise Control Vibr Red; 6(7), July: 205–9.
Myhvrold A, Zachariassen S, Ask JA. (2001) Experience from supervision of operator companies' assessment of chemical risk. Proceedings of the occupational health offshore conference. Aberdeen, 27–29 March 2001. HSE Offshore Technology Report 2001/041. pp. 147–9. ISBN 0-7176-2260-6.
Norman JN, Ballantine BN, Brebner JA, *et al*. (1988) Medical evacuations from offshore structures. Br J Ind Med; 45: 619–23.
NPD (2000) Norwegian Petroleum Directorate Annual Report. NPD 2000 (www.npd.no).
OCA (2002) Guidance notes for good practice within the oil and gas industry. Hand arm vibration syndrome. Offshore Contractors' Association. (www.oc-online.co.uk/).
Ormerod AD. (1997) Occupational dermatitis in oil rig workers. Dermatol Prac; 5: 16–8.
Ormerod AD, Wakeel RA, Mann TAN, Main RA, Aldridge RD. (1989) Polyamine sensitization in offshore workers handling drilling muds. Contact Derm; 21: 326–9.
Ormerod AD, Dwyer CM, Goodfield MJD. (1998) Novel causes of contact dermatitis from offshore oil-based drilling muds. Contact Derm; 39: 262–3.
OSPAR. (2002) www.ospar.org/eng/html.
Ruth JH. (1986) Odor thresholds and irritation levels of several chemical substances: a review. Am Ind Hyg Assoc J; 47: A142–A151.
Sathiakumar N, Delzell E, Cole P, Brill I, Frisch J, Spivey G. (1995) A case-control study of leukemia among petroleum workers. J Occup Environ Med; 37: 1269–77.
Schnatter AR, Thériault G, Katz AM, Thompson FS, Donaleski D, Murray N. (1992) A retrospective mortality study within operating segments of a petroleum company. Am J Ind Med; 22: 209–29.
Simpson AT, Groves JA, Unwin, J, Piney M. (2000) Mineral oil metal working fluids (MWFs)—development of practical criteria for mist sampling. Ann Occup Hyg; 44: 165–72.
Taylor W. (1973) Noise. In Cumming RP, Taylor W, editors. Aspects of health and safety in oil development. Proceedings of a symposium held in Lerwick, 17–18 March 1973. Lerwick: The Shetland Times Ltd. pp. 61 –75.
UKOOA. (1990). UKOOA Procedure on industrial hygiene for the safe use of drilling fluids. Issue 1, Nov 1990, United Kingdom Offshore Operators Association Safety Committee—Environmental Health Working Group.
UKOOA. (2000). Guidelines for medical aspects of fitness for offshore work. A guide for examining physicians. Issue 4, Jan 2000. United Kingdom Offshore Operators Association Ltd, Health Advisory Committee.
Wiige H. (1996) Frequency of work-related diseases—an indictor of working environment standard. Proceedings of the third international conference on health, safety and the environment in oil and gas production. New Orleans. pp. 303–6.
Yang C, Zhang X. (1991) Incidence survey of leukemia in China. Chin Med Sci J; 6: 65–70.