GREENPEACE

AMENDMENTS TO THE LONDON CONVENTION

DISCHARGES FROM THE OFFSHORE INDUSTRY

THE ENVIRONMENTAL EFFECTS OF OIL AND GAS EXPLORATION AND PRODUCTION

Submitted by Greenpeace International to the
18th Consultative Meeting of the London Convention

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ABSTRACT

Offshore exploration and drilling for oil results in wide ranging adverse effects on the environment. Areas of particular concern are the impacts of seismic surveying; minor spills of oil during production; transfer and transportation of the finished product; and operational discharges of process wastes, such as drill cuttings, drilling muds and additives, produced waters, deck drainage and domestic sewage. This report shows that there is considerable potential for adverse impacts to arise from the normal operating procedures of the oil industry. Regulation to control these polluting activities are weak and no body exists to police adherence. For these and related reasons, it is important that the parties to the London Convention (LC) take urgent steps within that regime, as well as others, to ensure that operational discharges from offshore installations be regulated, controlled and restricted, and that LC Article III (c) be deleted or amended in order to meet that objective.

1. SUMMARY

1.1 Environmental Impacts

Offshore exploration and drilling for oil results in wide ranging adverse effects on the environment. Areas of particular concern are the impacts of seismic surveying; minor spills of oil during production; transfer and transportation of the finished product; and operational discharges of process wastes, such as drill cuttings, drilling muds and additives, produced waters, deck drainage and domestic sewage. Concerns relating to these impacts include the following:

1) seismic exploration involves the geophysical exploration for oil reserves by acoustic means. High pressure air guns have replaced explosives, but still generate sound waves which may be audible several tens of kilometres from the survey site.

There is little information on the effects of such activities in deep waters, and even less in shallow systems. Studies in Norwegian sectors indicate that fish stocks are severely reduced within 5 miles of a test site, with little recovery several days later.

Many marine mammals are particularly sensitive to acoustic pulses; studies of whales indicate wide avoidance of seismic test sites and other associated behavioural changes. No deaths or visible physical injuries have yet been related to airgun surveys. However, there is a lack of data on chronic effects on health such as auditory damage or other long-term physiological, behavioural and population distribution effects.

The paucity of information about potential effects on bird life, highlights the inadequacy of knowledge of seismic impacts on near shore systems;

2) spillage of oil can occur from production platforms, during transfer of oil from platforms to ships, and to and from storage facilities. Such spills, although generally relatively small, are frequent enough to be a problem, particularly in near shore waters. Corrosion of submarine pipelines has also been more rapid than predicted and many may now be in danger of rupture. Impact depends on location, hydrography and weather conditions, but the potential for localised acute and chronic damage is significant. For example, even small amounts of ingested oil may contribute to breeding failure in seabirds;

3) disposal of drill cuttings and drilling muds which are residues of the rock strata from drilling the well together with the synthetic muds used to cool, clean and lubricate the drill bit and control of well pressure. Drilling muds are specially formulated mixtures of clays or polymers, weighting agents and a variety of other

constituents suspended in petroleum-based material (oil-based muds, OBM) or water (water based muds, WBM). Additives include lubricants, surfactants, wetting agents, corrosion inhibitors and biocides; among these are a range of complex organic compounds and heavy metals. It is frequently impossible to obtain details of composition for commercially available products.

Because of the toxicity of diesel, used as a base in early OBM's, this was replaced in 1985 with a "low toxicity" formulation. However, recent research indicates little improvement of affected benthic communities and discharges of low-toxicity OBM's may still affect benthic community structure over a wide area surrounding a platform.

Immediate effects include smothering of resident flora and fauna. Long-term impacts, related to the spread of hydrocarbons and other contaminants, are the subject of much debate. Recent studies in Norwegian waters have overturned assumptions that toxic effects are restricted to a small area surrounding the discharge. Significant perturbations in community structure have been detected several kilometres from platforms.

A variety of sub-lethal effects have been demonstrated in organisms exposed to contaminated drill cuttings, including:

i) inhibition of growth and reproductive development in scallops;

ii) decreased feeding activity in deposit-feeding bivalves;

iii) reduced settlement of a range of benthic organisms;

iv) changes in immune responses of fish;

v) reduced spawning by herring in oil-contaminated sediments.

Low levels of dissolved oil-fractions can affect the viability of fish larvae and the growth of adult fish. Elevated levels of hydrocarbons, particularly PAH's, have been documented for fish tissue from drilling areas, which may also be linked to the reported higher incidences of liver diseases.

WBM may contain parts per thousand concentrations of hydrocarbons and, like OBM's, many other residues. WBM may raise local levels of heavy metals (notably copper, mercury, lead and zinc) in sediments. Even relatively neutral components, such as the clays and weighting agents, may significantly reduce colonisation and burrowing by polychaetes and amphipods. Little is known about the ways in which these complex mixtures of compounds react under extreme conditions in the well;

4) disposal of produced waters consisting of formation water from the well, mixed with production effluent. This accounts for the greatest discharge volumes

from offshore installations and, although oil concentrations may be relatively low, the hydrocarbons present can be carried over a wide area and may account for a high proportion of total oil discharges (e.g. 45% in Norwegian waters). The volume of production water increases with the age of the oil or gas field. In turn, the amount of oil discharged via production water will also increase.

Treatment prior to disposal typically involves gravity separation of oil and water phases after addition of chemicals to break the emulsion. However, final effluent may still contain elevated concentrations of water-soluble oil fractions (e.g. simple aromatics, naphthalene's, etc.), heavy metals (e.g. barium, vanadium, nickel, copper, cadmium, lead, mercury and zinc), radioactive salts and residues of other additives such as organic surfactants and biocides. Elevated cadmium and mercury levels have been demonstrated for waters in oil production areas;

5) -disposal of production chemicals - additives to drilling muds. A variety of such compounds are used, frequently added as poorly defined commercial products. Although there has been a move away from use of organochlorines as biocides, alternatives are generally toxic to a wide range of organisms and, for many, few ecotoxicological data exist. Some surfactants, notably the nonylphenols, are known to disrupt endocrine function in freshwater fish and may affect sexual development.

Formulation of chemicals is governed largely by process requirements, leading to production of low-grade, high impurity bulk chemicals. The environmental hazards of many are poorly understood, and yet no formal audits of chemical use are in place;

6) discharge of domestic sewage which could add significantly to local nutrient budgets, adding large pulses of bioavailable nitrogen and phosphorus to what might otherwise be nutrient-impoverished surface waters. Their contribution to overall nutrient budgets for inshore waters should also be evaluated; and

7) habitat disturbance affecting deep and shallow sea benthos through placement of platforms and pipelines and increased marine traffic especially during exploration drilling. Alteration of coastal habitats is also caused by construction of transport, storage and refining facilities. Some studies suggest lighting of structures may affect navigation in migrating birds. There have been no detailed studies of the impacts of continuous, low-level noise outputs related to routine production processes.

1.2 Regulatory Considerations

The Oslo and Paris commissions, to which UK is a signatory, have made a number of rulings and recommendations with respect to discharges from offshore installations.
Decision 92/2 on oil-based muds limits the oil content of OBM for discharge. Some PARCOM countries, notably the Netherlands and Norway, have taken further action, banning sea disposal of OBM contaminated wastes and insisting instead on land-based decontamination. The UK refuses to follow their initiative. Currently there is no regulatory body to police such discharges.

The CHARM model - based on the 1990 North Sea Ministerial Conference decision "to develop and adopt a harmonised, mandatory control system", the Chemical Hazard Assessment and Risk Management model - is still under development. A number of reservations about it have been raised, including:

i) heavy reliance on lethal toxicity tests;

ii) use of a small range of test organisms, which may not be most sensitive or representative;

iii) the interdependence of benthic and water column processes; and

iv) limitations on hazard determination imposed by commercial confidentiality of product formulations.

The information discussed above highlights the inadequacy of the CHARM model as with all similar risk assessment based approaches. Much damage may already have been done as many of the chemicals released will persist for years or decades in the environment. Further damage is to be expected as a result of increasing moves to explore and drill in inshore waters.

This report shows that there is considerable potential for adverse impacts to arise from the normal operating procedures of the oil industry. Regulation to control these polluting activities are weak and no body exists to police adherence. Models being developed to control chemical pollution are flawed and unlikely to form reliable regulatory tools. Seismic surveys and disturbance from general marine traffic have no controls at all.

The North Sea is currently suffering pollution stress as a result of wastes received from all countries on its borders. Areal deposition of pollutants is being increasingly recognised as a problem. Disturbing signs such as diseased and mutated fish are becoming increasingly common. The complexity of the inputs and the North Sea make it impossible to attribute changes to any one input. Recognition of the impossibility of establishing direct cause-effect relationships with regards to environmental problems has been one of the factors leading to the development of the precautionary principle.

Because it is clear that the processes of oil extraction in the North Sea are adding to the burden of pollutants and causing generalised disturbance, the precautionary principle should also be applied to these activities. Within the London Convention context, State Parties have shown a strong commitment to applying the precautionary principle in relation to ocean dumping and protection of the marine environment. For these and related reasons, it is important that the Parties to the London Convention (LC) take urgent steps within that regime, as well as others, to ensure that operational discharges from offshore installations be regulated, controlled and restricted, and that LC Article III(c) be deleted or amended in order to meet that objective.

2. INTRODUCTION

When you ask the majority of people what pollution risk is posed by oil and gas exploration and production they are most likely to cite the catastrophic oil spills from grounded tankers such as the Torrey Canyon, Amoco Cadiz or Exxon Valdez. Obviously oil transport accidents are of great and grave concern. However, little attention is paid to the smaller accidental spills and routine discharges that occur during normal operations associated with oil and gas exploration and production. During offshore exploration and drilling, a wide variety of liquid, solid and gaseous wastes are produced on the platform, some of which are discharged into the ocean. Discharged substances include cooling water from machinery, deck drainage, domestic sewage, drill cuttings, drilling fluids (muds) and produced waters. In addition, submerged parts of the platform may be protected against bio-fouling and corrosion with antifouling paints and sacrificial electrodes. All of these may release small amounts of toxic heavy metals to the water column, such as Aluminium, Copper, Mercury, Indium, Tin, and Zinc, (Dicks 1982).

Furthermore, few consider the additional adverse environmental effects associated with exploration, construction and transport of equipment, materials and product. The sequence of activities that takes place from evaluation of the resource potential, through to exploration, development, production and refining of oil and gas from offshore regions are summarised in Table 1, together with an abbreviated description of their potential effects (Neff et al; 1987).

The purpose of this report is to examine the different stages of oil and gas development from exploration to production and identify areas and practices that are of most concern and that could potentially affect the marine environment and species within it. The report also examines the regulations relating to offshore oil and gas development to determine whether these are adequate to address the risks identified.

Table 1. Major Activities in the Development of an Offshore Oil and Gas Field and Their Potential Effects on Marine and Coastal Environments.(Neff et al., 1987)

ACTIVITY	POTENTIAL EFFECT
EVALUATION	
Seismic Survey	Noise effect on fish and mammals
EXPLORATION	
Rig Fabrication	Dredging and filling of coastal habitats
Rig emplacement	Seabed disturbance due to anchoring
Drilling	Discharge of drilling fluids and cuttings; risk of blowouts
Routine rig operations	Deck drainage and sanitary wastes
Rig servicing	Discharges from support vessels and coastal port development
DEVELOPMENT AND PRODUCTION	
Platform fabrication	Land use conflicts and increased channelization in heavily developed areas
Platform installation	Coastal navigation channels, seabed disturbance resulting from placement and subsequent presence of platform
Drilling	Larger and more heavily concentrated discharges of drilling fluids and cuttings; risk of blowouts
Completion	Increased risk of oil spills
Platform servicing	Dredges and coastal port development; discharges from vessels
Separation of oil and gas from water	Chronic discharges of petroleum and other pollutants
Fabrication of storage facilities and pipelines	Coastal use conflicts
Offshore emplacement of storage and pipelines	Seabed disturbances; effects of structures
Transfer to tankers and barges	Increased risk of oil spills; acute and chronic inputs of petroleum
Construction of onshore facilities for transportation and storage	Coastal use conflicts; pipeline corridors
Pipeline operations	Oil spills and chronic leak

3. SEISMIC EXPLORATION

3.1 WHAT IS SEISMIC EXPLORATION?

Seismic exploration refers to geophysical exploration by acoustic means. In the past high explosives were commonly used as energy sources, however, arrays of airguns, gas exploders and vibrators are the dominant sources nowadays. When used in water these produce sounds with overall source levels of 220-225 dB re 1 uPa-m. Much of the seismic energy is directed downwards. However, there is also considerable seismic energy directed horizontally. Underwater sound pulses from airgun arrays and similar sources are often audible many tens of kilometres away (Richardson et al. 1995a in press).

There has been much concern expressed about the effects of seismic exploration. This ranges from the effects on fisheries and fish larvae especially in spawning areas, to the effects on birds and marine mammals, especially cetaceans, who use sound for communication, orientation and catching food. Information on the potential effects of seismic exploration is limited.

3.2 EFFECTS ON FISHERIES.

Research on the potential effects of seismic exploration on fisheries has increased recently. A number of Norwegian studies have raised worries over the effects of seismic testing on fish. Engas (1993) showed that seismic shooting with air guns has an effect on fish distribution and catching rates for cod and haddock, not only locally where the shooting takes place, but also in the surrounding area. The total quantity of cod and haddock in the investigation area, as measured acoustically, was reduced by 45% compared to the pre-shooting quantity. The reduction was largest within 5 nautical miles from the centre of the shooting area. The fish quantity decreased in both pelagic and bottom parts of the water column. Furthermore, the results from the catching trials agreed well with the acoustic abundance computations. When shooting began, the catch rates for cod by trawling and haddock by trawling and long lining decreased by about 50%, throughout the trial area. The reduction was greatest within the shooting area, where the decline in trawl catches was 70% compared to the level before the shooting began.

No increase in fish quantity was observed in the area during the subsequent five days in which the trials continued, after the shooting had ended (Engas, 1993). Other studies have drawn similar conclusions in this field with regard to reduced catches (Lokkeborg, 1991; Lokkeborg and Soldal, 1993).

A recent report commissioned by the United Kingdom Offshore Operators Association (UKOOA, 1994), points out that much of the Norwegian research was carried out in deep waters, 50-300m. For inshore waters there is limited evidence as to what the effects would be. To date one study has been conducted in the UK in inshore waters. Initial indications were that the catchability and distribution of the bass studied were not affected (Turnpenny and Nedwell, 1994. Fishing News 26/8/94). Each fishing boat caught an average of only 6.3lb (£23 worth) of bass per day during the period of the seismic survey, yet the report stated that catch rates were unaffected. This report was followed by a number of responses from fishermen claiming financial loss and drops in catch rates of bass, cod, dogfish, whiting and skate (Fishing News, 16/9/94), and even queen scallops (Fishing News, 30/9/94) during periods of seismic activity.

3.3 EFFECTS ON MARINE MAMMALS.

Detailed studies of the effects of seismic exploration on marine mammals in general is limited. However, research in North America has established that both baleen and toothed whales (cetaceans) have shown evidence of avoidance of seismic vessels which may in turn temporarily disturb the structure of local resident populations. Baleen whales are usually considered to be particularly at risk because they rely on low frequency sound in the same range as that used in seismic surveys for communication.

Baleen whales; A number of studies of the effects of seismic testing on large baleen whales, have highlighted behavioural responses. A review by Richardson and Malme (1993) on man-made noise and behavioural responses in bowheads, concluded that research from a number of studies, collectively showed that when an operating seismic vessel approaches within a few kilometres, most bowheads exhibit strong avoidance and specific changes in surfacing, respiration and dive patterns. Bowheads exposed to pulses from vessels more than 7.5 km away rarely show avoidance, but their surfacing, respiration and dive cycles tend to be altered in the same manner of those whales closer to the vessel. Experiments have shown that grey whales migrating along the Californian coast react to strong airgun pulses (Malme et al. 1983; 1984). Richardson et al. (1995a, in press) concluded that baleen whales seem quite tolerant of low and moderate level noise pulses from distant seismic surveys. However, in bowhead and grey whales, strong avoidance occurs when received levels are 150-180 dB, as occurs several kilometres from an airgun array. Bowheads sometimes swim a few kilometres away, and normal activities can be disrupted for an hour or more.

Richardson goes on to say that these short term observations provide no information about long term effects on baleen whales. It is not known whether impulsive noises affect reproduction rate or distribution and habitat use in the longer term.

Toothed whales; Very little research has been carried out as to the effects of seismic testing on toothed whales. Most energy from airgun arrays and other "high energy" sources is below 100Hz (Richardson et al, 1995a in press) which is considered to be below the frequency of the calls and optimum hearing of small odontocetes (toothed whales) (Richardson et al, 1995a in press; UKOOA, 1994). Thus, they may be rather insensitive to these sound pulses. However, Richardson goes on to point out that even at distances of many kilometres, overall received levels of airgun pulses are often > 130 dB re 1 uPa and thus potentially audible to toothed whales. Also, these pulses often include energy up to 200-500 Hz, where odontocete hearing is more sensitive. Thus, despite the apparently poor low frequency hearing of odontocetes, airgun pulses may often be audible to them out to a radius of 10-100km (Richardson et al, 1995a in press).

Dolphins have been known to approach survey vessels (Turnpenny and Nedwell 1994). Although this behaviour has been construed by some as demonstrating that seismic sound is of no threat or damage to them, it cannot be ruled out that this is due to other behavioural responses, relating to disturbance in the dolphins' resident area.

Research by Mate et al (1994), indicated that behavioural reactions by sperm whales to seismic pulses may occur at long ranges. Apparently sperm whales in the Gulf of Mexico appeared to move up to 50Km away from the site, when a seismic survey began. In addition to this sperm whales in the Indian Ocean ceased calling some of the time when seismic pulses were recorded from an airgun array > 300km away (Bowles et al. 1994).

The effects of seismic testing on marine mammals may not be limited to disturbance. Work on airguns has shown that their emissions have not been shown to be lethal to any species so far studied, nor has any other type of injury been demonstrated. However, damage to auditory systems, so far not investigated, cannot be ruled out (Turnpenny and Nedwell, 1994). Furthermore, in marine mammals noise can also influence non auditory physiology (Fletcher, 1971), by driving the stress response towards lowering resistance to disease and promoting hypertension and endocrine imbalance.

The conclusion of UKOOA's report (UKOOA, 1994) on the effects of seismic on cetaceans relied heavily on the assumption that one of the UK's largest populations of dolphins, in the Moray Firth has persisted in spite of the area's exposure to intensive seismic surveying using airguns over the last 30yrs. It is quite true that there is a resident group of animals in this area and that seismic activity has been common. However, as local researchers pointed out, there was no information as to the distribution or abundance of animals prior to the start of seismic activity. Indeed one of the potential concerns about disturbance is that animals may have few alternative areas to which they can move in order to avoid disturbance to their foraging and breeding activity. Therefore, the presence of animals in an area which is subjected to seismic testing is not evidence for lack of effect (Thompson, Pers Comm).

3.4 EFFECTS ON BIRDS.

Research on the effects of seismic testing on birds is minimal. Stemp (1985), refers to work carried out on chemical charges and airguns in the Hudson Strait, off Canada's eastern coast. Abundance surveys showed no significant difference between numbers of any of the three species studied, with or without seismic shooting. However as Stemp points out, the conclusions may not apply to inshore areas close to large bird aggregations or breeding colonies. The energetic requirements of birds are very finely balanced, especially during the breeding season. In important areas, such as breeding sites, food availability is crucial to breeding success (and as mentioned in section 2.2 seismic exploration may affect fish stocks). This problem is compounded when extensive seismic surveying is carried out over long periods. In Cardigan Bay, Chevron oil company were shooting continually during October and November 1994, followed by Marathon shooting in adjacent blocks during November and December. This amounted to three continuous months of seismic exploration in an area, nationally and internationally important for its seabird populations (Green, pers comm).

4. DISCHARGES RESULTING FROM OIL AND GAS EXPLORATION AND PRODUCTION.

Environmental impacts of offshore exploration and production can result from obstruction, debris, accidental spillage, chemical discharge and physical disturbance. All of these should be considered when assessing offshore exploration and production. Of these, oil and chemical inputs raise the most questions and concerns. Four major sources of oil and chemical discharge can be identified from offshore operations. Quantitatively oil is the most important, but substantial numbers of other chemicals are used in routine operations.

4.1 ACCIDENTAL OIL SPILLAGE.

Offshore oil and gas development carries with it the risk of oil spills at the platform and in transporting the oil from the platform to shore. In some cases oil is stored offshore and then transferred to tankers or barges. This method is considered the least safe as it creates an increased risk of both acute and chronic inputs. Minor spills during transfer to tankers etc. may be of little significance individually but are frequent enough to present a problem. For example, there were over 250 minor spills (most < 1 tonne) in UK waters alone in 1987 (Kingston 1992). Blowouts and leaks can occur at the platform during both exploratory and production drilling. Most

oil and gas produced offshore is transported onshore through pipelines. Pipelines can rupture or suffer chronic leaks. Davies (1991) highlights the problems associated with corrosion of long-distance oil transfer pipes which run exposed over the sea bed in deep waters. The assumed lifetime of these pipes (60-100 years) may have been over-estimated through determination under ideal conditions of transport of sterile and oxygen-free contents.
In practice, corrosion from the inside may already have significantly weakened pipes in many areas, increasing the risk of breakage if encountered by deep-water trawling gear (Davies 1991).

In the North Sea accidental spillage accounts for a relatively small proportion of the total oil extracted by the offshore industry in normal operation. Nonetheless, reported spills from the offshore industry have risen steadily from 92 in 1980 to 249 in 1991. In 1991 35% of the spills reported were over 100 gallons in size (DOE 1993). Offshore blowouts could alter that picture considerably: the Ekofisk Bravo blow-out spilt between 15-22kt of crude oil over a period of seven days as compared to the Gulf of Mexico spill of 455kt over a nine month period from the Ixtoc I.

The impact of spills depends on a number of factors. These include the type of oil, the size of the spill and weather conditions. The success of any attempt to recover the oil will also depend heavily on the season and weather conditions. Even under good conditions, the maximum percentage of oil recovered from a spill is 10-15%. Obviously the larger the spill, the worse the potential environmental consequences. However, in inshore areas which are known to be environmentally sensitive even regular, small- scale spills and leaks may cause considerable environmental damage.

4.2 DRILL CUTTINGS AND MUDS

4.2.1 Use and Derivation.

During exploration and the initial phases of production extensive drilling operations are undertaken. The major discharges associated with these processes are drill cuttings and drilling muds. Drilling muds are used to cool and lubricate the drill bit, to remove rock Chipping's from the well and most importantly, to maintain safety during drilling by assisting in well pressure control (UKOOA 1994). Drill cuttings are particles of crushed sedimentary rock produced by the action of the drill bit as it penetrates into the substrata. The cuttings are transported to the surface with the drilling mud, which comes out at the drilling bit, and returns (with the cuttings) to the drill floor on the platform. The mixture of drilling mud and cuttings is put on a moving sieve. The drilling muds that drain off this mixture is (often) reused, the cuttings polluted with either oil based muds or water based muds is either discharges or stored for transport to land.

4.2.2. Contents of Drilling Muds

There are two main types of drilling muds, water based muds (WBM) or oil based muds (OBM). The components of WBM and OBM are numerous, including barite with variable amounts of toxic heavy metals, bentonite, inorganic salts, surfactants/detergents, a variety of organic polymers, corrosion inhibitors, biocides and lubricants suspended or dissolved in water (WBM) or in oil / water emulsions (OBM) (Zevenboom et al. 1992). In spite of their name, water based muds also contain significant levels of hydrocarbons (100-7000 ppm reported), (Morris pers. comm.).

During drilling, the mud engineer continually tests the drilling fluid and its composition to counteract changes in "down hole" conditions. Composition is changed by varying amounts of core ingredients and the addition of various other ingredients. There are over 1000 additional trade name or generic materials available for drilling fluid formulation (World Oil, 1980) that can be added to drilling muds. The exact chemical composition of many of the additives are closely guarded secrets by competitive manufacturers. In the recent exploration drilling off Pembrokeshire, Wales, the oil company Marathon discharged a total of 896 tonnes of drilling muds. Both Marathon and the Department of Trade and Industry only provided the trade name of chemicals. An example of how misleading this can be is with the additive known commercially as "SOLTEX". Marathon describe soltex as Lignite (Non asphaltic) and further describe it under a common name as cellulose based. However, Greenpeace UK were able through a confidential source to get a typical analysis for heavy metal content of SOLTEX, as shown in Table 2.

Table 2. Typical Analysis of Heavy Metal Content of Product "Soltex".

COMPONENT	Concentration (mg/kg)
Antimony	6.0
Arsenic	0.4
Barium	16.0
Cadmium	0.6
Chromium (Total)	1.2
Cobalt	2.0
Copper	1.3
Fluoride	200.0
Lead	3.0
Mercury	0.2
Nickel	11.0
Vanadium	16.0
Zinc	2.1

Irrespective of the exact concentrations of heavy metals, it is disturbing that the product can be described simply as cellulose based, with no reference made to the fact that it also contains toxic substances.

It is often the inactive and more unusual ingredients that are identified in details of material used or disposed of at sea, such as "pecan shells and Hog hair". However, as Table 3 indicates, in addition to inactive ingredients which are found in both WBM and OBM, there may be a range of toxic and caustic agents. Of these compounds, arsenic, asbestos, compounds of chromium and zinc, organophosphates and potassium hydroxide and lead are particularly hazardous.

Chromates and arsenicals have been used extensively as corrosion inhibitors and additives in drilling muds and fluids. Lead is the primary component of drill collar and pipe joint compounds commonly referred to as "pipe dope". During the drilling operation, when it becomes necessary to replace worn or broken drill bits, the string of pipe pieces in the bore hole must be pulled and disengaged many times. The trips of the pipe string in and out of the bore hole require the use of many pounds of "pipe dope" or thread compound to treat the pipe joints. These compounds often contain in excess of 30% lead (Edwards, 1989).

Table 3. A Partial List of Components of Oil Well Drilling Muds and Fluids (Edwards, 1989).

Arsenic	Mineral wool
Asbestos	Olive pits
Asphalt	Organophosphates
Attapulgite	Organic polymers
Bagasse	Pecan shells
Barite	Polyphosphates
Bentonite	Potassium carbonate
Calcium bromide	Potassium chloride
Calcium carbonate	Potassium hydroxide
Calcium chloride	Quebracho
Calcium hydroxide	Sepiolite
Calcium oxide	Sodium bicarbonate
Calcium sulfate	Sodium chloride
Chromic chloride	Sodium dichromate
Chromium potassium sulfate	Sodium phosphate
Coal	Sodium sulfite
Cottonseed hulls	Starch
Diatomaceous earth	Tannins
Gilsontie	Vermiculite
Guar gum	Wood bark
Hog hair	Wood shavings
Lignite	Xantham gum
Lignosulfonates	Zinc bromide
Magnesium chloride	Zinc carbonate
Magnesium oxide	Zinc chromate
Mica	Zinc sulfate

4.2.3. Development of Drilling Muds

Oil based muds came into use in the North Sea, in response to frequent problems caused by the collapse of wells and sticking drill strings. After 1985, the use of diesel as a base oil was discontinued due to the high toxicity of its aromatic hydrocarbon content, in an attempt to lessen the environmental impact of the cuttings discharge (Kingston 1994). The diesel based muds were replaced with low aromatic based oils or "low toxicity" drilling fluids. However recent research has shown that similar effects have been observed for these as with diesel based muds (Kingston, 1987; Howarth, 1991 and Reiersen et al, 1989).

As a result of further research and environmental assessments the discharge of all oil-based drilling muds (including low aromatic based oil muds) is no longer permitted by certain North Sea States such as Norway, (Olsgard and Gray 1995) and the Netherlands. Although these muds are still used, contaminated drill cuttings containing oil based muds have to be taken ashore for treatment. However, in the UK sector of the North sea oil mud contaminated drill cuttings are still discharged into the sea and represent a major source of hydrocarbon input (Law 1992). Furthermore, in areas where they are no longer discharged or used, the hydrocarbons and heavy metals previously released can persist at elevated concentrations over a wide area for many years.

The recognised environmental impact of oil based muds led to the development of water based muds. These are presently promoted as the "environmentally friendly" alternative. However, as shown in previous section they still contain considerable quantities of hydrocarbons and numerous toxic chemicals and heavy metals.

4.3 PRODUCED WATER

4.3.1 Use and Derivation.

In addition to oil and natural gas, oil reservoirs may contain considerable quantities of water, termed connate (fossil or formation) water. As with the organic materials, water can accumulate where a layer of permeable sedimentary rock lies between impermeable layers (e.g. shale) and where lateral advection is prevented by rock formations. The reservoir formation layer is constituted according to relative density, with gas at the shallowest depths, then oil, and water at the greatest depths. The presence and relative proportions of these three phases may vary greatly between reservoirs (Neff et al. 1987), and over time in drilled wells as water flows in to replace abstracted oil and/or gas.

During production of oil and/or gas, formation water may come to the surface as well. At the production platform the formation water will be separated from the oil and/or gas. This separated water, which also contains hydrocarbons, chemicals from the reservoir and production chemicals injected during production is called production water. Production water is often, after simple treatment, discharged into the sea. Over time as an oil or gas field matures the amount of water produced with the oil or gas often increases as the amount of oil produced decreases (Read, 1978). In old fields, production may consist of 94% water and 5% oil or gas. (Neff et al .1987).

4.3.2 Contents of produced water.

Produced waters are principally salt solutions. However most are more concentrated than sea water (sea water contains 35 parts per thousand of salt) and are thought to be of marine origin. They have an ionic composition similar to an evaporate of sea water, and, with some exceptions, sodium and chloride are the most abundant ions. The content of elemental sulphur may also be high. In produced water from the Buccaneer gas and oil field in the North-western Gulf of Mexico the maximum concentration of sulphur was 1200 ppm and the mean 460 ppm (Middleditch, 1981). Based on available analysis metals may be present in substantially higher concentrations than in sea water (Middleditch, 1981). These include Barium, Beryllium, Cadmium, Chromium, Copper, Iron, Lead, Nickel, Silver and Zinc. Research in the Gulf of Mexico, analysing produced water effluent, identified high concentrations of Barium, Vanadium, Nickel, Zinc, Copper, Cadmium, Mercury and Lead. In most cases, concentrations of these nine metals exceeded levels normally found in freshwater and sea water by a factor of 1000 (Forstner and Wittman, 1983).

Produced water may also contain radionuclides, primarily in the form of radium. The radium is derived from the natural concentrations of uranium and thorium associated with the clay minerals and quartz sands that make up the matrix of the hydrocarbon/water reservoir (Reid 1983). In the North Sea, many platforms have accumulated Low Specific Activity (LSA) scale. LSA scale is produced when formation water, which dissolves radioactive salts in the rock, is mixed with treated sea water that has been injected (in the case of an oil field), to maintain pressure as the oil is extracted. The result is a precipitation of barium sulphate (AURIS, 1993), which may build up as scale on the inside of piping, or may be passed out in the produced water. Southern North Sea gas fields have a problem with polonium 210 contamination, although no detailed information exists in the public domain.

Production water also contains high concentrations of oil. A part of the oil is dissolved in the water, the other part is in dispersion. Oil and water phases are first allowed to separate in a gravity separator, the water may then be treated to remove dispersed oil through the use of emulsion or reverse-emulsion breakers, before being discharged into the sea. PARCOM regulations limit the oil content of produced waters to 40ppm. However, these PARCOM regulations only apply to aliphatic hydrocarbons and take no account of the aromatic hydrocarbons, including the very toxic Polynuclear Aromatic Hydrocarbons (PAH's). The produced water treatment system is designed primarily to remove particulate or dispersed oil and therefore has little effect on the concentration of dissolved petroleum hydrocarbons, other organic and metal ions in the produced water (Jackson et al., 1981; Lysyj, 1982). The toxicity of petroleum in formation waters is high relative to the parent oil, because these fluids are enriched in aromatic hydrocarbons which are the most soluble and toxic fractions of crude oil (Lysyj et al., 1981; Neff et al., 1987). Concentrations of soluble non-volatile organic compounds in produced water may be as high as 500-600mg/l and they are not removed by conventional treatment methods (Lysyj, 1982). Some chemical and physical characteristics of treated produced water from 10 platforms in the North-western Gulf of Mexico are summarised in Table 4.

Produced water may also contain a variety of chemicals from deck drainage effluent, including detergents, solvents and metals. This is often processed through the oil/water separator before discharge with the produced water into the ocean. In addition, a wide variety of chemicals may be added to the process stream of the oil/water separator and ultimately appear in the effluent water (Middleditch, 1984). These may include biocides, coagulants, corrosion inhibitors, cleaners, dispersants, emulsion breakers, paraffin control agents, reverse emulsion breakers and scale inhibitors (see section 4.4 production chemicals) The concentrations of these materials are not well known (Neff et al., 1987).

4.4. PRODUCTION CHEMICALS.

The precise scale of chemical usage in North Sea offshore operations is unknown. However the market in chemicals in early 1989 was estimated at 25 million Sterling per year (Vik et al., 1991). Very few studies have been directed at determining the discharge of chemicals which may be added into the process at concentrations between 0.5 and 100ppm. These chemicals can be introduced at any one of between 10 and 15 injection points on a continual or intermittent basis. Estimated total chemical discharge in the offshore industry is 57% of drilling chemicals and 30% of production chemicals amounting to 84,097 and 5934 tonnes respectively (Hudgins 1991). Chemicals used include biocides, corrosion inhibitors, scale inhibitors and gas treatments. Stimulation and workover chemicals include fracturing agents, propants and brines.

Biocides previously used in drilling muds included highly toxic organochlorines (e.g. dichlorophenol, chlorophenals; Tagatz et al. 1979). These highly persistent chemicals will tend to accumulate in the lipid rich tissues of marine organisms and may then bioaccumulate through the food web. There has since been a move towards formaldehyde based products which, although toxic, are less persistent and do not accumulate in body tissues. Drilling fluids also normally contain corrosion inhibitors (Kelley 1983), frequently complex organic compounds of nitrogen (e.g. amines, carboxylic acids with nitrogen substitutions). Although these are not among the most acutely toxic compounds, little is known of their sub-lethal effects at low concentrations or of their fate in biological systems. Compounds of chromium and arsenic, both highly toxic, are also widely used as corrosion inhibitors.

Surface active agents are commonly used to control viscosity, emulsion stability, drill friction and other aspects of fluid dynamics (Smith 1983). Derivatives of phenol and nonyl phenol are typically employed; nonyl phenols are one of many chemical groups possessing known oestrogenic effects, which have been demonstrated in freshwater fish. Cationic surfactants may be added as "oil-wetting" agents to ensure that the oils flow smoothly up the bore of the drill.

Occasionally it is necessary to add defoaming agents to the drilling fluid; a number of compounds are employed, including tri-n-butylphosphate, aluminium stearate, alcohols and polyethers (Smith 1983).

Many of these chemicals will be carried over into the produced water. Other substances may then be introduced to treat the produced water prior to discharge, such as emulsion breakers (or reverse emulsion breakers if the oil content is high) to split the aqueous and oil phases and minimise oil discharges to the surrounding waters.

The use of these chemicals has largely been governed by production needs with little apparent research upon effects. An overview has identified serious shortcomings in the adequacy and evaluation of offshore chemicals (Vik et al., 1991). No formal system of chemical use auditing is in place, while the environmental hazards are poorly understood in the case of most chemicals. Toxicological studies are limited by the lack of a defined toxicity/biodegradability test, while toxicity data is restricted largely to LC50 determinations (Hudgins 1991). Smith (1983) notes that the oil industry has an enormous demand for chemicals of low purity; the possible presence of unidentified contaminants in low-grade bulk chemicals is further cause for concern.

5. ENVIRONMENTAL EFFECTS OF DISCHARGES.

There are three main sources of discharge: **Accidental oil spills;**
Drill cuttings and muds;
and, Produced Water:

5.1 ACCIDENTAL OIL SPILLAGE

Although the evidence is far from conclusive that oil pollution has damaged fish populations on any large scale, there are a variety of reasons to believe that oil can indeed harm fisheries. Oil pollution clearly reduced spawning by herring on contaminated sediments following the Tsesis spill in Nellbring et al., (1980). Of the fish eggs spawned, a smaller percentage actually hatched on the contaminated sediments (Nellbring et al., 1980). For fish that spawn on sediments (as opposed to in the water column), sediment contamination may pose a long term threat because of the persistence of oil derived hydrocarbons. More than a year after the Exxon Valdez spill, pink salmon fry collected in spawning streams that had been contaminated with oil showed signs of being exposed to toxic components of that oil (as indicated by the induction of oil-detoxifying enzymes; ADEC, 1990). A variety of other fish species collected over contaminated sediments and near contaminated beaches showed a similar exposure to the oil (ADEC 1990)

The impact of a spill depends on a number of factors, one of which is the type of oil spilled. Oil containing high levels of Polynuclear Aromatic Hydrocarbons (PAH's) are of particular concern in that PAH's are known to be carcinogenic.

Oil can kill planktonic fish eggs, even at very low concentrations of dissolved hydrocarbons (Mironov, 1968; Johannessen, 1976; Longwell, 1978; Kuhnhold et al., 1978; Teal and Howarth, 1984). Vandermeulen and Capuzzo (1983) concluded that dissolved oil in concentrations as low as 2 to 10 ug per litre adversely affect the viability of fish larvae. Low-level oil pollution can also slow the growth of fish larvae. This would be expected to increase predation on the larvae, resulting in fewer adult fish (Howarth 1989). Because of its constancy over years and decades, chronic oil pollution, such as that from urban sources and from offshore oil development, may pose a serious risk to planktonic fish eggs and larvae. In addition, laboratory studies in the United States have shown that very small quantities of oil ingested by sea birds can lead to failed breeding in future years (Green, pers. comm.).

5.2 ENVIRONMENTAL EFFECTS OF DRILLING MUDS

Early research into the potential effects of discharged drill cuttings contaminated with drilling muds suggested that there were no evident effects. However, more recent research and refined sampling techniques are now pointing to wide-spread environmental effects. Whether oil based or water based, the initial effect muds can have is one of localised smothering. If there are a number of wells or platforms in a restricted area, then the dumping of contaminated drill cuttings may lead to a cumulative increase in sediment loads, with subsequent effects on, and possible exclusion of, benthic plants and certain bottom-dwelling invertebrates and fish.

The Paris Commission Group on Oil Pollution estimated that in 1988 alone, 22,500 tonnes of oil were discharged to the North Sea, attached to drill cuttings (Petersen et al. 1991). Although only "low toxicity" oil-based drilling muds were used in the North Sea in 1988 (and subsequent years), build up of these cuttings has been found to induce significant alterations in the benthic community structure (Gray et al.1990) . These "low toxicity" oil bases, consisting mainly of long-chain paraffins and saturated aromatics, are highly resistant to chemical and biological decay and so tend to persist in surface or underlying sediments (Petersen et al. 1991).

Although a large proportion of the drill cuttings may collect within a relatively small area around an individual platform, the combined impacts of several platforms may be much wider. For example, Kingston (1992) reported elevated hydrocarbon concentrations in sediments in an area approximately 5-10km radius surrounding the group of platforms in the Shetland Basin oil field. In spite of this it is still widely assumed that effects on the benthos are restricted to the areas of heavy cutting load immediately surrounding each drilling platform.

This assumption has recently been challenged. Prior to the application of multivariate statistical analyses, calculation of diversity indices had suggested that significant effects on the community were not detectable beyond a 1-1.5 km radius of drilling platforms. Using multivariate techniques, Gray et al. (1990) demonstrated that perturbations to the benthic community surrounding the Ekofisk field extended over 27 km2, rather than the 3 km2 previously estimated. Some effects were relatively subtle, such as changes in the presence/absence ratios of the rarer species, but nevertheless represented important perturbations to the natural community. Daan et al. (1990) reported that, while major impacts on species richness and abundance were generally limited to within 100-250m of a platform, the densities of sensitive species often showed clear gradients over the entire 5 km radius. The common sea urchin, Echinocardia cordata, appears to be a particularly useful indicator of low level cutting fluid contamination (Daan et al. 1994).

Similarly, Olsgard and Gray (1995) demonstrated significant contamination and biological impacts within a radius of 2-6km from disused drilling platforms in Norwegian waters. Although some degradation of hydrocarbon components did occur, the contaminated areas around platforms continued to increase in size over 9 years after cessation of drilling operations and cuttings discharge. Within the contaminated area, the levels of effects on benthic community structure correlated broadly to levels of contamination, although effects could not be attributed to any one factor present in the cuttings. Zevenboom et al. (1992) measured higher tissue hydrocarbon levels in caged mussels 5 km down current from a cuttings discharge than in control specimens incubated in clean water.

Previous studies have relied heavily on diversity indices and a small number of indicator organisms to determine the significance of contamination. While such measures may reliably indicate gross pollution, they are insufficiently sensitive to detect important, but more subtle, community-level effects (Parrish and Duke, 1990). A small change in the abundance of one organism can have a wider impact. For example, the echinoderm Amphiura filiformis, present at significantly lower densities in the vicinity of the Valhall and Gyda fields, is the principal food organism for plaice, dab and sole and an important prey for cod, haddock and whiting in Norwegian coastal waters (Olsgard and Gray, 1995). In other circumstances, the effects of decreasing toxicity in moving away from the contamination source may be masked by an increase in relative grazing pressure as the prey becomes more abundant Bonsdorff et al. (1990).

A variety of more subtle, sub-lethal effects have been observed in marine invertebrates.

1) Adult scallops from the Georges Bank, exposed to oil-based cuttings, showed decreases in development of tissues and reproductive cells and failure to accumulate lipid reserves (Cranford and Gordon 1991). These effects could not be attributed to any one constituent of the "low toxicity" drilling mud to which they were exposed;

2) Chronic exposure of Abra alba, a deposit feeding bivalve, to hydrocarbons and to oil-based drilling muds led to a decrease in faecal pellet production which appeared to be related to suppression of feeding activity (Stromgren et al. 1993). The effect, which could also reduce bioturbation rates of sediments in which this organism dominates, correlated well with the concentrations of naphthalene derivatives in the sediment; and,

3) Plante-Cuny et al. (1993) demonstrated a significant reduction in settlement of a range of benthic organisms (with the exception of Capitella capitata) on sediment contaminated with Arabian light crude or with diesel oil-based mud cuttings in experimental enclosures. These effects persisted for 3 months and for more than 1 year respectively.

Many sub-lethal effects have also been reported for marine vertebrates. For example, the dab (Limanda limanda) shows a complex immune response when exposed to diesel oil-based drilling muds (Tahir et al. 1993).

Gross pollution impacts close to the point of discharge are probably mediated by a mixture of physical (smothering and modification of sediment characteristics), microbiological (provision of organic substrates) and toxicological processes, which are difficult to separate. Dow et al.(1990) reported stimulation of microbiological activity in sediments amended with oil-based muds, leading to a decrease in redox potential and an increase in sulphide production (see also Bonin et al. 1990). High levels of contamination led to rapid anoxia and cessation of hydrocarbon deterioration, and could explain the long-term persistence of these compounds in sub-surface sediments (e.g. De Jong and Zevenboom 1993a, Daan and Mulder 1994). The localised redistribution of sediments can give a false impression of the extent of bioremediation of a contaminated site, as toxic components may simply become buried in patches under a thin layer of clean sediments (Stebbing et al. 1992). All macro- and meiofauna were excluded by sieving the sediment prior to this experiment, but any such organisms would undoubtedly have been killed by the low oxygen tensions. Further away from the site of deposition, changes in abundance and exclusion of organisms probably relate more to toxicological effects of heavy metals, PAHs and other constituents of both oil based and water based drilling mud.

Some longer-term studies (9-10 weeks) have suggested adverse effects of the neutral weighting agent, barite (found in both OBM's and WBM's), on the composition of macrofaunal and meiofaunal communities in sandy systems (Tagatz et al. 1978, Olsgard and Gray 1995), perhaps principally due to changes in the physical structure and organic content of the sediment, given the relatively low toxicity of the weighting agent itself. A layer of barite only a few mm thick significantly reduced colonisation by certain benthic organisms, notably polychaete worms and the amphipod Corophium sp.

It is well known that oil installations attract certain fish species (Picken & McIntyre 1989). Accumulations of rock cuttings from the well contaminated with oil based muds (known as the cuttings pile) could act as sources of hydrocarbon contamination. Cod livers sampled close to a drilling platform in the North Sea show clear contamination effects from the base oil used in the drilling mud. Comparisons were made with the tissues of fish caught off Stavanger and in Oslofjord. Levels of Polynuclear Aromatic Hydrocarbons (PAH's) were 5-10 times higher in the North Sea samples (Drangsholt et al., 1988). Studies carried out for the Bremerhaven workshop on biological effects of contaminants in the North Sea (Initiated by the IOC group of experts on the effects of pollution) have shown that PAH's are associated with liver disease in North Sea fish (Stebbing 1992b).

In oil based muds the base oil produced the most visible environmental effects. However, concern is now being expressed over the other ingredients within both oil based and water based muds. Information is gradually becoming available on heavy metals in sediments around offshore drilling locations. It is however difficult to present an overall picture as heavy metals are found in both OBM's and WBM's. In the Dutch North Sea sector, elevated levels of heavy metals (Cu, Hg, Pb, Zn) were detected in the sediments around a WBM drilling site and may be found up to 1km away from the discharge point.

Table 3 lists a considerable number of other chemicals associated with oil and water based muds. Identification of specific chemicals is unfortunately very difficult. Product names are available, but specific ingredients are subject to commercial confidentiality. Furthermore, components in the drilling mud will react with the formation being drilled, resulting in chemical and physical changes in the mud (Hudgins, 1991).

5.3 ENVIRONMENTAL EFFECTS OF PRODUCED WATER

Quantitatively production waters are one of the most important sources of oil entering the sea from offshore facilities although estimates vary. In 1985 it was estimated that 4,244 tonnes of oil were discharged via produced water in the North Sea (Vik et al., 1991). However, figures given in the 1986 North Sea Quality status report suggested a maximum figure in production waters of 2,876 tonnes of oil (DOE 1987).

The proportion of produced water increases over the lifetime of a well (Kingston, 1992). In old fields for example, production may be 94% water and 5% oil or gas (Neff et al., 1987). There is concern about the likely increase in produced water discharged from North Sea Installations. In 1987 Norwegian platforms discharged 4.5 million tonnes of produced water. By 1990 this had risen to 12.5 million tonnes (Valvatne, 1991). Despite the relatively low hydrocarbon content compared to the drilling muds, produced water accounted for approximately 45% of total oil discharges to Norwegian waters in 1992 (Furnes and Frydenbo 1994). Daniels and Means (1989) estimate 1.79 million barrels of produced water are discharged each day to the coastal and estaurine waters of Louisiana, USA. Estimates for all operations in the US indicate that some 70% of the total fluid volume produced is formation water (Vik et al., 1991). Furthermore, as the field gets older the levels of dissolved hydrocarbons and contaminants in the water increases.

The oil discharged in production waters is in the form of finely dispersed droplets which can elevate hydrocarbon levels some distance from the production rig. Oil in this form may be readily taken up by marine organisms. After separation of crude oil and water, salts of acetic, propionic and butyric acids occur in the water together with between 20 and 40mg/l of dissolved aromatic hydrocarbons such as benzene, toluene and xylene. The acetic acid content of produced waters may reach 700ppm (Stephenson 1992). The precise composition of the dissolved component tends to vary with individual fields. Produced water from gas condensate operation tends to be higher in phenols and low in molecular weight aromatic hydrocarbons than waters from asphaltenic oil production which may have high loadings of napthenic acids. Statements that impacts of such chemicals are restricted to an area close by the rigs (Somerville and Shirley 1992) must be counterbalanced against the findings that similar chemicals discharged from land based sources can persist in sea water some distances offshore (Law et al., 1991) and that the ecotoxicological data base for full evaluation of these chemicals is poor (Mathiessen et al., 1993) (see section 4 on PARCOM and CHARM models).

Kingston (1992) reported a shift from low molecular weight hydrocarbons in sediments close to a platform, to higher molecular weight compounds and a larger proportion of unresolved material at some distance away. This suggests that the latter, less refined, products may represent contamination from produced waters, which travel greater distances than cutting and mud wastes.

TABLE 4. Concentrations of selected petroleum hydrocarbons in produced water effluents from the Buccaneer platform in the north-western Gulf of Mexico: Concentrations in ug/l (ppb), (From Neff et al., 1987).

COMPOUND	FROM MIDDLEDITCH 1981	FROM SAUER 1981
AROMATIC HYDROCARBONS:		
Benzene	6100	1150
Toluene	5460	7460
Ethylbenzene	1200	850
m-p- and o-oxylenes		3570
Total C3-Benzenes	24.2	5590
C4-Benzenes	22.2	830
C5-Benzenes	4.5	NA
C6-Benzenes	3.2	NA
C7-Benzenes	0.9	NA
C8-Benzenes	1.2	NA
C9-Benzenes	2.4	NA
C10-Benzenes	1.0	NA
C11-Benzenes	0.3	NA
Naphthalene	11.1	170
Methylnaphthalenes	7.2	20
C2-Naphthalenes	10.4	NA
C3-Naphthalenes	4.3	NA
C4- and C5-Naphthalenes	0.9	NA
Biphenyl or Acenaphthene	2.8	NA
C1-and C2-Biphenyls	2.9	NA
ALKANES:		
C1-C13	3120	3100
Cycloalkanes	2580	1060
Alkenes	580	NA
C14-C29	1476	NA
Total Aromatics	12,860	16,070
Total Alkanes	4596	3170
Total Cycloalkanes	2580	1060
Total Alkenes	580	NA
	----------------	--------------
Total Hydrocarbons	20,616	20,300

A Dutch review of the effects of production waters on the marine environment (Slager et al., 1992) notes that the concentrations of chemical contaminants in gas/condensate platforms on the Dutch continental shelf are considerably higher than those found from oil production platforms. There is considerable variability in the toxicity of produced waters depending on the source field and the age of the field. The fate of chemicals in the production water will depend upon a number of interacting biotic and abiotic processes. Overall toxicity appears to result from the additive interactions of the individual toxic components. The review concludes that reliable field data are lacking and that a particular need exists to evaluate potential bio-accumulation of the metals cadmium and mercury and the persistent PAH's. Moreover, the various dispersion models used to asses potential impacts lead to widely variable values, further impeding an accurate assessment. Nonetheless, the possibility of chronic impacts of production water at distances up to 1km from the site was identified together with bio-accumulation of hydrocarbons.

In addition to oil and hydrocarbon chemicals, the produced water may contain heavy metals, natural radionuclides, process chemicals and salts. Data taken from a number of studies have shown high concentrations in produced waters (Stephenson 1992). These include cadmium which has been found at concentrations of up to 98ug/l (mean 27ug/l). Chromium and lead have been found at concentrations of 390ug/l and 5700ug/l with means of 186 and 315 ug/l respectively. These mean values substantially exceed the background levels of dissolved cadmium and lead in the water entering the North Sea via the English Channel (Tappin et al., 1993).

There are indications from a survey of mercury in the North Sea that elevated reactive mercury concentrations in sea water result from operations of the oil and gas industry (Schmidt 1992). Surveys in the summer of 1986 and the winter of 1987, both found high mercury concentrations off the north east coast of Scotland. In the winter survey, levels in excess of 200ng/l were found at 10 stations off this coast. The study concluded that these elevated levels could be due to the high levels of gaseous elemental mercury known to be present in gas reserves from some fields. Evidence of elevated cadmium levels in sea water along the same transect where elevated levels of PCBs were found by Schultz-Bull et al, (1991) points to oil operations as a source of dissolved cadmium (Hydes and Kremling 1993).

Predicting or understanding the potential for long-term environmental impacts arising from the discharge of produced water into coastal waters is impeded because biological effects of whole produced waters have received little attention (Neff et al., 1987). To the extent that laboratory bioassays have so far been applied to produced waters, most indicate that these wastes do not appear to be acutely toxic. However, such experiments are normally based on lethal toxicity tests with single species systems (e.g. Acarti tonsa; Girling 1989). For example Krause et al., (1992), found that brief exposure of sea urchin gametes and prolonged (96hr) exposure of zygotes did not result in increased mortality even at the moderately high concentration of 1% produced water. However, they did detect sub-lethal responses to produced water at substantially lower levels; statistically significant responses of young purple sea urchins were detected at produced water concentrations as low as 1 part per million, with the magnitude of the response(s) increasing with increased concentration of effluent. It has been argued that such sub-lethal or chronic effects may be a better gauge of potential environmental significance than the acute lethality of an effluent (e.g. Capuzzo, 1987; Neff, 1987). The initial study by Krause et al (1992) was laboratory based. However, effects under field conditions were examined by exposing urchin gametes and larvae to water collected at different distances from the produced water diffuser and compared these results with those obtained from known concentrations of produced water (Krause, unpublished data). These results suggest that although produced water is rapidly diluted (The diffuser is designed for an initial sea water effluent dilution of 125:1), detectable developmental effects can persist out to 100-500m, where produced water concentrations drop to approximately 1ppm (Krause et al., 1992).

Other recent biochemical studies indicate that the water-soluble-fractions (WSF) of oils, such as may be present in produced waters, may interfere with a wide range of physiological processes at very low concentrations. For example, cod (Gadus morhua) are capable of detecting petroleum hydrocarbons at concentrations as low as 0.0001 ppm, and will avoid waters containing > 0.1 ppm (Blaxter and Ten Hallers-Tjabbes 1992). 0.01 ppm kerosene WSF inhibits prey recognition in the bivalve Nassarius obsoletus, while 0.025 ppm Prudhoe Bay Crude WSF reduces foraging efficiency in the shrimp Pandolius americanus. Predation avoidance in the echinoderm Strongylocentrotus droebachiensis is impaired by Prudhoe Bay Crude WSF at 0.05 ppm, and reproductive behaviour in the sea slug Onchidoris bilamellata is suppressed in the range 0.015-0.06 ppm.

It is often stated that impacts of production waters in the marine environment are negligible due to the dilution factors. A recent report by the UK Offshore Operators Association (UKOOA 1994) stated that, "no detectable environmental impacts have arisen from this practice (disposal of produced water), because the minute amounts of oil are rapidly dispersed and biodegraded". However, research is increasingly showing significant environmental effects of such discharges. Planktonic larvae can be adversely affected by produced water plumes even from discharges in high energy, open coast environments (Raimondi and Schmitt, 1992). Osenburg (1992) also concluded that the production of tissue in mussels was affected by produced water out to a distance of at least 100m and perhaps beyond 1 km from a produced water outfall. Osenburg's results like those of Raimondi and Schmitt (1992), also suggested that important biological effects can occur over large spatial scales, despite the discharge into a high energy environment. Rabalais et al (1992) working on bio-accumulation in oysters, showed the clear potential for uptake and accumulation of produced water origin contaminants, both in close proximity to discharges, but also to greater distances (350 to 1000m).

With the move to inshore exploration and production in increasingly shallower water the potential effects of produced water need to be fully assessed. As with oil based muds and chemicals within oil based and water based muds some PARCOM members have expressed concern over the emissions from produced water, particularly PAH'S (Polynuclear Aromatic Hydrocarbons). PARCOM are now presently carrying out an assessment of the significance of PAH emissions from offshore installations and to consider possibilities for reducing these emissions.

6. OTHER IMPACTS.

So far this report has discussed the potential effects of exploratory seismic surveys and exploration and production discharges. There are, however further potential effects to consider such as physical habitat alteration which can result from the placement of installations and disruption of bottom substrate during pipeline emplacement or by anchors or other devices dragged across the sea bed (Neff et al., 1987).

In shallow water pipelines have to be buried. This process results in large disturbance of surface sediments and there communities and in some cases, a long lasting alteration of the bottom topography.

Once production platforms are in place there are further disturbances and potential effects to consider. Manned oil and gas platforms are supported at sea by supply vessels. These are required to remain on standby at all times. The more platforms, the more vessels are required, adding to marine traffic and risk of accidents, discharges, disturbance and ultimately pollution. In the recent Chevron oil company seismic exploration in Cardigan Bay carried out by the Horizon seismic company ships, rubbish including plastic was thrown over the side in contravention of international regulations (Green, pers com).

Onshore oil and gas development activities are further potential for environmental change. Most pipelines terminate ashore and consequently must cross coastal environments. In addition, increased marine traffic and offshore activities will require coastal support bases. This in turn may lead to increased need for navigation channels and their associated alterations of coastal habitats.

In addition to potential habitat alteration, there are further indirect affects on specific types of wildlife. Brightly lit oil rigs and gas flares may affect migrating birds. This is of obvious concern in areas that are internationally important for bird species such as Cardigan Bay. There has been little research into the possible effects of the attraction of bright lights or flares on platforms to passing birds. This could be of particular importance at night or in conditions of poor visibility. Hope-Jones (1980) found some attraction to a gas flare in a short study in the North Sea, with no fatalities. However he does point out the situation with oil platforms is perhaps analogous to lighthouses where large numbers of migrants may be attracted and hundreds of birds have been recorded as dying in one night. Perhaps, therefore, there may be a similar periodicity in attraction and mortality at rigs and flares.

Increased rubbish whether accidental or deliberate will have a potential impact on birds and marine mammals (e.g. tangling and ingestion).

Although noise disturbance from seismic exploration has been discussed, there is still potential for affects from increased noise associated with production activities. In marine mammals noise can influence non-auditory physiology (Fletcher, 1971), by driving the stress response towards lowering resistance to disease and promoting hypertension and endocrine imbalance. Offshore oil and gas activity would be detrimental if it resulted in a reduction in population size, shift in distribution away from a preferred habitat, or deterioration of the health of a significant number of individuals. In simplest terms, population decline may follow long-term reproductive failure or excessive mortality due directly to oil. Areas of high productivity or prime breeding sites might be abandoned if animals fail to habituate to oil production activities. This and the associated stress of accumulated toxic compounds could compromise health, leaving the group more susceptible to pathogens and other short-term insults (Neff et al., 1987).

7. THE ROLE OF PARCOM AND DISCHARGES FROM OIL AND GAS INSTALLATIONS

The Paris and Oslo Commissions to which the UK Government is a signatory, has made certain rulings and recommendations with regards to discharges from oil and gas installations:

7.1 DECISION 92/2 ON OIL BASED MUDS

The Paris and Oslo Commissions (PARCOM) adopted decision 92/2 on the use of oil based muds at the 1992 OSPAR Ministerial Meeting. This decision stipulates that the average oil content on cuttings discharged into the sea from sections of the well where oil based muds are used should not exceed the target standard of an average 10 grams of oil per kilogram of dry cuttings; the target standard of 10 grams of oil per kilogram dry cuttings shall be achieved as soon as possible and practicable and , in any event, have a full effect for exploration and appraisal drilling not later than 31 December 1993, and for all wells not later than 31 December 1996. Meanwhile the target standard of 100g oil/Kg dry cuttings must not be exceeded.

However, some PARCOM members were so concerned about the potential environmental effects of oil based muds that they have taken this further. As a result of environmental impact assessments the Netherlands and the Norwegian authorities have banned the dumping of drill cuttings containing oil based muds and insisted that any cuttings contaminated with such muds be brought ashore. Moreover, Danish have not used oil based muds since 1991. Unfortunately this is not the case in the U.K. UKOOA recently stated that, "there is an inherently high safety and pollution risk in transferring large quantities of cuttings from offshore platforms and drilling rigs to the shore, and there is a lack of suitable onshore facilities and sites for disposal of large amounts of oil cuttings produced annually" (UKOOA 1994). Given that both Dutch and Norwegian offshore oil industries between them represent the shallow southern North Sea waters and deep northern North Sea waters of the U.K.C.S. and have an operative system of retrieval to shore, the U.K. claim appears to be unfounded.

In addition to the arguments relating to whether or not these muds can be brought ashore, the question must be raised as to the compliance and regulation of the PARCOM 1% maximum discharge. It is considered by many that is not possible to meet this target. Furthermore, there is no regulatory body to police discharges or check that discharge regulations are adhered to. "Operational difficulties" do occur and may result in higher quantities of oil based muds having to be discharged. Drilling muds can be discharged from other sources in addition to that with the drill cuttings. As drill heads are changed, muds are spilled onto the drill deck and can be washed into the sea. There is also potential for muds to leak from the drilling collar and to mix with reservoir water and be passed out with the produced water discharges.

7.2 OIL CONTENT OF PRODUCED WATER

The Paris Commission adopted in its annual meeting in Lisbon in 1988 a revised sampling and analysis procedure for implementing the target standard for platforms and agreed that it should be reviewed by its GOP(working group on oil pollution) in 1991. This revised procedure corrects the oil content for the aromatic hydrocarbons. Only the aliphatic content will be measured. This excludes the aromatic oil content.

In the Dutch Environmental Impact Assessment for the discharge of oil containing mixtures from mining installations at sea (Lozing oliehoudende mengsels vanaf mijnbouwinstallaties op zee) published by the engineering company Grontmij nv. Projectbureau Milieu by order of the Department of Economical Affairs in 1990 indicated that If oil- and/or natural installation would comply to the (Parcom) regulation for the
discharge of oil from production platforms (meaning that the aliphatic oil content would be limited to 40 mg/l) than the aromatic oil content of gas production platforms would be on average 40mg/l, but could even increase to 450 mg/l. This means that for gas production platforms only 50% (down to 9%) of the total oil content would be measured.
For oil production platforms the aromatic oil content would be on average 40 mg/l. This means that for oil production platforms only 50% of the total oil content would be measured.

7.3 The CHARM Model.

At the Third International Conference on the Protection of the North Sea (March 1990) Ministers agreed "to develop and adopt a harmonised mandatory control system for the use and discharge of offshore E&P chemicals".

In 1993 the Dutch and Norwegian authorities, together with the offshore industry initiated the development of a decision supporting model, the so called "CHARM" model (Chemical Hazard Assessment and Risk Management Model). The basic requirement of the CHARM model was to provide a transparent and simple calculation of hazard and risk levels for the marine environment on the basis of all relevant hazardous properties of chemicals, with logic rules for data handling, default definitions and calculation principles. However, a number of criticisms have been raised even before the model has been completed:

1) The Model relies heavily on LC5O laboratory tests, which cannot account for sub lethal or chronic effects;

2) Species used in laboratory test are not always the most sensitive or representative;

3) Toxicity testing within the CHARM model is only carried out on three broad groups of organisms;

a) algae
b) crustacea in water column
b) benthic crustacea, particularly amphipods.

Only if the product is known to come into direct contact with the sediment is a sediment toxicity test carried out. If it does not come into contact with the sediment juvenile turbot can be used as test species. In view of the fact that there is very little knowledge as to the potential effect of chemicals in the marine environment, some have argued that standard toxicity tests should be carried out, as mandatory, on both benthic and pelagic organisms. This is particularly important as many chemicals released at the surface in produced waters, not in direct contact with the benthos, ultimately accumulate in the sediment through sedimentation of biotic and abiotic particles (Boesch 1991).

4) Although the project has been ongoing for over two years, as yet very few of the vast number of chemicals have been tested. This is primarily due to lack of co-operation between parties involved. Because many of the products needing to be tested are commercially produced, companies producing and supplying them to the oil industry are unwilling to release details of their chemical ingredients, citing commercial confidentiality; and,

5) The CHARM model requires bio-accumulation data in the form of a log Pow (which is a measurement of the partitioning of a substance between octanol and water) and if this data is only available from an OECD 107 test the CHARM model applies a very large safety factor to the calculation of the hazard quotient. Therefore a meaningful hazard assessment cannot be conducted under the current calculation rules of CHARM. This renders the CHARM model effectively inoperative.

By initiating the formation of a chemical hazard assessment and risk management model PARCOM has recognised the dangers to the environment from oil and gas industry discharges. However, the CHARM model fails to address the chemical inputs and their potential hazards effectively. Furthermore, it can be argued that any model will be inadequate to deal with the complexities of the interactions between effluent and environment. After 30 years of oil and gas exploration and production, it seems surprising that only now are attempts being made to asses chemical inputs into the ocean from oil and gas exploration and production. What is even more surprising is that in the UK inshore exploration in environmentally sensitive areas is going ahead, despite the inadequacies of this model and the fact that it is far from completion.

8. CONCLUSIONS

This report was commissioned following the significant increase in offshore licensing in the UKCS and the growing evidence that indicates that exploration and production activities and discharges are having a noticeable effect on the marine environment. Oil companies and representative bodies such as UKOOA have continuously produced literature and public information packages that advocate certain activities such as seismic exploration, dumping of drilling muds and release of produced water, despite the growing scientific evidence that effects are being found from such activities. As highlighted in the summary and as detailed in the various sections that follow, this report has shown that damaging impacts on the environment arise from a wide array of the activities of oil extraction.

Seismic testing

Fish, cetaceans and birds are all susceptible to harm from acoustic surveys. Recent research in Norway has shown that seismic testing with airguns can have substantial effects on fisheries. In many cases this has been to drive fish away from the area of seismic activity and effect catches during and for periods after testing has ceased. Areas known to be important spawning and nursery sites for fish species could also be affected. In many cases these are inshore areas and at present in the UK there is a major push to license such areas for oil and gas exploration.

Marine mammals are protected species under many European and International agreements. Studies have shown that both baleen and toothed whales will exhibit avoidance behavioural characteristics when near seismic testing. The limited studies carried out so far show no lethal effects caused by airgun emissions. However, damage to auditory systems has not been studied and cannot be ruled out. Furthermore, in marine mammals noise can influence non-auditory physiology, by driving the stress response towards lowering resistance to disease and promoting hypertension and endocrine imbalance.

Accidental spillage

Spillages are a constant source of exposure of the marine environment to oil. This can take the form of routine operations spillage or catastrophic accidents such as tanker accidents, well blowouts or pipeline leaks or ruptures. Although in many areas accidental spillage accounts for a relatively small proportion of the total oil extracted by the offshore industry, reported spills have risen steadily from 1980 to 1991. The risk of accidents will vary with the type, age and location of the field as well as the method of transport to shore for refining. Oil pollution has been shown to reduce fish spawning by certain species after large scale oil pollution incidents. Furthermore, oil can kill planktonic fish eggs at very low concentration of dissolved hydrocarbons (2-10ug/l) and slow the growth of fish larvae.

Drilling Muds

Drilling muds contain large numbers of different mixtures of potentially toxic chemicals and pose one of the greatest threats to the environment from oil extraction activities. Whether oil based or water based muds are used the initial effects are the localised smothering of the sea bed.

Research has shown that oil based muds previously discharged into the marine environment are still affecting marine life . Furthermore the effects which at first were thought only to exist locally around a platform, are now being found to cover considerable areas of seabed. In Norway contaminated areas around platforms studied continued to increase in size for over nine years after drilling operations and cuttings discharge stopped.

The most noticeable effects from discharged drill cuttings contaminated with drilling muds were caused by the oil present in the mud as a lubricant . This has lead to the use of water based muds. However, both oil based and water based muds contain numerous other chemicals and heavy metals and there is now growing evidence to suggest that these too may be affecting the marine environment. In the Dutch North Sea sector, elevated levels of heavy metals (Cu, Hg, Pb, Zn) were detected in the sediments around a WBM drilling site. The reason for changes in attitudes as to the effects of both oil based and water based muds is the level of sensitivity of tests previously carried out. Previous tests have concentrated on lethal effects rather than more sensitive studies to asses sub-lethal or chronic effects.

There are over 1,000 trade name or generic materials available for drilling fluid formation. However, for reasons of commercial confidentiality the specific chemical constituents of these additives are rarely known. Furthermore, components in the drilling mud will react with the formation being drilled, resulting in chemical and physical changes in the mud. Therefore, even if the chemicals added to the mud were known, unless used muds are analysed it may not represent the true toxicity of the discharge.

Produced water

Produced water consists of the naturally existing water that is brought up with the oil or gas and mixed with effluent and chemicals from processing on board the platform, as well as production chemicals that may have entered the oil reservoir. Produced water contains dissolved hydrocarbons known as Polynuclear Aromatic Hydrocarbons, radioactive salts concentrated from the oil and various heavy metals including significant levels of chromium lead and cadmium. Production water is discharged over the side of the platform and it has always been maintained that the mixing with the sea water would dilute any harmful substances. However, research is now showing that this is not the case. Lethal effects are rarely found but sub-lethal and chronic effects are being measured. Planktonic larvae can be adversely affected by produced water plumes even from discharges in high energy open coast environments.

The environmental effects caused by produced water are especially important as an oil or gas field ages, because both the amount of produced water discharged and the amount of dissolved hydrocarbons and contaminants in the water increases. In old fields, production may be 94% water and 5% oil or gas. Although the oil content of produced water is small compared to drilling muds, research in Norway has shown that produced water accounted for approximately 45% of total oil discharges to Norwegian waters in 1992.

Other Impacts

In addition to seismic testing, accidental oil spillage, drilling muds and produced water, oil and gas development can alter the physical habitat and effect wildlife. Placement of platforms and pipelines can disrupt and destroy benthic communities. Once in place, increased shipping traffic, noise and dumping of rubbish can disturb and threaten certain marine species.

PARCOM and CHARM model

The Paris and Oslo Commissions (PARCOM) have made rulings and recommendations with regards to discharges from oil and gas installations. Decision 92/2 on oil based muds, highlights the differing opinions and actions of certain member states. The Dutch and Norwegians require oil based mud contaminated cuttings to be brought ashore, whilst the UK still persist in dumping them over the side. PARCOM has introduced the 1% rule, but many consider this to be unattainable. Furthermore, there is no regulatory body to police discharges or check that discharge regulations are adhered to and "operational difficulties" do occur and may result in higher quantities of oil based muds having to be discharged.

The CHARM model emphasises the difficulties in design and inadequacies of hazard and risk assessment models. Furthermore, growing evidence of the environmental effects of offshore discharges, shows that further international regulation is needed.

This report has shown that there is considerable potential for adverse impacts to arise from the normal operating procedures of the oil industry in the North Sea. Regulation to control these polluting activities are weak and no body exists to police adherence. Models being developed to control chemical pollution are flawed and unlikely to form reliable regulatory tools. Seismic surveys and disturbance from general marine traffic have no controls at all.

The North Sea is currently suffering pollution stress as a result of wastes received from all countries on its borders. Ariel deposition of pollutants is being increasingly recognised as a problem. Disturbing signs such as diseased and mutated fish are becoming increasingly common.

The complexity of the inputs and the North Sea make it impossible to attribute changes to any one input. Recognition of the impossibility of establishing direct cause-effect relationships between environmental problems has been one of the factors leading to the development of the precautionary principle. Because it is clear that the processes of oil extraction in the North Sea is adding to the burden of pollutants and causing generalised disturbance, the precautionary principle should also be applied to these activities.

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