ENVIRONMENTAL EFFECTS OF PETROLEUM EXPLORATION: A PRACTICAL PERSPECTIVE

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The paper presents an overview of environmental issues associated with petroleum exploration, and is based on the reported experience in offshore drilling. Seismic surveying, for instance, has a potential for impact through shock waves and noise emissions, particularly in nearshore or shallow waters. Experimental studies and predictive models allow some quantitation of the anticipated impact. Concerns over exploratory drilling focus on the chronic effects of discharges from drilling activities, as well as on the potential for a blowout from the well, in which case environmental effects tend to be acute and longer-lived. In general, environmental concerns include loss of habitat, community and population changes, renewable resource losses and tainting by petroleum hydrocarbons, as well as persistence of effects and the potential for recovery. Negative effects can be managed through integration of physical, biological and engineering information, applied to waste control, operational adjustments to minimise conflict with sensitive environments or species, environmental monitoring and effective contingency planning for emergencies.

INTRODUCTION

This paper presents an overview of the environmental issues identified with offshore petroleum exploration. The significance of environmental effects will be discussed in the context of ecological, social, regulatory and industry perspectives, recognising that the four are not necessarily mutually exclusive.

The exploitation of petroleum resources offshore is an effort of considerable scientific and technological ingenuity. In addition to engineering concerns over safe and efficient operations in this difficult environment, it is necessary to consider the effects of an offshore operation on the natural environment, which is the subject of this paper. The topic draws extensive scientific and public interest, evidenced by the large number of conferences and recent publications on the subject.

A summary of the major activities of offshore petroleum exploration associated with an environmental concern is presented in Table 1. This table includes some potential impacts which are not necessarily shown by the environmental component, but are nonetheless related because they relate to the use of an environmental resource.

Exploratory drilling has a potential for environmental impact from routine activities, as well as from blowouts due to loss of well control. The effects of routine activities tend to be short-lived and localised and are usually of neither ecological nor socio-economic consequence unless the activity takes place in a locale of particularly high environmental sensitivity. It is the blowouts and oil spills, however, which draw the greatest level of concern because of their serious acute effects and degree of damage. Additionally, it is recognised that the potential for environmental impact increases when petroleum exploitation enters the

Exploration Activity	Environmental Disturbance Factor	Potential Effect
Seismic	Air gun discharges Chemical explosives Vessel transits	Displacement or loss of biota, especially fish and wildlife Loss of fishing gear Displacement of fishing activities
Drilling	Discharge of toxic drilling fluids Discharge of fines and solids from drilling Operational noise Vessel and aircraft traffic Loss of well control leading to gas and oil spills	Loss of habitat Displacement or loss of biota Tainting of fish and shellfish Degradation of beaches Displacement of fishing activities
Well suspension and abandonment	Debris Vessel and aircraft traffic	Disturbance of biota Loss of fishing gear Displacement of fishing activities

Table 1: Environmental disturbance factors and potential effects of offshore petroleum exploration

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production phase, encompassing field development, production drilling and hydrocarbon recovery. The scientific basis for our understanding of the environmental impacts of petroleum exploration, both routine disturbances and otherwise, is discussed in subsequent sections.

SEISMIC EXPLORATION

A number of studies have been carried out in recent years in both Canada and the United States to help define the effects of seismic exploration, and to evaluate effects models. The studies have included evaluations of fish kill from linear chemical explosives, the disturbance of seals by sharp explosives deployed on ice, and the disturbance of large whales and of fish and shellfish by airgun discharges. The following paragraphs are based on a review of the subject which was carried out for the purpose of drafting regulatory guidelines for explosives use (Engelhardt *et al.*, 1985).

It has been shown that non-chemical discharges (for example, airguns) have minimal effects on marine life such as free-swimming larval crabs, adult fish, seabirds and marine mammals. Behavioural changes attributable to airgun use have been observed in pelagic commercial fish and in grey and bowhead whales, but these effects appear to be restricted to the immediate area of seismic discharges. Indirect effects on marine mammals and seabirds from the disturbance caused by seismic activities are difficult to evaluate and remain a concern, especially in northern waters. By comparison, chemical explosives, including linear discharges, have been shown to kill fish, generally within a limited zone of influence and particularly affecting those species with swimbladders.

Over all, seismic exploration using modern geophysical methods appears to have only limited direct impact on marine life. Indirect, disturbance-related impacts are less well defined but can normally be mitigated by avoiding biologically sensitive locations or seasons. The effects of point source chemical explosions, as may be used in refraction seismic investigations, in reflection seismic under ice or in marine construction, are more hazardous for marine life; but, in this instance, the effects occur in a more restricted locality, permitting consideration of mitigative measures such as air curtains or other shock wave minimising methods.

A different issue associated with seismic, although not strictly environmental, is conflict with commercial fishing activity. There is concern that seismic arrays can damage crab and lobster fishing gear and fish trawls, or otherwise displace the fisherman from an active fishing area because a vessel towing a seismic array is considered as having the right of way. In practice, however, these types of interaction are rare and are generally avoided through good communication mechanisms between the two industries.

DRILLING

The predominant concern raised about routine exploratory drilling activities is the discharge of drilling muds and drilled solids, both as a regular emission during the drilling phase and as a bulk discharge of surplus drilling muds at the end. The substances at issue are various chemicals comprising drilling fluids (for example, viscosifiers, thinners and deflocculants, flocculants, polymers, fluid loss control agents, lubricants, spotting fluids, shale control agents, detergents, emulsifiers, defoamers, corrosion inhibitors, bacteriocides, and weighting agents). The various organic and inorganic, water soluble and insoluble, volatile and non-volatile compounds have seen much evaluation of their toxicity in recent years, and have been found in regulatory screening tests, with only few exceptions, to be of low or negligible toxicity (Leutermann *et al.*, 1989). A recent detailed review of the drilling waste issue, touching on both water- and oil-based drilling muds, has been published as proceedings of the 1988 International Conference on Drilling Wastes, held in Calgary, Canada (Engelhardt et al., 1989). This recent conference served as a landmark update of two earlier conferences; in Houston (US Environmental Protection Agency, 1975) and in Lake Buena Vista (Lake Buena Vista Symposium Steering Committee, 1980).

The outcome of such meetings has been a better understanding of the methods of control and treatment and of the fate and effects of discharged drilling chemicals. Deficiencies in information from actual field applications are being remedied, and more reliable and consistent toxicity data are being generated for a growing list of drilling chemicals. Any effects attributable to single well exploratory drilling can now be better differentiated from those associated with petroleum production scenarios. The following lists the main issues that surround the question of discharges of drilling mud and cuttings, and highlights some of the recent findings:

(a) The fate and bioavailability of heavy metals from drilling muds and cuttings has seen much attention. Barium, chromium, lead, mercury, zinc, and cadmium are found variously associated with drilling muds, in particular weighting agents. In exploratory drilling, these metals are restricted to an area of discharge within about one hundred to a few metres of the drilling site. On a basis of mass balance, the retention of metals in sediment was found to be low, suggesting an active redistribution; only barium was found to be present in significant measurable quantities (Boothe and Presley, 1989; Bothner *et al.*, 1985). Most commonly, heavy metals in drilling muds, and especially when associated with barite, are present as sulphides and have been found in separate laboratory evaluations carried out in Canada and the USA to be of low bioavailability and toxicity.

(b) Methods of measurement to determine the spatial distribution of discharged drilling wastes have been limited. Although barite has been used with good success to determine the extent of deposition around a drilling site, a method for lignosulfonate muds has been described only recently (Sauer *et al.*, 1989). When oil based drilling muds are used, measurement of hydrocarbons in sediment has been both quantitative and a good method for fingerprinting the contamination source (Erickson *et al.*, 1989; Yunker and Drinnan, 1987).

(c) The discharge of diesel oil, used in spotting pills or as a drilling fluid lubricant in circumstances of differential sticking or increased torque, continues to receive attention in Canada and the USA. Recent studies have shown that most of the diesel oil goes into the water column on discharge (Boehm *et al.*, 1989), but questions remain about residual toxicity of the mud after attempts at removal of the diesel pill, or what an acceptable level of diesel might be when discharged after its use as a general lubricant in a water-based mud.

(d) Questions continue to surround the relative environmental advantages of oil-based versus water-based drill ing muds. Although the concerns mainly address production scenarios (Davies *et al.*, 1989; Reiersen et al., 1989), there remain outstanding questions on the recovery rate of discharge areas; perhaps slower when the oil-based muds are used as compared to water-based, and no difference between the discharge of cuttings coated with low-toxicity mineral oil- and diesel oil-based muds (Bakke *et al.*, 1989).

(e) Tainting of fish caught in the vicinity of drilling sites has drawn much attention because of its obvious commercial implications. At issue is the discharge of hydrocarbons when diesel spotting pills are used, as well as when hydrocarbons from oil-based drilling muds are discharged on cuttings (Davies *et al.*, 1989; Sjogren *et al.*, 1989; Ernst *et al.*, 1987). A potential for taint exists for groundfish, even with only single well discharges, but it is assessed to be short-lived, in the order of days or less, and restricted to the immediate area of the well-site.

(f) There is increasingly better segregation of the effects of routine activities from development or production and those from exploration. Any variance between the two situations can be attributed to a mathematical difference in the number of wells drilled at a multi-well production site versus the single well exploration site. Until recently, however, the lack of environmental data at exploration sites has forced a tacit application of information from, for instance, North Sea production installations (Davies *et al.*, 1989, Reiersen *et al.*, 1989). It appears that in the case of single well sites, contamination along the axis of the prevailing current is one quarter or less the distance found for development/ production sites (Davies *et al.*, 1989; Reiersen *et al.*, 1989; Yunker and Drinnan, 1987; Erickson *et al.*, 1989; Jenkins *et al.*, 1989). The zone of biological effects is also less in the case of single exploratory wells, generally within 250 m of the drilling site. A summary of UK North Sea data on contamination from oil-based drilling muds is presented in Table 2. Recent reports from the Norwegian North Sea (Reiersen *et al.*, 1969) suggest that for certain production sites using oil-based drilling mud extensively, the zones of contamination and biological effects may be even larger than calculated by Davies and colleagues. At one Norwegian platform (Statfjord C), hydrocarbon contamination was observed as far out as 12 000 m, and a possible change in fauna out to 5000 m.

Zone	No. of Well Sites	Size/shape of zone
Major biological effects	40 development	500 m radius
	380 single	250 m radius
Subtle biological changes	40 development	2000 X 1000 m ellipse
	380 single	1000 X 500 m ellipse
OBM hydrocarbons present	40 development	4000 X 8000 m ellipse
	380 single	1000 X 2000 m ellipse

Source: Davies *et al.*, 1989.

Table 2: Area of seabed around UK North Sea drilling sites affected by oil-based drilling muds (OBM).

An additional consideration is the element of time, coupled with the physical oceanographic regime at a particular well site. Contamination and biological effects from exploratory wells can be expected to last for much shorter times, perhaps not beyond one season of winter storms, particularly in shallow waters. Davies *et al.* (1989) have also evaluated their data sets for indications of recovery. It appears that even heavily contaminated production areas show a decrease in the extent of effects once drilling ceases, so that after one to two years, the effects zones become smaller with onset of biodegradation of contaminants and recolonization of the affected area by benthic organisms. Further, the North Sea data for biological effects is especially relevant for oil-based drilling muds, in the past diesel-, and more currently mineral oil-based. It is very probable that a biological effects zone for water-based drilling muds will not be any larger.

OIL SPILLS

Blowout incidence

The major area of concern about negative environmental effects from petroleum exploration is the threat of oil spills. Although oil spills of large magnitude are very rare, much attention is focused on this issue because the effects can be far-reaching, both spatially and over time. Ironically, it is the more frequent incidence of oil spills from shipping accidents which has sensitised both the public and government regulators, although there is usually little parallel between the petroleum resource industry and its legislated control, and that of the marine shipping industry. Nonetheless, it is a valid assumption that a major spill, such as the *Exxon Valdez* in Prince William Sound of Alaska earlier this year, will have a great influence on the public perception of petroleum exploration and exploitation, and this being generally negative. Governments in the US and Canada, for instance, are currently involved in an evaluation of the risk of oil spills, both from shipping and petroleum development. In the US in particular, momentum is building to block offshore frontier drilling as a result of the many recent oil spills from tankers, although of the 33 largest oil spills on record before the Exxon Valdez accident, only two were caused by drilling accidents (Oil & Gas Journal, 1989).

Further to the question of oil spill risk, a recent study commissioned by the Canada Oil and Gas Land Administration (Manadrill Drilling Management Inc., 1985) evaluated the incidence of oil spills from blowouts from the world record. As summarised in Table 3, the study concluded that the chance of a significant oil blowout, one with potential for measurable and lasting environmental damage, is extremely low: approximately 1/100 000 wells drilled on land and 1/7500 wells drilled offshore. Further, the majority of all blowouts involved gas as the produced fluid, but blowouts of exploratory wells were found to be three times more frequent than development wells.

Environmental effects

The environmental effects of oil spills, at least those of a biological nature, have been examined extensively over the years and have led to many important review publications (Malins, 1977; Neff, 1979; National Research Council, 1985; among others). Most of these have focused on temperate waters, although oil spill effects in the polar/cold

Total No. of wells[1]	36 633
Blowout incidence[2]	1 in 225
Oil blowout incidence	1 in 3055
Significant oil blowout incidence[3]	1 in 7325

[1] From worldwide record, 1955-1980
[2] Incidence for exploratory wells three times that of development wells
[3] Greater than 50 000 bbl
Source: Manadrill Drilling Management Inc., 1985

Table 3: Analysis of blowout incidence in offshore drilling.

water environment have also been evaluated (Engelhardt, 1985). In addition, the proceedings from scheduled international oil spill conferences have greatly added to the available information base. The recognised biological effects can be summarised as follows:

Microbial effects and biodegradation Interest in this trophic level centres on two main aspects: a recognition that microbial systems constitute the bioenergetic basis of the marine ecosystem; and that microbes, in particular bacteria, can degrade contaminants such as hydrocarbons. It has been determined that the composition of the microbial community changes with exposure to hydrocarbons, generally in favour of hydrocarbon degraders, the oleoclasts. Such changes may take days to months; both low temperatures and nutrient limitations appear to contribute to this. Biodegradation is most effective for lighter oils and in particular for the alkanes.

Benthic invertebrates The benthic invertebrate biota is an important component of the marine ecosystem, providing an energy base for fish, seabirds and marine mammals. It responds to disturbance and represents an ideal effects monitoring system. Bivalves and echinoderms show behavioural changes to hydrocarbon exposure which may limit their survival, such as emergence from sediment in mussels and clams, and narcosis in many species. This can occur after acute, post-spill exposure as well as after long-term chronic contamination in the parts-per-billion range. In addition, benthic invertebrates are able to accumulate hydrocarbons to high levels from the surrounding medium, suggesting biotransfer as a possible concern. The population significance of acute effects in benthic invertebrates tends to be tempered by being geographically limited. Oil spill effects could be significant, however, if a local benthic population becomes reduced or contaminated in obligatory feeding areas for animals such as marine mammals or seabirds, or happens to be a commercial shellfish resource. An uncontrolled blow-out situation with its potential for wider-ranging chronic effects may become a concern.

Plankton Marine phyto- and zooplankton tend to be fairly sensitive to even low levels of hydrocarbons in water, with a lethal range of parts-per-billion to a few parts-per-million. Effects determined in the laboratory range from reduced fecundity to death. It is unlikely, however, that the planktonic component of marine life would be significantly affected by oil pollution, mainly because of a high rate of recruitment from non-affected areas assured by the wide distributions and large population sizes of plankton.

Fish Adult fish appear to be fairly resistant to oil exposure, in contrast to their sensitive egg and larval stages which are often planktonic. Fish are assumed to leave areas of oil spill contamination since relatively little mortality is recorded. Sublethal effects include impaired physiological salt and water balance, which could be crucial to anadromous fish such as salmon when they enter the fresh water phase of their spawning cycle. There is little proof, however, that standing stocks of fish have been much changed by oil spills. A more likely consequence is impact on harvest activities, because such fish either have become or are perceived to be tainted through contact with oil.

Seabirds The fate of seabirds has drawn great attention for several reasons. There is little doubt that birds exposed to oil fare very poorly, especially in a cold environment. The primary problems are a loss of thermal insulation, along with a decrease in buoyancy and increase in metabolism. Should oil-coated birds survive acute effects, decreased reproductive success from ingestion of oil and oiling of eggs during incubation appear to be a problem. Certain species form special sensitive cases. The alcids are particularly susceptible, especially in those areas where they breed in a very few but large colonies, typically with a low reproductive turnover. An oilspill in the vicinity of such a breeding area has a potential for serious impact on the population.

Marine mammals Investigations of oil spill incidents have generally not been conclusive in defining the toxicity of petroleum in seals or whales, even though mortality has been attributed to oil exposure at sea. Only some of the species have demonstrated a clear sensitivity to petroleum. Recent studies in seals, sea otters, polar bears and whales have helped to round out the limited information base on the subject. It is still not certain, however, if all marine mammals would avoid oil spills at sea. Contact with viscous oils can lead to long-term coating of the body surface of the furred marine mammals such as sea lions and polar bears to result in thermoregulatory stress, or may interfere with the filtering capabilities of baleen in the great whales. A limited experimental data base suggests that seals, whales, sea otters and polar bears differ in degree of clinical toxicity damage following exposure to petroleum. Tainting of harvested marine mammals is considered a potential problem, especially in those areas of the world where they form a traditional food source.

The impacts of oil on marine organisms are influenced not only by the degree of inherent sensitivity of a given species, but also by physical oceanographic factors, the chemistry of the oil and the particular coincidence of both organisms and spilled oil in space and time. Overall, based on laboratory and field studies of the effects of oil on biota and on observation from several specific blowout events, the environmental impacts associated with an offshore oil blowout are not as catastrophic as generally perceived. Additionally, the impacts of an offshore gas blowout are generally negligible.

STRATEGY FOR ENVIRONMENTAL EFFECTS MONITORING

In general, environmental effects monitoring programmes should be undertaken to address the uncertainties associated with environmental impact predictions, to assess the effectiveness of mitigative measures and to reassure the public. This is distinct from an environmental compliance monitoring programme which serves to assess the performance of control equipment and practices to assure that potentially impacting inputs into the environment remain within limits determined through legislation, specific regulatory approval conditions and the requirements for safe operational practices.

There are a number of strategic implications for the design and deployment of a monitoring programme. For instance, an environmental effects monitoring programme must primarily be able to measure change, be quantitative by design, and include spatial and temporal dimensions. The programme should place emphasis on the *far field* rather than *near field* around the operations facility or spill site since it is known that the latter area is in any case subject to high impact. This assures that any wide reaching, perhaps long-term effects which may occur are identified and assessed. Finally, the assessment of impacts in the *near field* area should be geared to evaluating pollution control technology and its efficiency in restricting environmental disturbance to acceptable levels.

A comprehensive environmental monitoring programme should contain the following elements: a statement of objectives; applicability to statutes, regulations and guidelines; sources and types of contaminants and disturbance. The emphasis in the programme would be on the inputs into the environment and their measurement. For instance, the choice of contaminants would be determined by the characteristics of the drilling fluids or an oil spill, while disturbance sources might be seismic emissions, lights, and airborne and waterborne noise. The receiving environment, that is water column, sediments, atmosphere and shorelines, should be spatially circumscribed as *zones of influence* based on predicted distributions of the input. Distribution models for drilling discharges and oil spill trajectory models have been used successfully to characterise a monitoring programme spatially. Useful sampling designs incorporate measurements pre-, during and post-activity, and include physical, chemical and biological assessment as appropriate. For instance, contaminants from drilling discharges are measured most effectively in marine sediments, and as a body burden of resident benthic biota. Indices of biological effects could be of direct ecological implication, such species diversity and other population indices, or be more suitable as an early warning system, for example, mixed function oxidases and other biochemical monitors. The two approaches to biological monitoring do differ: population indices have the greatest potential ecological meaning but are labour intensive, time consuming and costly, while the biochemical monitors are more sensitive and can be easier to apply, but are more difficult if not impossible to interpret as being of ecological significance.

The need for, magnitude and specific design of an environmental effects monitoring programme should be geared to the level and location of the petroleum activity. Exploratory drilling in deep water in the far offshore would be expected to have no significant impact; monitoring does not seem practical. In nearshore waters or those of particularly high environmental value, it would be useful to have an environmental monitoring programme, but tailored to the level of industrial activity and the physical and biological characteristics of the drilling site. It is in the field development and production scenario that environmental monitoring becomes particularly important because the discharge at a fixed site is much larger.

A PERSPECTIVE ON THE ISSUE

The concerns about environmental issues associated with offshore oil and gas vary from country to country, and even from one region of a country to another. However, these variations are to a large extent differences in degree rather than kind. Whether or not loss of well control is caused by the collision of a drilling unit or production platform with an iceberg in polar reaches or with an ocean-going vessel in temperate waters, the major environmental concern centres on the accidental release of petroleum and its potential effects on the local environment. The degree of importance that is attached to such impacts is frequently proportional to the effects that they may have on social activities and the importance of these activities in the regional economy and culture. Although environment issues are important in both northern and southern hemispheres, public input on a variety of proposed major development projects strongly suggests that social issues, such as impacts on traditional lifestyles and cultures, and access to employment and economic benefits are of equal importance to environmental concerns. Nonetheless, the more traditional environmental issues of impacts on habitat and biota may have additional relevance when related to the protection of threatened or endangered species of marine mammals and seabirds.

In the Arctic, for example, local environmental concerns focus principally on the impact that oil and gas activities may have on marine mammals, birds, caribou and fish, because the harvesting of these resources is central to the indigenous cultural and economic milieu. Similar situations can be expected to drive public concern in other specialised areas of the world, as for instance in areas of Maori cultural value in New Zealand.

Perhaps the most clearly defined issues in Canada, the US, North Sea and other jurisdictions are associated with potential interactions between the offshore petroleum industry and the fishery. Specifically, the issues relate primarily to direct damage or loss of fishing gear caused by seismic and supply boat activity, debris or oil spills, as well as to compensation schemes for covering such losses. The fisheries sector has also expressed concern about possible secondary effects from oil and gas activities such as fish tainting from oil or condensate spills, loss of access to fishing grounds during exploration or development, and the potential consequent curtailment of the operation of on-shore processing plants because of a reduced fish supply. Virtually all of the above externalities have more of a social connotation than an environmental one in the sense that they are not caused by an absolute impairment to the natural resource base.

Although the individual impacts of offshore petroleum activities remain of some considerable interest, an increasing focus at the present time is on the long-term cumulative effects of all pollution sources from offshore oil and gas activities on biological productivity. This concern is greatest in polar environments, where there is little world-wide experience to draw upon and where there is a high degree of uncertainty about the dynamics of the ecosystem, the effects of chronic pollution and resultant cumulative impacts. This type of potential gradual environmental degradation is also a major concern to governmental fisheries agencies with respect to loss of fish habitat, and to environmental agencies with respect to environmental quality in general.

The environmental issues are typically managed through a legislative framework for managing petroleum exploration and development. It is essential that the environmental management approach be both flexible and comprehensive. Flexibility is needed to allow incorporation of the broad range of administrative processes and instruments, including negotiation, authorisation, inspection, enforcement, coordination, advisement, and research. It needs to be comprehensive from three perspectives. First, it may cover a broad range of offshore environments. Second, and more importantly, it should include all aspects of exploration and development planning, including an initial evaluation of offshore lands to determine their environmental suitability for permitting petroleum activities, ranging from exploration to final abandonment. Third, the environmental management approach should provide access to the expertise of all principal environmental agencies in both government and appropriate non-governmental sectors.

An administrative process for offshore petroleum activities should be able to respond to changes in government policies, as well as the rapid evolution of industry priorities and environmental awareness. The legislative basis underlying administrative arrangements should be able to accommodate the dynamics of change in offshore petroleum exploration, development and production technologies. As a final comment, it is useful for our sense of perspective to remember that it is unlikely that any other industrial sector, with the possible exception of the nuclear power industry but including large scale land development, agriculture and forestry, is so intensely scrutinised and administered from an environmental point of view.

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