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Informal Report

FRAMEWORK FOR A COMPARATIVE ENVIRONMENTAL ASSESSMENT OF DRILLING FLUIDS

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November 1998

Prepared for:
National Petroleum Technology Office
Office of Fossil Energy
United States Department of Energy
Tulsa, Oklahoma

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DISCLAIMER

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ACRONYMS

ACGIH	American Council of Governmental Industrial Hygienists
API	American Petroleum Institute
BAT	Best Available Technology Economically Achievable
BAF	Bioaccumulation Factor
BCF	Bioconcentration factor
BCT	Best Conventional Control Technology
BNL	Brookhaven National Laboratory
BPJ	Best Professional Judgement
DOE	United States Department of Energy
ELG	Effluent Limitation Guidelines
EMO	Enhanced Mineral Oil-Based Mud
EPA	United States Environmental Protection Agency
FR	Federal Register
GC	Gas Chromatography
IO	Internal olefin, Isomerized olefin
LAB	Linear alkyl benzene
LAO	Linear alpha olefin
LP	Linear paraffins
LTMO	Low toxicity mineral oil
MMS	Minerals Management Service
MODU	Mobile Offshore Drilling Units
MSDS	Material Safety Data Sheet
NOIA	National Ocean Industry Association
OBM	Oil-Based Mud
OLF	Oljeindustriens Landsforening (Norwegian Oil Industry Association)
OSHA	Occupational Safety and Health Administration
OSV	Offshore supply vessel
PAH	Polycyclic Aromatic Hydrocarbon
PAO	Poly-alpha olefins
PEL	Permissible Exposure Level

RCRA	Resource Conservation and Recovery Act
SBM	Synthetic-Based Mud
THC	Total Hydrocarbons
TLV	Threshold Limit Value
TSP	Total Suspended Particulates
VOC	Volatile Organic Carbon
WBM	Water-Based Mud

EXECUTIVE SUMMARY

Introduction

During the drilling of an oil or gas well, drilling fluid (or "mud") is used to maintain well control and to remove drill cuttings from the hole. In response to effluent limitation guidelines promulgated by the United States Environmental Protection Agency (EPA) for discharge of drilling wastes offshore, alternatives to water and oil-based muds have been developed. These synthetic-based muds (SBMs) are more efficient than water-based muds (WBMs) for drilling difficult and complex formation intervals and have lower toxicity and smaller environmental impacts than diesel or conventional mineral oil-based muds (OBMs). A third category of drilling fluids, derived from petroleum and called enhanced mineral oils (EMOs), also have these advantages over the traditionally used OBMs and WBMs.

Synthetic drilling fluids may present a significant pollution prevention opportunity, because the fluids are recycled, and smaller volumes of metals are discharged with the cuttings than for WBMs. As compared to OBMs, drilling costs may be less, provided the cuttings associated with SBMs may be discharged, and smaller volumes of waste must be shipped onshore for disposal. Because of their high cost, industry will not continue to use these new drilling fluids if the cuttings cannot be discharged onsite.

EPA recognizes that SBMs and EMOs are new classes of drilling fluids, but their regulatory status is unclear. To address this uncertainty, EPA is following an innovative presumptive rulemaking process that will develop final regulations for SBM discharges offshore in less than three years (Veil and Daly, 1998).

To support this rulemaking, EPA and the petroleum and drilling industries are working together to identify and close data gaps concerning the potential environmental effects of SBM discharges, and to develop monitoring procedures and discharge limitations.

The decision about allowing discharge of cuttings with small amounts of associated SBMs should not be based solely on potential environmental impacts. Regulatory decisions about drilling fluid discharges should also consider the potential impacts associated with the alternatives. These potential impacts include impacts that are not directly related to the discharge, such as occupational accidents and chemical exposures, disposal costs, air emissions, and transportation and handling risks. Even without a complete, quantitative understanding of impacts, available data can be used to bound the problem, identify uncertainties, and balance potential impacts in making a risk management decision.

This report develops a framework for a comparative risk assessment for the discharge of SBMs and EMOs, to help support a risk-based, integrated approach to regulatory decision making. The framework will help identify potential impacts and benefits associated with the use of SBMs, EMOs, WBMs and OBMs; identify areas where additional data are needed; and support early decision-making in the absence of complete data. As additional data become available, the framework can support a full quantitative comparative assessment. Detailed data are provided to support a comparative assessment in the areas of occupational and public health impacts.

Drilling Fluids

Drilling fluids, or muds are suspensions of solids and dissolved materials in a base of water, oil, or other synthetic material. WBMs are used in less difficult wells and the shallow portions of difficult, deeper wells. OBMs, EMOs and SBMs are used in deeper well intervals and complex drilling situations because of their superior performance. Synthetic-based muds will be considered for use in place of OBMs in difficult drilling situations if the cuttings may be discharged. EMOs and purified paraffin oils may also replace OBMs in these situations. SBMs and EMOs may be cost-effective in replacing OBMs if the cuttings can be discharged offshore, saving the cost of shipping and disposal. Like OBMs, SBMs and EMOs are expensive, and operators recycle them for re-use, avoiding the need for discharge or disposal of the drilling fluid itself.

Water-based Muds

Most offshore wells are drilled using water-based drilling fluids. Water based muds are aqueous slurries of barite, clay, and formation solids that usually also contain low concentrations of polymers, lignites, lignosulfonates and caustic soda. They may also contain low concentrations of other materials used to solve special problems (e.g. defoamers, lime). Freshwater muds contain bentonite and caustic soda (NaOH), while saltwater muds may contain attapulgite clay instead of bentonite. Water-based muds generally consist of more than 90% water by volume (Burke and Veil, 1995).

Current offshore regulations allow offshore (greater than three miles) discharge of water-based drilling fluids and cuttings. The discharges must meet a 30,000 ppm 96 hour toxicity limitation on the suspended particulate phase, and no discharge of free oil, as measured by the static sheen test, is allowed.

One of the most important additives to drilling fluids is barite. Barite (naturally occurring barium sulfate ore) is a high-density material used to control downhole pressure. The Current Offshore Effluent Limitation Guidelines (ELGs) limit the concentration of cadmium and mercury in the stock barite to 3 mg/kg and 1 mg/kg, respectively. Barite is a component of most drilling fluid systems.

Oil-based Muds

In oil-based drilling fluids, oil serves as the continuous phase and water as the dispersed phase. Oil-based muds are used to improve lubricity, minimize problems with water-sensitive formations, and deal with other site-specific conditions. Oil-based muds are more expensive and more toxic than water-based drilling fluids, and the fluid and cuttings cannot be discharged overboard. OBMs are separated from the cuttings and recycled after use. Diesel oil and mineral oil are the major components of oil-based muds. Most OBMs currently in use are based on diesel oil.

Drilling fluids containing diesel oil may contain a number of conventional and non-conventional pollutants, including naphthalene, phenanthrene, phenol, zinc, lead, chromium and copper. Diesel oil may contain 20 to 60% by volume aromatic hydrocarbons. Other non-conventional pollutants in diesel oil include PAHs such as methylnaphthalene, methyl phenanthrene and alkylated forms of the listed organic priority pollutants. Conventional mineral oils have substantially lower concentrations of aromatics and other pollutants than diesel oil.

Table E-1 gives some major components of conventional mineral and diesel oil. Oil-based muds also contain a number of additives, including barite. The concentration of metals in oil-based fluids that come from metals in the stock barite will be similar to those in water-based drilling fluids.

Synthetic-based Muds

In SBMs, the synthetic liquid forms the continuous phase, while brine serves as the dispersed phase (Burke and Veil, 1995). SBMs are generally less toxic and hazardous than are diesel and conventional mineral oil-based drilling muds, and can be used in difficult drilling situations instead of oil-based fluids. Synthetic fluids are recycled after use.

Major types of synthetic drilling fluids currently in use include esters, Poly-alpha olefins (PAOs); Linear alpha olefins (LAOs); Internal Olefins (IOs) and LAO/PAO. Synthetic base fluids contain no priority pollutants and little or no aromatic content, which reduces their toxicity and environmental and human health impact. Table E-1 lists the general properties of the synthetic base fluids, compared to diesel oil and enhanced mineral oil. Table E-2 lists the major synthetic base fluid products that are currently available.

Other chemicals are added to the base fluid to tailor the properties of the drilling fluid to the well. These additives include chemicals to control density, lubricity, fluid flow, and corrosion and scale. Barite is a component of most synthetic-based mud systems, and the concentration of metals in synthetic drilling fluid will be similar to those in WBMs. The current Offshore Effluent Limitation Guidelines (ELG) limit the concentration of cadmium and mercury in the stock barite to 3 mg/kg and 1 mg/kg, respectively.

Drilling fluid systems refers to the product formulation that includes the synthetic base fluid and additives. Table E-2 lists the major synthetic drilling systems currently available.

Table E-1. General properties of synthetic, enhanced mineral oil and oil-based fluids (modified after Aquateam, 1996)

Base Fluid	Density (g/ml)	Viscosity (cst at 40°C)	Flash point °C	Aromatic content (%)
Diesel	0.85	3-4	66	25
Conventional Mineral Oil	0.80	2-3	90-110	1-7
Purified Paraffin Oil	0.77-0.79	2-3	90-102	<1
Enhanced Mineral Oil	0.80	1.7-3	80-110	<0.01-<0.2
Ester ca. C_{26}	0.85	5-6	179	0
Ether ca.C_{20}	0.83	6.0	166	0
Acetal C_{20}	0.84	6.0	>139	0
Poly-alpha olefin C_{20}	0.80	5-7	155	0
Linear alpha olefin C_{14}-C_{16}	0.77-0.79	2.1	114	0
Linear alpha olefin C_{16}-C_{18}	0.77-0.79	3.1	146	0
Internal olefin C_{16}-C_{18}	0.78	3.1	137	0

Table E-2. Major synthetic and enhanced mineral oil-based mud systems and base fluids.

Company	Type	System Name	Base Fluid Name
Amoco Chemical	LAO		AmoDrill 1100 synthetic olefin
Amoco Chemical	IO		AmoDrill 1000 synthetic olefin
Baker-Hughes Inteq	IO	Syn-Teq	Iso-Teq
Baroid	Ester	PETROFREE Mud	PETROFREE
Baroid	Ester/LAO	PETROFREE LE Mud	LE BASE
Baroid	EMO[1]	XPO7 Mud	XPO7
Chevron	IO		Gulftene 14/16/18/20
Exxon	EMO	NS	ESCAID 110
Exxon	EMO[2]	NS	ESCAID 240
Exxon	EMO[1]	NS	613 Drilling Fluid
Exxon	PAO[3]	NS	EXXDRILL S 175
MI Drilling Fluids	LAO	Novalite	LAO 14/16
MI Drilling Fluids	IO	Novaplus	IO 16/18
MI Drilling Fluids	PAO	Novadril	Novasol II
Shell	IO		Neodene
Schlumberger Dowell	LAO	Ultidrill Mud	Ultidrill

LAO; linear alpha olefin; IO: internal olefin; PAO: poly-alpha olefin; EMO: enhanced mineral oil
NS: no system available yet for EMOs made with SBM additives, EMOs have been used with conventional mineral oil mud additives
[1]purified paraffin oil, here classed with enhanced mineral oils
[2]has been used, generally not preferred because of its higher viscosity
[3]synthetic polymerized material made from olefins and fully hydrogenated, similar to PAO

Enhanced Mineral Oil-based Drilling Fluids

Enhanced mineral oils and purified paraffin oils are often included with the synthetic muds because they were developed in response to the same regulatory and environmental pressures and share many of the benefits of SBMs over OBMs. Enhanced mineral oils and purified paraffin oils cannot be strictly considered synthetic because they are derived from petroleum products. EPA has defined enhanced mineral oils (EMOs) as a petroleum distillate that has been highly purified and is distinguished from diesel oil and conventional mineral oil in having a lower polycyclic aromatic (PAH) content. Enhanced mineral oils typically have a PAH content of 0.001 or lower weight percent expressed as phenanthrene. Products described as purified paraffins may also be considered EMOs under this definition as they are also derived from petroleum. Purified paraffin oils may have undergone an additional purification step, such as application of a molecular sieve.

Because they are derived from petroleum, EMOs are currently treated as oil-based muds, and their cuttings are injected onsite or shipped onshore for disposal. EMO drilling systems will also contain metals from added stock barite. Currently available EMO base fluids are listed in Table E-2.

Framework For Comparative Assessment

The comparative risk assessment compares potential human health and environmental impacts of allowing the discharge of SBM and EMO cuttings to the potential impacts of not allowing their discharge. This assessment can be framed in terms of risk reduction to human health and the environment and pollution prevention (i.e. total reduction of contaminants released to the environment).

Baseline Assumptions

Table E-3 gives an initial set of assumptions to support development of a framework for a comparative risk assessment.

Most offshore wells are drilled using water-based muds. Water-based muds are cheaper than the alternatives, and the cuttings and waste drilling fluids can be discharged offshore. In the Gulf of Mexico, approximately 80% of the wells are drilled using WBMs. All of the deepwater wells are drilled using OBM or SBMs. Because of their higher cost, SBM/EMOs will replace only the diesel oil-based muds used in deeper wells, not WBMs.

Most oil-based muds used are based on diesel oil, because it is less expensive than conventional mineral oil, and both kinds of OBMs must be injected onsite or shipped to shore for disposal.

Table E-3. Baseline assumptions.

• Most wells are drilled using WBMs
• SBMs/EMOs will replace only OBMs, not WBMs
• 20% of wells in the Gulf of Mexico are drilled using OBMs or SBMs
• 50% of wells drilled using OBM/SBM use OBM; 50% use SBM
• All deepwater OBM/SBM wells are drilled with SBM
• An average of 12% of mud volume is retained on cuttings
• OBMs are based on diesel oil
• WBMs no longer use mineral oil for lubricity or to free stuck pipe
• SBM is used to free stuck pipe
• SBM for pill equals 100 bbl, 50% retained in mud and 50% on cuttings
• If SBM cuttings discharge is allowed, all OBM wells will switch to SBM due to economic incentive
• If no discharge is allowed, all OBM/SBM wells will be drilled using OBM due to economic incentive
• In the Gulf Of Mexico, deepwater wells can only be drilled using SBM

Because WBMs are so much cheaper than OBMs, EMOs and SBMs, industry expects to continue to use WBMs in drilling most offshore wells. If the discharge of SBM cuttings is allowed, it is assumed that all wells currently using OBMs will switch to SBM/EMOs because of the economic incentive.

If discharge of SBM/EMO cuttings is not allowed, it is assumed that all wells that cannot be drilled using WBMS will be drilled using OBMs, again because of the economic incentive. Deepwater wells in the Gulf of Mexico can only be drilled using SBMs because of the risk of a riser disconnecting during drilling and the potential environmental impacts associated the loss of OBMs. In these situations these wells will either be drilled using SBMs that will have to be recycled and the waste shipped to shore for disposal, or the wells will not be drilled at all.

Framework

SBMs and EMOs are expected to replace OBMs in difficult drilling situations. The major comparison in a comparative assessment, then, is between the use of diesel OBMs and SBMs/EMOs. It is also useful to compare the risks and environmental impacts associated with the use of SBMs and EMOs to those associated with the use of WBMs, because WBM discharges are allowed under the current offshore ELGs; and their impacts by default are considered acceptable.

Potential human health and environmental impacts associated with the use, discharge and disposal of WBM, OBMs, and SBM/EMOs are outlined in Table E-4. These impacts vary in their importance, duration, and certainty. Impacts include the direct impacts associated with onsite discharges (i.e. benthic and water column effects) and external effects such as air emissions and energy use, occupational injuries and exposures, and landfill impacts.

Potential direct water quality and benthic impacts are the environmental effects most often discussed. Cuttings dilute rapidly and settle after discharge, and water column effects are minimal. The primary concern is the potential for effects on benthic organisms, from the physical effects of the material, organic enrichment of the sediments, and potential toxic effects. Seabed surveys near WBM discharges have found contaminant enrichment of sediments and reduced richness and abundance of biota, (EPA, 1993b) although some studies have found no such effects (Neff, 1991). The extent and longevity of the impacts are variable, and dependent on the composition of the cuttings and the local physical environment.

There are limited data available to describe impacts associated with SBM discharges (Burke and Veil, 1995; Avanti, 1997). Toxic effects are not expected for SBM cuttings, but there is a concern that organic enrichment and anoxia may cause significant impacts to benthic communities. Industry is planning a multi-year survey to examine the extent and longevity of impacts of SBM cuttings discharge piles on seabed abundance and diversity (Veil and Daly, 1998).

Little or no bioaccumulation of the synthetic- and enhanced mineral oil base fluids are expected, and discharge of the drilling fluids associated with the cuttings should not present any risks to human health from ingestion in edible fish and shrimp. This assumption, however, is based on very little data, and bioaccumulation can be expected to vary with the chemical composition of the fluids. EPA will be conducting bioaccumulation tests to better characterize the bioaccumulation potential of SBMs.

There is little evidence to suggest that the metals discharged with the cuttings will bioaccumulate and present risks to human health above what is presented by metals naturally occurring in fish and shellfish in the Gulf of Mexico. Field studies have given varying results, with some studies reporting low levels of bioaccumulation of metals, and others finding no accumulation above background levels. In any case, the volume of metals discharged with SBM/EMO cuttings will be significantly smaller than in the past because of the ELG limitations on metals in the stock barite, and will always be less than the metals that may currently be discharged with WBMs.

Table E-4. Summary table: qualitative comparative assessment: potential human health, environmental, cost and resource impacts associated with use of drilling fluids.

ACTIVITY/RISK	RELATIVE IMPACT		
	OBMs	WBMs	SBMs/EMOs
DRILLING			
Occupational Risks			
• accidents	M	H	M
• chemical exposure	M	L	L
Public Risks			
• air emissions	L	M	L
Environmental Risks			
• air emissions	L	M	L
• spills	M	L	L
Energy Use	L	M	L
ONSITE DISCHARGE/SOLIDS CONTROL			
Occupational Risks			
• accidents	M	L	L
• chemical exposure	M	L	L
Public Risks			
• bioaccumulation and ingestion	0	L	N/U
Environmental Risks			
• water column effects	0	L	L
• bioaccumulation and effect	0	L	N/U
• benthic effects	0	M	L/U
Energy Use	L	L	L
LOADING AND TRANSPORTATION			
Occupational Risks			
• accidents	H	N	L
• chemical exposure	M	N	L
Public Risks			
• air emissions	L	N	N
• accidents	L	N	L
Environmental Risks			
• spills	H	N	L
• water emissions	L	N	N
• air emissions	M	N	N
Energy Use	M	N	N
ONSHORE DISPOSAL			
Occupational Risks			
• accidents	H	N	N
• chemical exposures	M	N	N
Public Risks			
• air emissions	M	N	N
• groundwater contamination	L	N	N
Environmental Risks			
• air emissions	M	N	N
• groundwater contamination	L	N	N
Energy Use	M	N	N
RESOURCE IMPACTS			
• landfill space/injection capacity	M	L	N
ECONOMIC IMPACTS	H	L	M
LIABILITIES	H	L	L

Qualitative relative ranking of impact, High (H), Medium (M), Low (L), Negligible risk (N); No risk because this activity not involved (0), Uncertain (U).

The indirect impacts are also uncertain, but they can be qualitatively described and an attempt made to quantify the health and environmental impacts. Transporting cuttings to shore involves using cranes on offshore platforms to load cuttings boxes onto supply ships, and transporting the waste cuttings to shore, increasing the potential for accidents. Replacing OBMs with SBMs/EMOs will reduce the need for these dangerous operations, also reducing accidents. Accidents associated with the disposal of cuttings in landfills will also be avoided if SBM/EMO cuttings can be discharged offshore.

The risks associated with occupational exposure to the drilling fluids will be reduced if SBMs and EMOs replace OBMs on offshore platforms. SBMs and EMOs have little or no aromatics or PAHs, eliminating the potential exposure to a carcinogen, and the flash points and volatility of the materials result in smaller inhalation exposures.

Air emissions would be reduced if SBMs/EMOs replaced OBMs, because the emissions associated with the loading, transportation and onshore disposal of drilling cuttings would be avoided. There would be a small reduction in total air emissions, and some very small benefit to human health.

Other factors to be considered are the impacts on landfill disposal and injection well capacities and the potential health and environmental impacts associated with landfill disposal and onshore injection of drilling wastes. Landfill impacts are primarily a resource issue. Landfill space is expensive and limited. It is also difficult to permit land disposal facilities, and citizen opposition and potential liabilities associated with onshore disposal make use of land disposal an unattractive option.

Disposal of potentially hazardous material in a landfill or injection into a disposal well also presents the small but reasonable potential for groundwater contamination and other public health problems associated with onshore waste disposal. OBMs used offshore are now primarily based on diesel oil, and the toxic components of the cuttings generated by SBMs/EMOs present less of a concern than those generated using OBMs.

Resource and economic issues are also important – if SBM/EMO discharges are not permitted, some deep wells will not be drilled, affecting both the available resource and the economy. The potential impacts associated with use of SBM/EMOs and offshore disposal of SBM and EMO cuttings should be balanced against the impacts associated with not allowing their use.

Human Health and Environmental Comparative Assessment

The human health and environmental comparative assessment compares the potential human health and environmental impacts of allowing the discharge of SBM and EMO cuttings to the potential impacts of not allowing their discharge. This assessment can be framed in terms of risk reduction (to human health and the environment) and pollution prevention (i.e. total reduction of contaminants released to the environment).

The specific comparison suggested here is between the risks associated with the use of OBMs (and the associated loading, transporting and disposal of cuttings), and the use of SBMs and EMOs, (assuming onsite discharge of the cuttings). Risks associated with the discharge of WBMs are relevant only as a baseline for what is accepted for wells that can be drilled with WBMs.

It will not be possible, reasonable or even necessary to quantify all of the benefits and costs associated with allowing discharge of SBM/EMO cuttings offshore. A clear presentation of what is expected in terms of pollution prevention and potential risk reduction, along with quantitative estimates where reasonable, is enough to allow regulators and stakeholders to make the necessary comparisons of costs and benefits. Table E-5 summarizes costs and benefits, in terms of pollution prevention and human health risks, associated with allowing the discharge of SBM and EMO cuttings offshore.

The amount of pollution prevention achieved through use of SBM/EMOs can be estimated per well and for the industry, based on data developed for the Offshore ELGs and being collected by EPA and industry for SBMs. Pollution prevention benefits are the reduction in air emissions associated with not having to load, ship and handle cuttings onshore, and the reduction in drilling waste disposed of in landfills. Pollution prevention costs are the amount of metals and SBM/EMO base fluid organics that will be discharged offshore.

The human health risk reduction (and risk added) achieved by allowing SBM/EMO cuttings discharge will be more difficult to quantify. Small occupational risk reductions will be realized through reducing accidents, and exposure to hazardous chemicals. Small reductions in risk to public health include a reduction in the risks associated with exposure to air pollutants and contaminants released to the environment during landfilling and landfarming. A small potential increase in human health risk is associated with the possible exposure of recreational fishermen to metals in fish caught near drilling platforms.

Table E-5. Human health and pollution prevention benefits and costs of allowing SBM and EMO cuttings discharge offshore

COSTS	BENEFITS
Pollution Prevention	
Small increase in metals and base fluid organics discharged to water column	Reduction in amount of waste, total cuttings and heavy metals disposed of onshore
	Small reduction in air emissions from solids loading, shipping and disposal
Human Health	
Small potential risk from bioaccumulation of trace metals in edible fish and shellfish	Small potential risk reduction (risk from exposure to contaminants in water and soil) from not disposing metals in onshore facilities
	Small potential benefit from reduced air pollution associated with solids shipping, transportation and disposal
	Small benefit in reduced occupational exposures and handling of carcinogens
	Small benefit in eliminating accidents associated with loading, transporting and disposing of cuttings

Additional work to support EPA and industry in developing discharge criteria for SBM/EMO cuttings offshore and in understanding the long-term impacts associated with the use of SBM/EMOs include:

- Collection of the toxicity, hazard, and bioaccumulation data needed to assess the human health impacts associated with the use and non-use of SBM/EMOs.
- Platform-specific risk assessment for metals bioaccumulated from drilling waste discharges to quantify risks from metals discharged in SBM/EMO cuttings.

A quantitative assessment of risk reduction and pollution prevention will require more detailed assumptions and data. These data are being developed by industry and EPA.

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1 INTRODUCTION

During the drilling of an oil or gas well, drilling fluid (or "mud") is used to maintain well control and to remove drill cuttings from the hole. In response to effluent limitation guidelines promulgated by the United States Environmental Protection Agency (EPA) for discharge of drilling wastes offshore, alternatives to water and oil-based muds have been developed. These synthetic-based muds (SBMs) are more efficient than water-based muds (WBMs) for drilling difficult and complex formation intervals and have lower toxicity and smaller environmental impacts than diesel or conventional mineral oil-based muds (OBMs). A third category of drilling fluids, derived from petroleum and called enhanced mineral oils (EMOs), also have these advantages over the traditionally used OBMs and WBMs.

Some of the benefits of SBMs over WBMs and OBMs have been described (Veil *et al.*,1996; Candler *et al.*, 1993). It has been suggested that, compared to WBMs, SBMs may facilitate drilling under difficult conditions and may also result in lower quantities of discharged solids. As compared to OBMs, drilling costs may be less, provided the cuttings associated with SBMs may be discharged, and smaller volumes of waste must be shipped onshore for disposal. Synthetic drilling fluids may present a significant pollution prevention opportunity, because the fluids are recycled, and smaller volumes of metals are discharged with the cuttings than for WBMs. Because of their high cost, industry will not continue to use these new drilling fluids if the cuttings cannot be discharged onsite.

EPA recognizes that SBMs and EMOs are new classes of drilling fluids, but their regulatory status is unclear. The extent to which current Best Available Technology (BAT) controls are appropriate for SBMs and EMOs is uncertain. To address this uncertainty, EPA is following an innovative presumptive rulemaking process that will develop final regulations for SBM discharges offshore in less than three years (Veil and Daly, 1998).

To support this rulemaking EPA and the petroleum and drilling industries are working together to identify and close data gaps concerning the potential environmental effects of SBM discharges, and to develop monitoring procedures and discharge limitations. This effort has focused on characterizing SBMs, but EPA recognizes that EMOs have many of the same environmental and health benefits as SBMs.

The decision about allowing discharge of cuttings with small amounts of associated SBMs should not be based solely on potential environmental impacts, especially those such as bioaccumulation or biodegradation that may be difficult to connect directly to effects on populations or ecosystems. Regulatory decisions about drilling fluid discharges should also consider the potential impacts associated with the alternatives. These potential impacts include impacts that are not directly related to the discharge, such as occupational accidents and chemical exposures, disposal costs, air emissions, and risks associated with transportation and handling. Even without a complete, quantitative understanding of impacts, available data can be used to bound the problem; identify uncertainties; and balance potential impacts in making a risk management decision.

This report develops a framework for a comparative risk assessment for the discharge of SBMs and EMOs, to help support a risk-based, integrated approach to regulatory decision making. The framework will help identify potential impacts and benefits associated with the use of SBMs, EMOs, WBMs and OBMs; identify areas where additional data are needed; and support early decision-making in the absence of complete data. As additional data become available, the framework can support a full quantitative comparative assessment. Detailed data are provided to support a comparative assessment in the areas of occupational and public health impacts.

2 REGULATORY DRIVERS

Final Offshore Effluent Limitation Guidelines for drilling muds and cuttings were issued in 1993. Limitations on the discharge of water-based muds and cuttings offshore include:

- No discharge of muds and cuttings that contain diesel oil.
- No discharge of free oil, as measured by the static sheen test.
- No discharge of drilling fluids and cuttings within three miles of shore.
- A 30,000 ppm 96 hour toxicity limitation on the suspended particulate phase.
- Limitations on the cadmium (3 mg/kg) and mercury (1 mg/kg) content of barite used in muds.

This regulation did not address the requirements for discharge of synthetic drilling fluids or enhanced mineral oils.

Final Coastal Effluent Limitation Guidelines for drilling muds and cuttings were issued in 1996. Discharges of drilling muds and cuttings were prohibited in coastal locations, except for Cook Inlet Alaska. Discharge limitations for Cook Inlet were the same as those promulgated in the Offshore rule.

The Coastal Effluent Guideline defined SBMs and EMOs (see Section 3) and provided some limited guidance to permit writers for SBMs. EPA suggested that Gas Chromatography (GC) be used as confirmation of the absence of free oil, and that the current static sheen, toxicity and barite limits on mercury and cadmium in barite be met. In the Coastal Effluent Guidelines, EPA considered that EMOs, while capable of passing the static sheen and mysid shrimp toxicity tests, may not biodegrade and allow recovery of the cuttings pile any better than diesel oils. Because of the lack of available data, Effluent Limitation Guidelines for WBMs were not considered appropriate for EMOs.

Permit writers and industry need more specific guidance for SBM cuttings. Currently, some operators are discharging SBM cuttings, and applying WBM discharge limits. Other operators are shipping SBM cuttings to shore for disposal because they are concerned about potential liabilities. Other operators continue to use OBMs. There is evidence that the static sheen test, meant to identify the presence of free oil, is not appropriate for synthetic fluids (Burke and Veil, 1995). Enhanced mineral oils are not being discharged offshore but are being handled as OBMs.

EPA is conducting an accelerated rulemaking process for SBMs and EMOs to address this need (Veil and Daly, 1998). Industry, the Minerals Management Service (MMS) and the United States Department of Energy (DOE) are providing data and technical support to EPA to facilitate this effort.

3 DEFINITIONS

Defining the various materials referred to as drilling fluids is important because of the number of different materials available, the distinction made between a synthetic-based fluid and one derived from petroleum products, and the difference between the chemical characteristics of the entire drilling fluid as compared to the base fluid and individual additives.

In the Coastal Effluent Guidelines, EPA provided the following definitions for four classes of drilling fluids.

> "The term drilling fluid refers to the circulating fluid (mud) used in the rotary drilling of wells to clean and condition the hole and to counterbalance formation pressure. The four classes of drilling fluids are
>
> a) A water-based drilling fluid has water as its continuous phase and the suspending medium for solids, whether or not oil is present.
> b) An oil-based drilling fluid has diesel oil, mineral oil, or some other oil, but neither a synthetic material nor enhanced mineral oil, as its continuous phase with water as the dispersed phase.
> c) An enhanced mineral oil-based drilling fluid has an enhanced mineral oil as its continuous phase with water as the dispersed phase.
> d) A synthetic-based drilling fluid has a synthetic material as its continuous phase with water as the dispersed phase."

EPA also defined "synthetic material" and "enhanced mineral oil". The term enhanced mineral oil means a petroleum distillate that has been highly purified and is distinguished from diesel oil and conventional mineral oil in having a lower polycyclic aromatic (PAH) content. The term synthetic material as applied to synthetic-based drilling fluid means material produced by the reaction of specific purified chemical feedstock, as opposed to the traditional base fluids such as diesel and mineral oil which are derived from crude oil. See Appendix A for EPA's specific definition.

The synthetic-based drilling fluid systems currently available can be categorized by the chemical form of the base fluid. These include esters, ethers, linear paraffins and olefins. Another category of base fluid, often discussed with SBMs and EMOs, are purified paraffin oils. Because they are derived from petroleum these purified paraffin oils may also be considered EMOs.

The base fluids (diesel oil, conventional mineral oil, water, enhanced mineral oil or synthetics) make up varying percentages of the whole drilling fluid by volume. Additives to the base fluid include weighting material (barite), viscosifying agents, shale control additives, chemical control additives and brines. The base fluid and additives are mixed onsite to meet the specific requirements of a given well. The base fluids and additives together constitute a drilling fluid system.

4 DRILLING A WELL OFFSHORE AND DISPOSING OF DRILLING WASTE

4.1 Drilling a Well

To drill a well offshore, the well is first "spudded" by hammering or drilling a large diameter pipe or conductor casing into the seafloor. The well is then drilled using rotary drilling. A drill bit is attached to the end of a drill string or pipe, which is lowered through the inside of the casing to the bottom of the hole. The bit rotates and is lowered as the hole is formed. Periodically the drill string is lifted out of the hole and casing is placed into the hole.

A circulating drill fluid is used to move the drill cuttings out of the borehole. This drilling fluid is mixed at the drill site based on site-specific drilling conditions. The drilling fluid is pumped into the hole through the drill string, and is ejected out of nozzles in the drill bit. The drilling fluid and cuttings are circulated to the surface through the casing.

A solids control process that typically consists of a shaleshaker, desander and desilter is used to separate cuttings, sand and silt from the drilling fluid. The shaleshaker is a vibrating screen that removes large particles (> 75 microns) from the drilling fluid. The desander is a hydrocyclone that removes particles greater than 44 microns by centrifugal force. The desilter is a hydrocyclone that uses centrifugal forces to remove smaller particles (>8 microns). The processed drilling fluid is recirculated to the well.

Some of the drilling fluid remains associated with the cuttings after the solids control process. The volume of the drilling fluid that remains with the cuttings varies with the type of formation, drilling fluid, characteristics of the cuttings, and the efficiency of the solids removal system. A general rule of thumb often used is that five percent drilling fluid by volume is associated with the cuttings.

Excess drilling fluid is removed from the system when the fluid is diluted to maintain rheological properties, changed over when drilling conditions change, or when casing or cement is placed downhole.

A water soluble or synthetic spotting fluid is used to aid in freeing stuck pipe. A slug or "pill" of the synthetic based fluid is pumped down the drill string. The pill remains with the mud system.

The volume of drill cuttings generated depends on the dimensions of the well and the percent washout, the type of formation being drilled, the type of drill bit, and the type of drilling fluid used.

4.2 Disposing of Drilling Waste

If the cuttings and waste drilling fluids do not contain free oil and pass the mysid toxicity test and other permit requirements, they can be discharged overboard. If the cuttings are contaminated with oil from an oil-based mud or from oil in the formation they must be brought to shore for disposal or injected onsite. Waste oil-based drilling fluids, synthetic-based, and enhanced mineral oil drilling fluids are hauled to shore for recycling. Veil (1998) summarizes current offshore drilling waste disposal practices and costs.

Drilling wastes are exempted from federal regulation as hazardous wastes under Subtitle C of RCRA. States have their own requirements for disposal of drilling wastes. In the Gulf Coast states, drilling wastes have requirements specific to non-hazardous oil field wastes.

Most WBM drilling fluids and cuttings are discharged offshore. Most synthetic-based muds are recycled, and most SBM cuttings are discharged. Some SBMs are treated as oil-based muds and are disposed of onshore (Veil, 1998).

Most oil-based muds are recycled, and most OBM cuttings are disposed of onshore (Veil, 1998). In some cases, OBM drilling wastes are injected into an underground formation onsite. Muds and cuttings are ground into a slurry and injected into the formation through a dedicated injection well.

On rigs used in deep water, cuttings are stored in cuttings boxes on the deck of the rig. Cuttings boxes are transported to and from supply vessels using cranes. Spent drilling fluids are pumped from the rigs to tanks located on the deck or within the hull of the supply vessel. In shallow water, barge mounted rigs must be used. Barge mounted rigs have limited deck space and cuttings boxes cannot be used. In these instances cuttings barges are used to handle cuttings.

Some disposal sites are located at marine stations and may not need transportation by truck or barge. Wastes may be transported from the supply vessels to barges that transport the waste to the drilling site on waterways, or trucks may be used.

Most drilling waste transported to land (in the Gulf of Mexico) goes to a facility that treats the waste and injects the resulting liquid fraction into a disposal well. The remaining solid fraction is clean enough to be used as landfill cover material. Another disposal method for offshore drilling waste is disposal in landfills or treatment at landfarming facilities. The most common waste handling method for land disposal of drilling waste is stabilization (solidification and fixation) of the mud followed by landfilling (EPA, 1993a). Chemicals are added to the waste that react to form a solid material. Disposal may be in lined impoundments or pits. In a landfarming facility, wastes are spread over small areas and allowed to biodegrade. Drilling waste may be stabilized and solidified into useable construction material (EPA, 1995a).

5 DRILLING FLUIDS

Drilling fluids, or muds are suspensions of solids and dissolved materials in a base of water, oil, or other synthetic material. WBMs are used in less difficult wells and the shallow portions of difficult, deeper wells. OBMs, EMOs and SBMs are used in deeper well intervals and complex drilling situations because of their superior performance. Synthetic-based muds will be considered for use in place of OBMs in difficult drilling situations if the cuttings may be discharged. EMOs and purified paraffin oils may also replace OBMs in these situations. SBMs and EMOs may be cost-effective in replacing OBMs if the cuttings can be discharged offshore, saving the cost of shipping and disposal. Like OBMs, SBMs and EMOs are expensive, and operators recycle them for re-use, avoiding the need for discharge or disposal of the drilling fluid itself.

5.1 Water-Based Drilling Fluids

Most offshore wells are drilled using water-based drilling fluids. Water based muds are aqueous slurries of barite, clay, and formation solids that usually also contain low concentrations of polymers, lignites, lignosulfonates and caustic soda. They may also contain low concentrations of other materials used to solve special problems (e.g. defoamers, lime). Freshwater muds contain bentonite and caustic soda (NaOH), while saltwater muds may contain attapulgite clay instead of bentonite. Water-based muds generally consist of more than 90% water by volume (Burke and Veil, 1995). Tables 1, 2 and 3 describe the major properties of six generic water based drilling fluids tested by EPA (EPA, 1993a).

Current offshore regulations allow offshore (greater than three miles) discharge of water-based drilling fluids and cuttings. The discharges must meet a 30,000 ppm 96 hour toxicity limitation on the suspended particulate phase, and no discharge of free oil, as measured by the static sheen test, is allowed.

In the past, low concentrations of conventional mineral oils were used to improve lubricity; however, due to the toxicity and sheen limitations this practice has been largely eliminated. Also, in the past, OBM spotting fluids were used to free stuck pipe. Today, SBM (primarily polyalphaolefins) and water-soluble spotting fluids are used, again to avoid exceeding the toxicity and sheen limitations.

Table 1. Water-based mud systems, generic composition (from EPA, 1993a).

Generic Water Based Drilling Fluid Type	Base Components
Potassium/Polymer	KCL Drispac (Super-Lo) X-C Polymer Barite Starch Seawater
Seawater/Lignosulfonate	Attapulgite Chrome Lignosulfonate Lignite Polyanionic Cellulose Caustic Barite Seawater
Lime	Bentonite Lime Barite Chrome Lignosulfonate Caustic Lignite Distilled Water
Nondispersed	Bentonite Acrylic Polymer (for suspension) Acrylic Polymer (for fluid loss control) Barite Deionized
Spud (slugged intermittently with seawater)	Bentonite Lime Barite Seawater/Freshwater Caustic
Seawater/Freshwater Gel	Bentonite Polyanionic Celluose Sodium Carboxymethyl Cellulose Barite Sodium Hydroxide Seawater/Freshwater
Lightly Treated Lignosulfate Freshwater/Seawater	Bentonite Chrome Lignosulfonate Lignite Soda Ash Carboxymethyl Cellulose Barite
Lignosulfate Freshwater	Bentonite Chrome Lignosulfonate Lignite Carboxymethyl Cellulose Sodium Bicarbonate Barite Deionized Water

Table 2. Organic pollutants detected in generic water-based drilling fluids (EPA, 1993a).

Generic Water Based Drilling Fluid Type	Contaminant µg/kg				
	Phenanthrene	Dibenzofuran	N-Dodecane	Diphenylamine	Biphenyl
#1 Potassium/Polymer	--	--	899	--	--
#2 Seawater/Lignosulfonate	--	--	--	--	--
#3 Lime	--	--	809	--	--
#4 Nondispersed	--	--	819	--	--
#5 Spud (slugged intermittently with seawater)	--	--	854 (822)	--	--
#6 Seawater/Freshwater Gel	--	--	847 (802)	--	--
#7 Lightly Treated Lignosulfate Freshwater/Seawater	--	--	736	--	--
#8 Lignosulfate Freshwater	--	--	780	--	--
#2-01 Mud #2 + 1% mineral oil*	1,060	--	726	--	--
#8-01 Mud #8 + 1% mineral oil*	--	--	--	--	--

* mineral oil is percent by volume and is now rarely used to improve lubricity.

Table 3. Metal concentrations in generic water-based drilling fluids (EPA, 1993a).

Generic Water Based Drilling Fluid Type	Contaminant mg/kg dry weight basis							
	Zn	Be	Al	Ba	Fe	Cd	Cr	Cu
#1 Potassium/Polymer	26.20	<1.0	190	246.0	1,890	0.220	<3.0	3.96
#2 Seawater/Lignosulfonate	42.40	<1.0	1,150	74.0	2,860	0.472	764	27.50
#3 Lime	37.00	<1.0	743	41.2	2,170	0.378	908	40.60
#4 Nondispersed	35.90	<1.0	876	286.0	1,120	0.446	<3.0	6.78
#5 Spud (slugged intermittently with seawater)	8.68	<1.0	347	293.0	833	0.074	<3.0	1.61
#6 Seawater/Freshwater Gel	3.28	<1.0	536	65.4	392	0.042	<3.0	0.70
#7 Lightly Treated Lignosulfate Freshwater/Seawater	2.26	<1.0	541	408.0	660	0.142	299	2.86
#8 Lignosulfate Freshwater	90.40	<1.0	1,150	54.6	5,110	0.36	770	72.20
#2-01 Mud #2 + 1% mineral oil*	43.40	<1.0	1,200	71.3	2,250	0.395	740	26.80
#8-01 Mud #8 + 1% mineral oil*	86.80	<1.0	988	1,240.0	4,980	0.18	610	68.90
	Ni	Pb	Hg	Ag	As	Se	S	Ti
#1 Potassium/Polymer	<6.0	7.74	0.2610	0.089	4.640	<3.0	4.000	0.078
#2 Seawater/Lignosulfonate	<6.0	1.82	0.2640	0.126	2.400	<3.0	0.260	0.201
#3 Lime	<6.0	41.2	0.7530	0.314	17.200	<3.0	1.060	0.129
#4 Nondispersed	<6.0	52.5	0.4370	0.228	5.250	<3.0	0.473	0.114
#5 Spud (slugged intermittently with seawater)	<6.0	3.51	<0.010	<0.060	0.258	<3.0	<0.060	<0.060
#6 Seawater/Freshwater Gel	<6.0	1.53	0.2970	<0.060	0.621	<3.0	<0.060	<0.060
#7 Lightly Treated Lignosulfate Freshwater/Seawater	<6.0	1.42	0.0961	<0.060	0.497	<3.0	<0.060	<0.060
#8 Lignosulfate Freshwater	<6.0	17.80	0.3550	0.244	11.700	<3.0	0.794	0.071
#2-01 Mud #2 + 1% mineral oil*	7.76	6.83	0.1070	0.110	1.470	<3.0	0.239	0.175
#8-01 Mud #8 + 1% mineral oil*	<6.0	24.50	0.3910	1.390	12.200	<3.0	2.650	0.080

* mineral oil is percent by volume and is now rarely used to improve lubricity.

One of the most important additives to drilling fluids is barite. Barite (naturally occurring barium sulfate ore) is a high-density material used to control downhole pressure. A statistical analysis of a database describing trace metal concentration of barite found some correlation between cadmium and mercury concentrations, and the concentrations of other trace metals in the barite (EPA, 1993a). The Current Offshore Effluent Limitation Guidelines (ELG) limit the concentration of cadmium and mercury in the stock barite to 3 mg/kg and 1 mg/kg, respectively. Barite is a component of most drilling fluid systems. Barite used to be the primary source of listed toxic metals in drilling fluid discharges, but the new ELG limits result in much smaller discharges of metals in muds and cuttings.

Table 4 gives estimated metal concentrations in used drilling fluids based on barite that meets the ELG stock limitations. These concentrations discharged in water-based muds and cuttings are allowed under the Offshore Effluent Limitation Guidelines.

Table 4. Metal concentrations in drilling fluids where "clean" barite was used (from EPA, 1995).

Metal	"Clean" Barite Concentration (mg/kg)
Priority	
Cadmium	1.1
Mercury	0.1
Antimony	5.7
Arsenic	7.1
Beryllium	0.7
Chromium	240.0
Copper	18.7
Lead	35.1
Nickel	13.5
Selenium	1.1
Silver	0.7
Thallium	1.2
Zinc	200.5
Nonconventionals	
Antimony	5.7
Barium	120,000.0
Iron	15,344.3
Tin	14.6
Titanium	87.5

5.2 Oil-based Drilling Fluid

In oil-based drilling fluids, oil serves as the continuous phase and water as the dispersed phase. Oil-based muds are used to improve lubricity, minimize problems with water-sensitive formations, and deal with other site-specific conditions. Oil-based muds are more expensive and more toxic than water-based drilling fluids, and the fluid and cuttings cannot be discharged overboard. OBMs are separated from the cuttings and recycled after use. Diesel oil and mineral oil are the major components of oil-based muds. Most OBMs currently in use are based on diesel oil.

In the past, conventional mineral oil was used in water-based muds to improve lubricity, but due to toxicity and sheen limitations this practice has been largely eliminated. Also, in the past, OBM spotting fluids were used to free stuck pipe. In most cases today SBMs and water-soluble spotting fluids are used, again to avoid exceeding the toxicity and sheen limitations.

Drilling fluids containing diesel oil may contain a number of conventional and non-conventional pollutants, including naphthalene, phenanthrene, phenol, zinc, lead, chromium and copper. Diesel oil may contain 20 to 60% by volume aromatic hydrocarbons. Other non-conventional pollutants in diesel oil include PAHs such as methylnaphthalene, methyl phenanthrene and alkylated forms of the listed organic priority pollutants.

Conventional mineral oils have substantially lower concentrations of aromatics and other pollutants than diesel oil. Conventional mineral oil-based drilling muds contain approximately 60% mineral oil by volume (EPA, 1993a). Table 5 gives some major components of conventional mineral and diesel oil. Average values for conventional mineral oil, used by EPA to represent contaminant concentrations in mineral oil in the development of the Offshore Effluent Limitation Guidelines, are given in Table 6.

Oil-based muds also contain a number of additives, including barite. The concentration of metals in oil-based fluids that come from metals in the stock barite will be similar to those in water-based drilling fluids (Table 4).

Table 5. Characteristics of diesel and conventional mineral oil (mg/l, from EPA, 1993a).

Organic Constituents	Gulf of Mexico Diesel	California Diesel	Alaska Diesel	EPA/API Ref Fuel Oil	Mineral Oil A	Mineral Oil B	Mineral Oil C
Benzene	ND	0.02	0.02	0.08	ND	ND	ND
Ethylbenzene	ND	0.47	0.26	2.01	ND	ND	ND
Naphthalene	1.43	0.66	0.48	0.86	0.05	ND	ND
Fluorene	0.78	0.18	0.68	0.45	ND	0.15	0.01
Phenanthrene	1.85	0.36	1.61	1.06	ND	0.20	0.04
Phenol (ug/g)	6.0	ND	1.2	ND	ND	ND	ND
Alkylated benzenes	8.05	10.56	1.08	34.33	30.0	ND	ND
Alkylated naphthalenes	75.68	18.02	25.18	38.73	0.28	0.69	ND
Alkylated fluorenes	9.11	1.60	5.42	7.26	ND	1.74	ND
Alkylated phenanthrenes	11.51	1.41	4.27	10.18	ND	0.14	ND
Alkylated phenols (ug/g)	52.9	106.3	6.60	12.8	ND	ND	ND
Total biphenyls	14.96	4.03	6.51	13.46	0.23	5.57	0.02
Total dibenziothiophenes (ug/g)	760	1200	900	2100	ND	370	ND
Aromatic content (%)	23.8	15.9	11.7	35.6	10.7	2.1	3.2

Table 6. Organic constituents in conventional mineral oil (EPA, 1995a)[1]

Constituent	Concentration (mg/l)
Benzene	ND
Ethylbenzene	ND
Naphthalene	0.05
Fluorene	0.08
Phenanthrene	0.12
Phenol (ug /l)	ND
Alkylated Benzenes	30.0
Alkylated naphthalenes	0.49
Alkylated fluorenes	1.74
Alkylated phenanthrenes	0.14
Alkylated phenols	ND
Total biphenyls	1.94
Total dibenzothiophenes	370

[1] average values (using only detected values) from analysis of three mineral oils
ND : not detected

5.3 Synthetic-Based Drilling Fluids

Base Fluids

In SBMs, the synthetic liquid forms the continuous phase, while brine serves as the dispersed phase (Burke and Veil, 1995). SBMs are generally less toxic and hazardous than are diesel and conventional mineral oil-based drilling muds, and can be used in difficult drilling situations instead of oil-based fluids. Synthetic fluids are recycled after use.

Major types of synthetic drilling fluids currently in use include:

- Esters
- Poly-alpha olefins (PAOs; C_{20}-C_{24})
- Linear alpha olefins (LAOs; C_{14}-C_{20})
- Internal Olefins (IOs)
- LAO/PAO

Esters are prepared from the condensation reaction of alcohols and organic acids generally under acid catalysis conditions. The organic acids used to make ester drilling fluids come from vegetable oils.

Linear alpha olefins (LAOs) are prepared from the catalytic chain growth of ethylene on triethyl aluminum. After the chain growth step the larger alkyl groups are displaced from the aluminum to give even numbered linear olefin products with carbon numbers from C_{14} - C_{20} (Lee, 1998). The olefin double bond is formed between the first and second carbons of the alkyl chain (the alpha position).

Internal or Isomerized Olefins (IOs) are produced from LAOs using an isomerization catalyst to move the olefin double bond from the alpha position to an internal position along the carbon chain (Lee, 1998). The internal double bond is distributed throughout the linear chain.

Poly-alpha olefins are prepared by the catalytic oligomerization of LAOs, in some cases followed by hydrogenation to remove the double bond. The oligomerization reaction produces oligomers with many different types of branched structures (Lee, 1998).

Synthetic base fluids contain no priority pollutants and little or no aromatic content, which reduces their toxicity and environmental and human health impacts. Table 7 lists general properties of the synthetic base fluids, compared to diesel oil and enhanced mineral oil. Table 8 lists the major synthetic base fluid products that are currently available.

Table 7. General properties of synthetic, enhance mineral oil and oil-based fluids (modified after Aquateam, 1996)

Base Fluid	Density (g/ml)	Viscosity (cst at 40°C)	Flash point °C	Aromatic content (%)
Diesel	0.85	3-4	66	25
Conventional Mineral Oil	0.80	2-3	90-110	1-7
Purified Paraffin Oil	0.77-0.79	2-3	90-102	<1
Enhanced Mineral Oil	0.80	1.7-3	80-110	<0.01-<0.2
Ester ca. C_{26}	0.85	5-6	179	0
Ether ca.C_{20}	0.83	6.0	166	0
Acetal C_{20}	0.84	6.0	>139	0
Poly-alpha olefins C_{20}	0.80	5-7	155	0
Linear alpha olefins C_{14}-C_{16}	0.77-0.79	2.1	114	0
Linear alpha olefins C_{16}-C_{18}	0.77-0.79	3.1	146	0
Internal Olefins C_{16}-C_{18}	0.78	3.1	137	0

Table 8. Major synthetic and enhanced mineral oil-based mud systems and base fluids.

Company	Type	System Name	Base Fluid Name
Amoco Chemical	LAO		AmoDrill 1100 synthetic olefin
Amoco Chemical	IO		AmoDrill 1000 synthetic olefin
Baker-Hughes Inteq	IO	Syn-Teq	Iso-Teq
Baroid	Ester	PETROFREE Mud	PETROFREE
Baroid	Ester/LAO	PETROFREE LE Mud	LE BASE
Baroid	EMO[1]	XPO7 Mud	XPO7
Chevron	IO		Gulftene 14/16/18/20
Exxon	EMO	NS	ESCAID 110
Exxon	EMO[2]	NS	ESCAID 240
Exxon	EMO[1]	NS	613 Drilling Fluid
Exxon	PAO[3]	NS	EXXDRILL S 175
MI Drilling Fluids	LAO	Novalite	LAO 14/16
MI Drilling Fluids	IO	Novaplus	IO 16/18
MI Drilling Fluids	PAO	Novadril	Novasol II
Shell	IO		Neodene
Schlumberger Dowell	LAO	Ultidrill Mud	Ultidrill

LAO; linear alpha olefin; IO: internal olefin; PAO: poly-alpha olefin; EMO: enhanced mineral oil
NS: no system available yet for EMOs made with SBM additives, EMOs have been used with conventional mineral oil mud additives
[1]purified paraffin oil, here classed with enhanced mineral oils
[2]has been used, generally not preferred because of its higher viscosity
[3]synthetic polymerized material made from olefins and fully hydrogenated, similar to PAO[1]

Additives

Other chemicals are added to the base fluid to tailor the properties of the drilling fluid to the well. These additives include chemicals to control density, lubricity, fluid flow, and corrosion and scale. Barite is a component of most synthetic-based mud systems, and the concentration of metals in synthetic drilling fluid will be similar to those in WBMs (Table 4). The current Offshore Effluent Limitation Guidelines (ELG) limit the concentration of cadmium and mercury in stock barite to 3 mg/kg and 1 mg/kg, respectively.

Drilling Fluid Systems

Drilling fluid systems refers to the product formulation that includes the synthetic base fluid and additives. Table 8 lists the major synthetic drilling systems currently available.

5.4 Enhanced Mineral Oil-based Drilling Fluids

Enhanced mineral oils and purified paraffin oils are often included with the synthetic muds because they were developed in response to the same regulatory and environmental pressures and share many of the benefits of SBMs over OBMs. Enhanced mineral oils and purified paraffin oils cannot be strictly considered synthetic because they are derived from petroleum products. EPA has defined enhanced mineral oils (EMOs) as a petroleum distillate that has been highly purified and is distinguished from diesel oil and conventional mineral oil in having a lower polycyclic aromatic (PAH) content. Enhanced mineral oils typically have a PAH content of 0.001 or lower weight percent expressed as phenanthrene. Products described as purified paraffins may also be considered EMOs under this definition as they are also derived from petroleum. Purified paraffin oils may have undergone an additional purification step, such as application of a molecular sieve.

Because they are derived from petroleum, EMOs are currently treated as oil-based muds, and their cuttings are injected onsite or shipped onshore for disposal. EMO drilling systems will also contain metals from added stock barite (Table 4). Currently available EMO base fluids are listed in Table 8.

6 FRAMEWORK FOR COMPARATIVE ASSESSMENT

The comparative risk assessment compares potential human health and environmental impacts of allowing the discharge of SBM and EMO cuttings to the potential impacts of not allowing their discharge. This assessment can be framed in terms of risk reduction to human health and the environment and pollution prevention (i.e. total reduction of contaminants released to the environment).

6.1 Baseline Assumptions

Table 9 gives an initial set of assumptions to support development of a framework for a comparative risk assessment. Baseline assumptions used here that differ from the assumptions EPA made in developing the current offshore ELGs (EPA 1993a) are that mineral oil is no longer used to improve lubricity or as a spotting fluid, and that all oil-based muds currently in use are based on diesel oil.

Table 9. Baseline assumptions.

- Most wells are drilled using WBMs
- SBMs/EMOs will replace only OBMs, not WBMs
- 20% of wells in the Gulf of Mexico are drilled using OBMs or SBMs
- 50% of wells drilled using OBM or SBM use OBM; 50% use SBM
- All deepwater OBM/SBM wells are drilled with SBM
- An average of 12% of mud volume is retained on cuttings
- OBMs are based on diesel oil
- WBMs no longer use mineral oil for lubricity or to free stuck pipe
- SBM is used to free stuck pipe
- SBM for pill equals 100 bbl, 50% retained in mud and 50% on cuttings
- If SBM cuttings discharge is allowed, all OBM wells will switch to SBM due to economic incentive
- If no discharge of SBM is allowed, all OBM/SBM wells will be drilled using OBM due to economic incentive
- In the Gulf Of Mexico, deepwater wells can only be drilled using SBM

Most offshore wells are drilled using water-based muds. Water-based muds are cheaper than the alternatives, and the cuttings and waste drilling fluids can be discharged offshore. In the Gulf of Mexico, approximately 80% of the wells are drilled using WBMs. Because of their higher cost, SBM/EMOs will replace only the diesel oil-based muds used in deeper wells, not WBMs. Approximately 20% of the wells drilled in the Gulf of Mexico now use OBMs or SBMs. All of the deepwater wells are drilled using OBM or SBMs.

The percent of the mud volume retained on the cuttings will vary with the specific drilling fluid used, the characteristics of the formation, and the processes used to remove solids from the drilling fluid. Industry is working to evaluate the extent to which SBMs are retained on cuttings and to develop better technologies for mud recovery. An industry work group evaluated the types of mud recovery devices used in the Gulf of Mexico for wells drilled using SBMs. Shale shakers are the predominant devices being used, with an average of 12% SBMs being retained on the cuttings (Veil and Daly, 1998).

A major assumption made in the development of the Coastal and Offshore Effluent Limitation Guidelines for drilling waste, was that oil-based muds were based primarily on conventional mineral oil, rather than diesel oil. This is no longer the case. Most oil-based muds used are based on diesel oil, because it is less expensive than conventional mineral oil, and both kinds of OBMs must be injected onsite or shipped to shore for disposal.

In the past, conventional mineral oil was often used for lubricity or to remove stuck pipe. This practice has been largely eliminated due to the toxicity and sheen limitations. Also, in the past, OBM spotting fluids were used to free stuck pipe. Today, SBM (primarily polyalphaolefins) and water-soluble spotting fluids are used, again to avoid exceeding the toxicity and sheen limitations.

Because WBMs are so much cheaper than OBMs, EMOs and SBMs, industry expects to continue to use WBMs in drilling most offshore wells. If the discharge of SBM cuttings is allowed, it is assumed that all wells currently using OBMs will switch to SBM/EMOs because of the economic incentive.

If discharge of SBM/EMO cuttings is not allowed, it is assumed that all wells that cannot be drilled using WBMs will be drilled using OBMs, again because of the economic incentive. Deepwater wells in the Gulf of Mexico can only be drilled using SBMs because of the risk of a riser disconnecting during drilling and the potential environmental impacts associated with a spill of OBMs. These deepwater wells will either be drilled using SBMs and the waste shipped to shore for disposal, or the wells will not be drilled at all.

6.2 Framework

SBMs and EMOs are expected to replace OBMs in difficult drilling situations. The major comparison in a comparative assessment, then, is between the use of diesel OBMs and SBMs/EMOs. It is also useful to compare the risks and environmental impacts associated with the use of SBMs and EMOs to those associated with the use of WBMs, because WBM discharges are allowed under the current offshore ELGs; and their impacts by default are considered acceptable.

Figures 1, 2 and 3 outline the process of drilling a well and managing the cuttings and waste drilling fluid. Potential environmental impacts associated with each activity are listed. SBMs and EMOs are treated together because of their similar environmental characteristics, although under current regulations, EMOs are considered OBMs and cuttings may not be discharged offshore.

Figure 1 shows the process of managing drilling wastes when a water-based mud is used. In most cases, the cuttings and drilling fluid will pass the static sheen and toxicity tests required by EPA and the wastes will be discharged onsite. When either of these tests are failed, the drilling mud and cuttings are shipped and disposed of onshore. Most drilling waste disposed of onshore is injected into dedicated disposal wells, but it may also landfilled or landfarmed.

Figure 2 outlines the process of drilling a well and managing the drilling wastes when oil-based drilling fluids are used. The first sections of the well are usually drilled using WBMs and the drilling wastes managed accordingly. No oil-based drilling fluids or cuttings may be discharged offshore, and these fluids are used only to drill through more difficult intervals. Because of the high cost of OBMs, the drilling fluid is taken ashore and processed for reuse. Cuttings associated with OBMs are shipped and disposed of onshore or injected onsite.

Figure 3 shows the process assumed for drilling with SBMs and EMOs. Because of the high cost of synthetic-based fluids, industry will probably not use SBMs and EMOs in place of OBMs if the cuttings cannot be discharged offshore. Also because of the high cost of SBMs, it is expected that the fluid will be taken ashore and processed for reuse, and only the drill cuttings discharged. This analysis assumes that the baseline for comparison for SBMs is discharge of the cuttings offshore. Current practice varies among operators, with some operators applying WBM discharge limits and discharging SBM cuttings, and other operators shipping them ashore for disposal. If discharge of SBM cuttings is allowed, EPA will probably require some form of testing prior to discharge. EPA is working on methods to develop discharge tests appropriate for SBMs. EMO cuttings currently cannot be discharged onshore, but because of their similarities in terms of human health and environmental impacts, this comparative assessment assumes they will also be discharged.

Figure 1. Use of water-based muds in drilling shallow offshore wells and approximately first 10,000 feet of deeper wells: flowchart and potential environmental impacts.

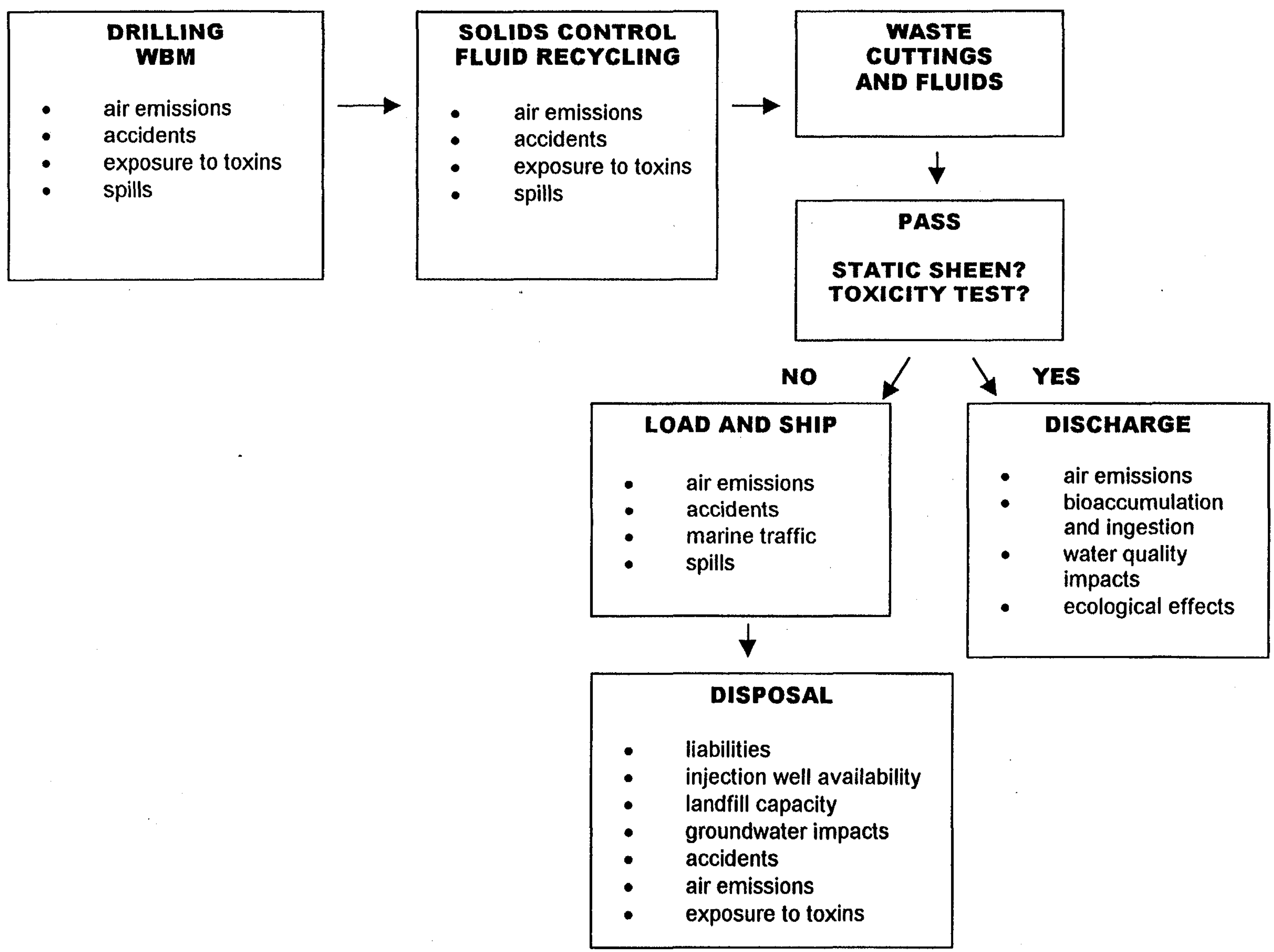


Figure 2. Use of oil-based muds in drilling deep offshore wells: flowchart and potential environmental impacts. Approximately first 10,000 feet drilled with WBMs, waste managed as shown in Figure 1.

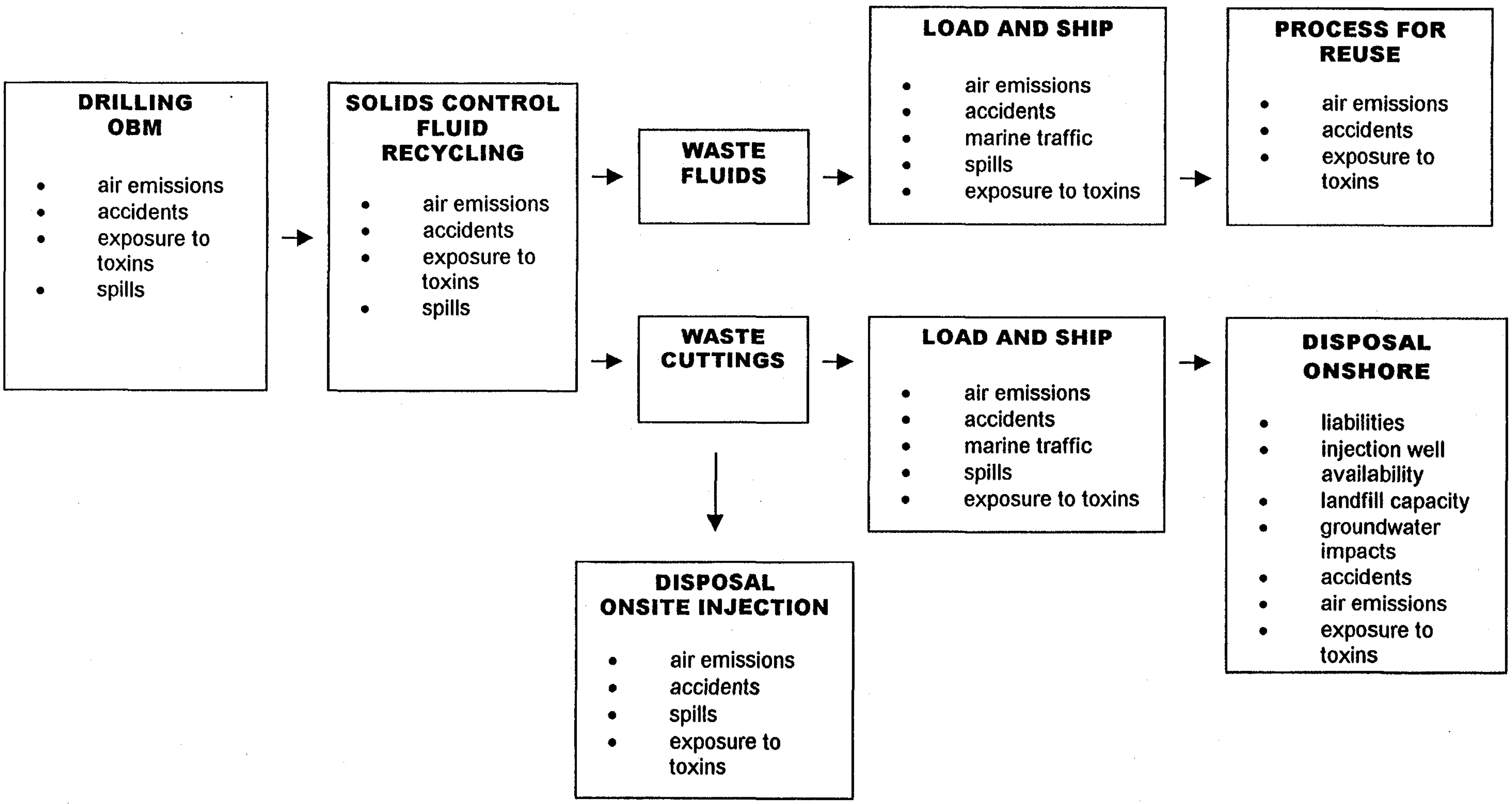
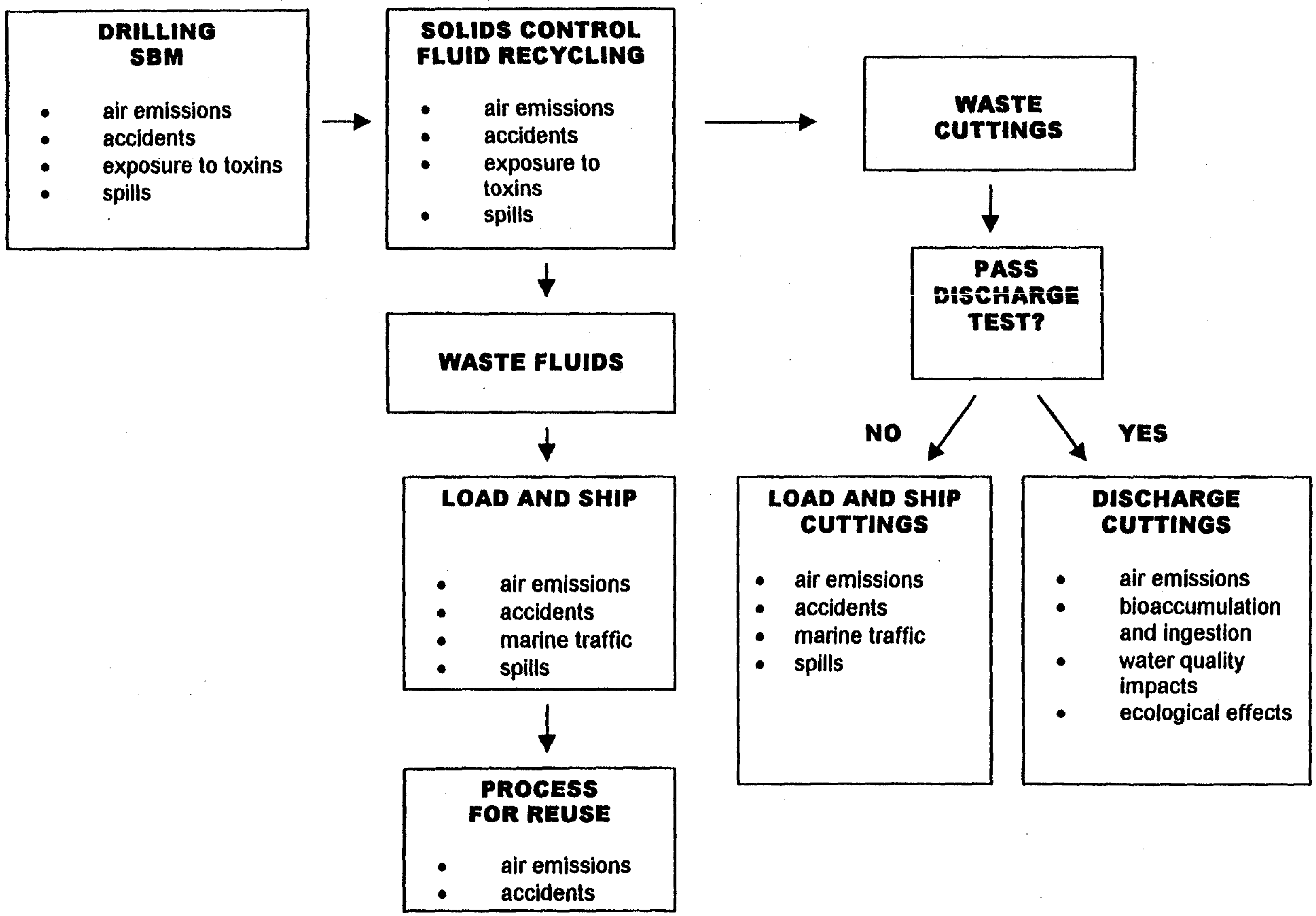


Figure 3. Use of synthetic- and enhanced mineral oil-based muds in drilling offshore wells: flowchart and potential environmental impacts. Approximately first 10,000 feet drilled with WBMs, waste managed as shown in Figure 1.



Potential human health and environmental impacts associated with the use, discharge and disposal of WBM, OBMs, and SBM/EMOs are outlined in Table 10. An expanded version of this table, giving more detailed reasons for each ranking, is given in Table 11. These impacts vary in their importance, duration, and certainty. Impacts include the direct impacts associated with onsite discharges (i.e. benthic and water column effects) and external effects such as air emissions and energy use, occupational injuries and exposures, and landfill impacts.

Potential direct water quality and benthic impacts are the environmental effects most often discussed. Cuttings dilute rapidly and settle after discharge, and water column effects are minimal. The primary concern is the potential for effects on benthic organisms, from the physical effects of the material, organic enrichment of the sediments, and potential toxic effects. Seabed surveys near WBM discharges have found contaminant enrichment of sediments and reduced richness and abundance of biota, (EPA, 1993b) although some studies have found no such effects (Neff, 1991). The extent and longevity of the impacts are variable, and depend on the composition of the cuttings and the local physical environment.

There are limited data available to describe impacts associated with SBM discharges (Burke and Veil, 1995; Avanti, 1997a). Toxic effects are not expected for SBM cuttings, but there is concern that organic enrichment and anoxia may cause significant impacts to benthic communities. Industry is planning a multi-year survey to examine the extent and longevity of impacts of SBM cuttings discharge piles on seabed abundance and diversity (Veil and Daly, 1998).

Little or no bioaccumulation of the synthetic- and enhanced mineral oil base fluids are expected, and discharge of the drilling fluids associated with the cuttings should not present any risks to human health from ingestion in edible fish and shrimp. This assumption, however, is based on very little data, and bioaccumulation can be expected to vary with the chemical composition of the fluids. EPA will be conducting bioaccumulation tests to better characterize the bioaccumulation potential of SBMs.

There is little evidence to suggest that the metals discharged with the cuttings will bioaccumulate and present risks to human health above what is presented by metals naturally occurring in fish and shellfish in the Gulf of Mexico. Field studies have given varying results, with some studies reporting low levels of bioaccumulation of metals, and others finding no accumulation above background levels. In any case, the volume of metals discharged with SBM/EMO cuttings will be significantly smaller than in the past because of the ELG limitations on metals in the stock barite, and will always be less than the metals that may currently be discharged with WBMs.

The indirect impacts are also uncertain, but they can be qualitatively described and an attempt made to quantify the health and environmental impacts. Transporting cuttings to shore involves using cranes on offshore platforms to load cuttings boxes onto supply ships, and transporting the waste cuttings to shore, increasing the potential for accidents. Replacing OBMs with SBMs/EMOs will reduce the need for these dangerous operations, also reducing accidents. Accidents associated with the disposal of cuttings in landfills will also be avoided if SBM/EMO cuttings can be discharged offshore.

The risks associated with occupational exposure to the drilling fluids will be reduced if SBMs and EMOs replace OBMs on offshore platforms. SBMs and EMOs have little or no aromatics or PAHs, eliminating the potential exposure to a carcinogen, and the flash points and volatility of the materials result in smaller inhalation exposures.

Air emissions would be reduced if SBMs/EMOs replaced OBMs, because the emissions associated with the loading, transportation and onshore disposal of drilling cuttings would be avoided. There would be a small reduction in total air emissions, and some very small benefit to human health.

Other factors to be considered are the impacts on landfill disposal and injection well capacities and the potential health and environmental impacts associated with landfill disposal and onshore injection of drilling wastes. Landfill impacts are primarily a resource issue. Landfill space is expensive and limited. It is also difficult to permit land disposal facilities, and citizen opposition and potential liabilities associated with onshore disposal make use of land disposal an unattractive option.

Disposal of potentially hazardous material in a landfill or injection into a disposal well also presents the small but reasonable potential for groundwater contamination and other public health problems associated with onshore waste disposal. OBMs used offshore are now primarily based on diesel oil, and the toxic components of the cuttings generated by SBMs/EMOs present less of a concern than those generated using OBMs.

Resource and economic issues are also important – if SBM/EMO discharges are not permitted, some deep wells will not be drilled, affecting both the available resource and the economy. The potential impacts associated with use of SBM/EMOs and offshore disposal of SBM and EMO cuttings should be balanced against the impacts associated with not allowing their use.

Table 10. Summary table: qualitative comparative assessment: potential human health, environmental, cost and resource impacts associated with use of drilling fluids.

ACTIVITY/RISK	RELATIVE IMPACT		
	OBMs	WBMs	SBMs/EMOs
DRILLING			
Occupational Risks			
• accidents	M	H	M
• chemical exposure	M	L	L
Public Risks			
• air emissions	L	M	L
Environmental Risks			
• air emissions	L	M	L
• spills	M	L	L
Energy Use	L	M	L
ONSITE DISCHARGE/SOLIDS CONTROL			
Occupational Risks			
• accidents	M	L	L
• chemical exposure	M	L	L
Public Risks			
• bioaccumulation and ingestion	0	L	N/U
Environmental Risks			
• water column effects	0	L	L
• bioaccumulation and effect	0	L	N/U
• benthic effects	0	M	L/U
Energy Use	L	L	L
LOADING AND TRANSPORTATION			
Occupational Risks			
• accidents	H	N	L
• chemical exposure	M	N	L
Public Risks			
• air emissions	L	N	N
• accidents	L	N	L
Environmental Risks			
• spills	H	N	L
• water emissions	L	N	N
• air emissions	M	N	N
Energy Use	M	N	N
ONSHORE DISPOSAL			
Occupational Risks			
• accidents	H	N	N
• chemical exposures	M	N	N
Public Risks			
• air emissions	M	N	N
• groundwater contamination	L	N	N
Environmental Risks			
• air emissions	M	N	N
• groundwater contamination	L	N	N
Energy Use	M	N	N
RESOURCE IMPACTS			
• landfill space/injection capacity	M	L	N
ECONOMIC IMPACTS	H	L	M
LIABILITIES	H	L	L

Qualitative relative ranking of impact, High (H), Medium (M), Low (L), Negligible risk (N); No risk because this activity not involved (0), Uncertain (U).

Table 11. Qualitative comparative assessment: potential human health, environmental, cost and resource impacts associated with use of WBMs, OBMs and SBMs/EMOs. Qualitative relative ranking of impact, High (H), Medium (M), Low (L), Uncertain (U), Negligible risk (N); No risk because this activity not involved (0).

ACTIVITY	RELATIVE IMPACT		
	OBMs	WBMs	SBMs/EMOs
DRILLING			
Occupational Risks			
• accidents	M (accident rates in industry are relatively high, fewer accidents associated with shorter drilling time)	H (accident rates in industry are relatively high)	M (accident rates in industry are relatively high, fewer accidents associated with shorter drilling time)
• chemical exposure	M (potential contact with hazardous materials)	L (generally lower toxicity than OBM, fewer fumes)	L (generally low toxicity, fewer fumes than OBM, no exposure to potential carcinogens)
Public Risks			
• air emissions	L (air emissions associated with drilling and associated health effects)	M (air emissions associated with drilling and associated health effects, higher emissions because of longer drilling times)	L (air emissions associated with drilling and associated health effects)
Environmental Risks			
• air emissions	L (air emissions associated with drilling)	M (air emissions associated with drilling, higher emissions because of longer drilling times)	L (air emissions associated with drilling)
• spills	M (potential for spills, components in OBM may be toxic)	L (limited risk associated with spills)	L (limited risk associated with spills)
Energy Use	L (energy use associated with drilling)	M (higher energy use because of longer drilling times)	L (shorter drilling times reduce energy use)

Table 11. cont.

ACTIVITY	RELATIVE IMPACT		
	OBMs	WBMs	SBMs/EMOs
ONSITE DISCHARGE AND SOLIDS CONTROL			
Occupational Risks			
• accidents	M (risk of accidents during solids control, larger volume handled)	L (risk of accidents during solids control)	L (risk of accidents during solids control)
• chemical exposure	M (potential exposure to hazardous materials)	L (limited exposure to hazardous materials)	L (limited exposure to hazardous materials)
Public Risks			
• bioaccumulation in edible fish and ingestion by fishermen	0 (assume no discharge)	L (only limited bioaccumulation, mostly of metals, small human risk)	N/U (only limited bioaccumulation, mostly of metals, volumes smaller than WBMs, negligible human risk, little data available on base fluids)
Environmental Risks			
• water column effects	0 (assume no discharge)	L (water column effects are limited, but more metals are discharged than *for SBMs and spent drilling fluid is* discharged as well as cuttings)	L (water column effects are limited)
• bioaccumulation and effects on biota	0 (assume no discharge)	L (only limited bioaccumulation, mostly of metals, small ecological risk)	N/U (only limited bioaccumulation, mostly of metals, volumes smaller than WBMs, negligible ecological risk, little data available on base fluids)
• benthic effects	0 (assume no discharge)	M (some impact reported, burial effects in low energy environments)	L/U (little data, some impacts reported, depends on specific SBM, may degrade quickly)
Energy Use	L (energy used in solids control)	L (energy used in solids control/discharge)	L (energy used in solids control/discharge)

Table 11. cont.

ACTIVITY	RELATIVE IMPACT		
	OBMs	WBMs	SBMs/EMOs
LOADING AND TRANSPORTATION			
Occupational Risks			
• accidents	H (high potential for accidents)	N (only small volumes shipped)	L (offsite transport only drilling fluid for reuse)
• chemical exposure	M (potential contact with hazardous material)	N (only small volumes shipped)	L (only drilling fluid handled, material less hazardous than OBMs)
Public Risks			
• air emissions	L (emissions from transportation)	N (small volumes reduce emissions from transportation)	N (offsite transport only drilling fluid for reuse)
• accidents	L (potential for marine accidents)	N (small volumes reduce potential for accidents)	L (offsite transport only drilling fluid for reuse)
Environmental Risks			
• spills	H (potential for spills and associated environmental impacts)	N (small potential for spills, environmental impacts would be smaller)	L (offsite transport only drilling fluid for reuse)
• water emissions	L (discharges to water from transportation)	N (only small volumes shipped)	N (offsite transport only drilling fluid for reuse, expect minimal environmental impact)
• air emissions	M (emissions from transportation)	N (only small volumes shipped)	N (offsite transport only drilling fluid for reuse)
Energy Use	M (energy used for transportation)	N (only small volumes shipped)	N (energy used for transportation)

Table 11. cont.

ACTIVITY	RELATIVE IMPACT		
	OBMs	WBMs	SBMs/EMOs
ONSHORE DISPOSAL			
Occupational Risks			
• accidents	H (accidents associated with disposal)	N (accidents associated with disposal, small volume)	N (only disposal of recycle waste)
• chemical exposures	M (risk associated with handling of hazardous materials)	N (only small volumes disposed of onshore)	N (only disposal of recycle waste)
Public Risks			
• air emissions	M (air emissions associated with landfill or injection operation)	N (only small volumes disposed of onshore)	N (only disposal of recycle waste)
• groundwater contamination and exposure	L (small potential for human exposure)	N (only small volumes disposed of onshore)	N (only disposal of recycle waste)
Environmental Risks			
• air emissions	M (air emissions associated with landfill or injection operation)	N (air emissions associated with landfill or injection operation, small volumes)	N (only disposal of recycle waste)
• groundwater contamination	L (small potential for groundwater contamination)	N (small potential for groundwater contamination, small volumes)	N (only disposal of recycle waste)
Energy Use	M (energy used in landfill or injection operation)	N (energy used in landfill or injection operation, small volumes)	N (only disposal of recycle waste)

Table 11. cont.

ACTIVITY	RELATIVE IMPACT		
	OBMs	WBMs	SBMs/EMOs
RESOURCE IMPACTS			
• landfill space/injection well capacity	M (reduces available landfill space)	L (reduces available landfill space)	0 (assume no offsite transport)
ECONOMIC IMPACTS			
	H (OBMs are expensive and must be disposed of onshore)	L (WBMs lower cost, avoid disposal costs for most of the volume)	M (SBMs expensive, cost-effective if cuttings can be discharged; EMOs may be less expensive than SBMs, but more expensive than OBMs, synthetics will not replace WBMs)
LIABILITIES			
	H (liabilities associated with onshore disposal)	L (only limited onshore disposal)	L (only limited onshore disposal)

6.3 Human Health and Environmental Comparative Assessment

The human health and environmental comparative assessment compares the potential human health and environmental impacts of allowing the discharge of SBM and EMO cuttings to the potential impacts of not allowing their discharge. This assessment can be framed in terms of risk reduction (to human health and the environment) and pollution prevention (i.e. total reduction of contaminants released to the environment).

The specific comparison suggested here is between the risks associated with the use of OBMs (and the associated loading, transporting and disposal of cuttings), and the use of SBMs and EMOs, (assuming onsite discharge of the cuttings). Risks associated with the discharge of WBMs are relevant only as a baseline for what is accepted for wells that can be drilled with WBMs.

It will not be possible, reasonable or even necessary to quantify all of the benefits and costs associated with allowing discharge of SBM/EMO cuttings offshore. A clear presentation of what is expected in terms of pollution prevention and potential risk reduction, along with quantitative estimates where reasonable, is enough to allow regulators and stakeholders to make the necessary comparisons of costs and benefits. Table 12 summarizes costs and benefits, in terms of pollution prevention and human health risks, associated with allowing the discharge of SBM and EMO cuttings offshore.

Data and Assumptions

The data needed to calculate pollution prevention and to some extent human health risk are available in USEPA's development documents for the Coastal and Offshore ELGs, and are being collected by EPA and industry specifically for SBMs.

- Number of wells and volume of OBM cuttings expect SBM/EMOs to replace

- Number of crane lifts, supply boat trips, man-hours needed to handle drilling waste per well.

- Percent of drilling fluid retained on cuttings (12% is currently assumed, EPA and industry are developing these data).

- Concentration of metals and organics (priority pollutants) in OBM and SBM drilling fluid (EPA 1993a, additional data being developed by industry and EPA).

- Total water emissions associated with discharging SBM cuttings (derive based on concentration of contaminants in cuttings and number of wells and volume of cuttings).

- Total air emissions associated with loading, transporting, disposing of OBM drilling waste (EPA 1993a); derive based on number of wells and volume of cuttings.

Table 12. Human health and pollution prevention benefits and costs of allowing SBM/EMO cuttings discharge offshore

COSTS	BENEFITS
Pollution Prevention	
Small increase in metals and base fluid organics discharged to water column	Reduction in amount of waste, total cuttings and heavy metals disposed of onshore
	Small reduction in air emissions from solids loading, shipping and disposal
Human Health	
Small potential risk from bioaccumulation of trace metals in edible fish and shellfish	Small potential risk reduction (risk from exposure to contaminants in water and soil) from not disposing metals in onshore facilities
	Small potential benefit from reduced air pollution associated with solids shipping, transportation and disposal
	Small benefit in reduced occupational exposures and handling of carcinogens
	Small benefit in eliminating accidents associated with loading, transporting and disposing of cuttings

Pollution Prevention

The amount of pollution prevention achieved through use of SBM/EMOs can be estimated per well and for the industry, based on data developed for the Offshore ELGs and being collected by EPA and industry for SBMs. Pollution prevention benefits are the reduction in air emissions associated with not having to load, ship and handle cuttings onshore, and the reduction in drilling waste disposed of in landfills. Pollution prevention costs are the amount of metals and SBM/EMO base fluid organics that will be discharged offshore.

Human Health Risk Reduction

The human health risk reduction (and risk added) achieved by allowing SBM/EMO cuttings discharge will be more difficult to quantify. Small occupational risk reductions will be realized through reducing accidents, and exposure to hazardous chemicals. Small reductions in risk to public health include a reduction in the risks associated with exposure to air pollutants and contaminants released to the environment during landfilling and landfarming. A small potential increase in human health risk is associated with the possible exposure of recreational fishermen to metals in fish caught near drilling platforms.

Occupational Risk: Accidents

SBMs and EMOs present a small benefit over OBMs in terms of reducing accidents associated with loading, transporting and disposing of cuttings. It is difficult to quantify this reduction, but estimates of accidents per man-hour for similar operations can be used to derive an estimate. A low-end estimate of the number of loading accidents that could be saved by allowing SBM cuttings to be discharged offshore can be derived by estimating the number of man-hours needed to load and unload cuttings boxes per well (e.g. 4 hours x 6 trips x 4 men) and for the industry, and multiplying this by 0.79 accidents per 200,000 man-hours. Accidents associated with transportation and disposal can be more easily estimated using available data.

Occupational Risk: Chemical Exposure

SBMs and EMOs present a small, but real benefit over OBMs in terms of potential exposures because they are less volatile, causing smaller exposure to vapor and mist, may be less irritating to the skin, and do not contain the aromatics and the potentially carcinogenic and mutagenic components found in mineral oil. This benefit is best left as a qualitative benefit because of the range of materials and their properties.

Public Risk: Air emissions

Public health risks averted from the air emissions saved are expected to be minimal. Attempts to quantify health risks averted from allowing the discharge of SBM cuttings will require complex modeling of emissions and effects on ozone and particulate concentrations, estimates of populations that may experience a reduction in exposure and application of concentration response relationships developed for priority pollutants. This benefit is best left as a qualitative benefit because of the range of materials and their properties.

Public Risk: Ingestion of metals

Public risks from ingestion of metals discharged in SBM/EMO cuttings are expected to be minimal. Attempts to quantify this risk from an industry wide perspective will overestimate risks by multiplying small potential bioaccumulations of metals by the large amounts of fish harvested and eaten by recreational fishermen in the Gulf of Mexico.

A more defensible approach is to state the concentrations expected to be discharged by well and by the industry, and compare that to the levels currently allowed to be discharged in WBMs. If there remains concern about metals discharged with drilling waste, site specific risk assessments should be done to estimate risks associated with background metals in fish and shellfish in the Gulf of Mexico, and the incremental risks associated with metals actually measured in fish caught near specific drilling locations.

Public Risk: exposure to contaminants in water and soil

Injecting, landfilling and landfarming drilling wastes may present some small potential for public exposure to contaminants in soil, air and groundwater. Current technologies and regulations for land disposal of wastes will generally prevent these exposures, but the potential does exist. This benefit should be left as a qualitative description.

Additional Data and Analysis Needs

Additional work to support EPA and industry in developing discharge criteria for SBM/EMO cuttings offshore and in understanding the long-term impacts associated with the use of SBMs and EMOs include:

- Collection of the toxicity, hazard, and bioaccumulation data needed to assess the human health impacts associated with the use and non-use of SBMs and EMOs.

- Platform-specific risk assessment for metals bioaccumulated from drilling waste discharges to quantify risks from metals discharged in SBM cuttings.

A quantitative assessment of risk reduction and pollution prevention will require more detailed assumptions and data. These data are being developed by industry and EPA. Data and approaches to estimating human health impacts are discussed in more detail in Sections 7 through 10.

7 OCCUPATIONAL RISKS FROM CHEMICAL EXPOSURE

7.1 Exposure

Contact with the drilling fluid during the drilling of a well is almost unavoidable (Grieve, 1988). Contact with the skin occurs on the drilling floor, and there can be inhalation of vapor and mist in the mud room and shale shaker room. OLF (1996) summarized process areas and operations that may involve personnel exposure (Table 13) to chemicals during drilling with OBM or SBM/EMOs.

On the drill floor surfaces become covered with mud and the fluid may be splashed or sprayed. People working on the drill floor may have extensive contact with the drilling fluid, and there is the potential for contact with unprotected skin and splashes in the eye (Davidson et al., 1988).

The mud storage and processing areas may or may not be enclosed. Where shale shakers and storage tanks are open to the atmosphere, mist and vapor may be generated. During the manual addition of liquid and powder additives to the drilling fluid, the skin and eyes can come into contact with these materials, and airborne dust or vapor can be inhaled (Davidson et al., 1988).

Table 13. Process areas and operations with possible occupational health hazards (OLF, 1996).

Process Areas/Operations	Occupational Hazard
Drill Floor. Moving drill pipe out of well.	Dermal exposure (during manual handling).
Flowline from top of well to separation equipment (open flowline on some rigs).	Inhalation of vapor from drilling fluid or gas from formation.
Shale shakers.	Continuous inhalation of mist/vapor from drilling fluids. Dermal exposure during maintenance.
Sand traps, desanders/desilters, centrifuges.	Inhalation of vapor during maintenance.
Drilling fluid tanks (rigs with open tanks)	Inhalation of vapors during inspections.
Drilling fluid storage tanks (rigs where manual emptying of tanks is necessary).	Dermal exposure during emptying of tanks. Inhalation of vapor during emptying of tanks.
Repairing drilling fluid pumps.	Dermal exposure.
Manual drilling fluid mixing	Dermal exposure. Inhalation of dust/vapor from additives.

The chemical and physical characteristics of the base oil and additives and the operating conditions affect the levels of contaminants in air. Liquid aerosols can be mechanically formed in the shale shakers, and by condensation of the vapor phase. The following conditions promote evaporation (OLF, 1996):

- Low boiling point/high vapor pressure of the base oil
- Large amounts of hydrocarbons and solvent based additives
- High fluid temperature (increase with well depth)
- High circulation of fluid combined with a large evaporation area (shale shakers)

Occupational limits for oil mist in the US are given in Table 14. Studies with conventional mineral oil-based drilling fluids in the Norwegian sector of the North Sea have reported time-weighed average concentrations from personal monitors of total airborne organics that are usually less than 300 mg/m^3 (Eide, 1990). On installations where efforts have been made to reduce levels of aerosol and vapor, time-weighted average concentrations below 100 mg/m^3 have been achieved (Eide, 1990). Data from the British sector of the North Sea reported time-weighted average concentrations of 10 - 200 mg/m^3 on the drill floor and 20 - 450 mg/m^3 in the mud area (Davidson *et al.*, 1988). Analysis of the vapor from mineral based drilling fluids have found that more than 90% of it originates from the base oil (Eide, 1990). Low aromatic mineral oils result in vapor that is composed of aliphatic and napthenic hydrocarbons mainly in the range C9-C15 (Eide, 1990). Toluene, xylene and methanol have also been identified (Eide, 1990).

Synthetic and enhanced mineral oil based fluids have higher boiling points and flash points and reduced vapor pressure than drilling muds based on diesel oil, resulting in lower concentrations of vapor and oil mist (Table 15, Aquateam, 1996; Park et al., 1993; Friedham and Conn, 1996). Concentrations of vapor have been reported for synthetic base drilling fluids used in the North Sea, usually lower than 10 mg/m^3. The identified components were not the synthetic base fluids, but may originate from the solvents used in additives, or reaction products from decomposition of the base fluid (Hagemann and Eide, 1996). Surveys of drilling operations using synthetic oils in the North Sea have shown relatively low concentrations of mist, usually below 1 mg/m^3 (Hagemann and Eide, 1996). Table 16 presents data reported by drilling fluid manufacturers for vapor concentrations of SBMs. No occupational standards exist for most of the components of synthetic fluids.

Table 14. Occupational standards in the United States.

	PEL
Oil mist	5 mg/m^3
Nuisance particulates	15 mg/m^3
Silica[1]	10 mg/m^3 / %SiO_2 + 2
Quartz respirable	10 mg/m^3/ %SiO_2 + 2
Quartz total dust	30 mg/m^3 / %SiO_2 + 2
Calcium hydroxide	5 mg/m^3

[1] crystalline quartz (respirable)
[2] total dust

Table 15. General properties of synthetic, enhanced mineral oil and oil-based fluids (modified after Aquateam, 1996)

Base Fluid	Flash point °C	Aromatic content (%)
Diesel	66	25
Conventional Mineral Oil	90-110	1-7
Enhanced Mineral Oil	80-110	<0.01-<0.2
Purified Paraffin Oil	90-102	<1
Ester ca. C_{26}	179	0
Ether ca. C_{20}	166	0
Acetal C_{20}	>139	0
Poly-alpha olefins C_{20}	155	0
Linear alpha olefins C_{14}-C_{16}	114	0
Linear alpha olefins C_{16}-C_{18}	146	0
Internal olefins C_{16}-C_{18}	137	0

Table 16. Vapor concentration data, SBM base fluids

BAROID PETROFREE MUD

- Atmospheric vapor in mud tank room, highest value: 7.38 mg/m^3
- Esters in mud pit room, shakerhouse, near mudman and shakerman: 0.5-1.0 mg/m^3

MI DRILLING FLUIDS

	NOVADRIL	NOVAPLUS	NOVALITE	MINERAL OIL
Vapors collected				
40C	0.46 ppm	2.1 ppm	3.9 ppm	2.7 ppm
90C	3.4 ppm	22.0 ppm	101.0 ppm	260.0 ppm

Workers may also be exposed to airborne dust originating from the barite used as an additive to both oil and synthetic based drilling fluids. Table 14 gives US standards for exposure to nuisance particulates. In a study of airborne dust generated during drilling of a well using water-based mud in the Danish sector of the North Sea Hansen *et al.* (1991) found concentrations of dust at about 1 mg/m^3 near open shale shakers, with lower levels at the mud cleaners and working location. The major element in the dust was barium, with other elements (Al, Si, S, Cl, Ca, Fe) present in much lower concentrations.

7.2 Hazards

OLF (1996) reports that for North Sea operations, acute and readily detectable effects such as skin and eye irritation, contact dermatitis, headache and nausea are common in daily operations. Grieve (1988) suggested that true toxicity and carcinogenic effects associated with drilling fluid are unlikely, but irritation to the skin, mucous membranes or respiratory system is possible. Potential effects associated with exposure to base fluids and additives include chronic toxicity, irritation and sensitization, and mutagenicity/ carcinogenicity.

Synthetic- and enhanced mineral oil-based fluids are generally less toxic and less likely to create harmful vapors and aerosols than are drilling fluids based on conventional mineral or diesel oil. Table 17 summarizes hazard data available in Material Safety Data Sheets (MSDS) and product descriptions for some of the available SBM and EMO base fluids, and Table 18 summarizes data for some of the mud systems. A qualitative comparison of the occupational hazards associated with exposure to OBMs and SBM/EMOs is given below.

Irritation, Sensitization and Chronic Toxicity to the Skin: Skin sensitization is not expected to be a hazard with mineral base oils or the high molecular weight compounds that make up synthetic base fluids (Hagerman and Eide, 1996). Hydrocarbons may remove skin lipids, which causes irritation of the skin. Prolonged contact may result in redness of the skin, cracking and dermatitis. The effects are reversible, but secondary infections may occur in badly damaged skin (MacFarland, 1988). Damage to the outer layer of the skin, resulting from irritant effects, can lead to an enhanced adsorption of low molecular weight compounds through the skin. Mineral oils present a skin irritancy hazard. The primary skin irritancy properties of petroleum distillates decrease with increasing boiling point. Distillate oils with boiling point ranges above 315 C are not primary skin irritants (Hagerman and Eide, 1996). N-alkenes, iso-alkanes, naphthenes and aromatics are mildly irritating to the skin. Synthetic base fluids are also generally mildly irritating, but may present less of an irritation hazard than conventional mineral oil.

Neurotoxicity: Some monoaromatic hydrocarbons may be neurotoxic after chronic exposure to relatively high concentrations. In general, it is believed that removing aromatics from the base fluid removes this hazard. There is, however, evidence that some saturated hydrocarbons are distributed to the brain more efficiently than are the corresponding aromatic compounds. In general the risk for neurotoxicity associated with conventional mineral oil, synthetic and EMO based drilling fluids is low.

Chronic toxicity and respiratory irritation to the lung: Studies of workers exposed to mist and vapor from conventional mineral oils found increased prevalence of pulmonary fibrosis (Skyberg et al., 1986, 1990). Inhalation of aerosols is the major concern for workers drilling a well. These potential effects are associated with diesel and conventional mineral oils. There is less concern for inhalation effects of SBMs/EMOs, although little data are available to evaluate their toxicity. Occupational exposure standards for oil mist and vapor in the US are given in Table 14. Respiratory irritation can be caused by nuisance dusts during transportation and storage prior to mixing (Grieve, 1988). Permissible exposure Limits (PEL) standards for particulates are given in Table 14. Risks from nuisance dusts are similar for OBMs, EMOs and SBMs because they result from the barite and other additives to the drilling fluid systems.

Aspiration Hazard: Liquid organic compounds with low viscosity present an aspiration hazard. If these compounds are introduced into the lung or aspirated during vomiting, a severe chemical pneumonitis occurs (MacFarland, 1988). The aspiration hazard of liquid hydrocarbons is increased with low surface tension and low viscosity. Diesel oil, conventional mineral oil, SBMs and EMOs all present this hazard.

Carcinogenic and mutagenic effects: Diesel oils contain compounds that may be mutagenic or carcinogenic. Some PAHs are carcinogens when applied to the skin or inhaled over a long period. Benzene may also be detected in mineral or diesel oils, and is classified as a carcinogen, acting on the hematopoietic system. Currently used conventional mineral oils are low in aromatics and probably present only a minimal carcinogenic hazard. Most SBMs contain no priority pollutants or components that are classified as carcinogenic. EMOs may contain very small concentrations of PAHs.

7.3 Summary

Drilling fluids used offshore present hazards to workers exposed during the drilling of a well, during preparation of the mud, and during the solids control process. Risks, however, are generally small, and are managed using standard industrial hygiene practices involving containment of the drilling fluid where possible, local ventilation, protective clothing, and adherence to Occupational Safety and Health Administration (OSHA) and other guidelines. SBMs and EMOs present a small, but real benefit over diesel OBMs in terms of potential exposures because they are less volatile, causing smaller exposure to vapor and mist, may be less irritating to the skin, and do not contain the aromatics and the potentially carcinogenic and mutagenic components found in diesel oil. More data are needed to describe the occupational risks of base fluids and major additives.

Table 17. Material Safety Data Sheet (MSDS) hazard data for SBMs and EMO base fluids.

COMPANY Base Fluid	Base Fluid Type	% aromatics	Flash Point	Boiling Point	Viscosity	VP	HAZARD[1,2]			
							H	F	R	HAZARD
Amoco Chemical **AmoDrill 1100 synthetic olefin**	LAO	0	113C	245-279C		0.1mm Hg at 20 C	0	0	0	• aspiration hazard • may cause drowsiness at high vapor concentration
Amoco Chemical **AmoDrill 1000 synthetic olefin**	IO	0	>94 C	285-316 C			0	1	0	• aspiration hazard
Baker-Hughes Inteq **Iso-Teq**	IO	0	>245 F	>464 F		<0.05@ 40C	1	1	0	• aspiration hazard • nuisance particulates • repeated or prolonged contact could cause slight irritation to eyes and skin • prolonged contact with the skin can cause dermatitis • inhalation may cause cough or irritation • ingestion may cause vomiting
Baroid **PETROFREE**	Ester	0	179 C				1	1	0	• slight eye and skin irritant • low acute inhalation toxicity • ingestion may cause GI irritation/nausea/vomiting/ diarrhea; ingestion of large amounts may cause central nervous system depression

[1] H: health; F: flammable; R: reactive

[2] 0: minimal; 1: slight; 2: moderate; 3: serious; 4: severe

Table 17 (cont). Material Safety Data Sheet (MSDS) hazard data for SBMs and EMO base fluids.

COMPANY Base Fluid	Base Fluid Type	% aromatics	Flash Point	Boiling point	Viscosity	VP	HAZARD[1,2]			
							H	F	R	HAZARD
Baroid **PETROFREE LE**	Blend	0	>272F	518 F			2	1	0	• eye irritant • skin irritant, prolonged or repeated contact could result in defatting and drying of the skin which may result in irritation and dermatitis • low acute inhalation toxicity • low acute ingestion toxicity, but may result in vomiting
Baroid **XPO7**	EMO	<0.05%	185 F			<1mm Hg	1	2	0	• may cause eye irritation • prolonged or repeated contact tends to remove skin oils, possibly leading to irritation and dermatitis • may cause irritation to the respiratory tract
Chevron **Gulftene 14/16/18/20**	IO	0	132C	250	2.9 cst@40C		1	1	0	• aspiration hazard • skin irritant
Exxon **Escaid 110**	EMO	<0.2%	76.7 C	209-228 C	1.7	0.2 mm Hg @ 20C	1	2	0	• aspiration hazard • eye irritant • high vapor concentrations (>700 ppm) will irritate eyes and respiratory tract • prolonged or repeated exposure to skin could lead to irritation and dermatitis

[1]H: health; F: flammable; R: reactive
[2] 0: minimal; 1: slight; 2: moderate; 3: serious; 4: severe

Table 17 (cont). Material Safety Data Sheet (MSDS) hazard data for SBMs and EMO base fluids.

COMPANY Base Fluid	Base Fluid Type	% aromatics	Flash Point	Boiling point	Viscosity	VP	HAZARD			
							H	F	R	HAZARD[1,2]
Exxon **Escaid 240**	EMO	<0.5%	105 C	249-268 C	3.46 cst@25C	0.04 mm Hg @20C	1	1	0	• aspiration hazard • eye irritant • high vapor concentrations (>700 ppm) will irritate eyes and respiratory tract • prolonged or repeated exposure to skin could lead to irritation and dermatitis
Exxon **Exdrill S 175**	PAO[3]	<0.05%	81 C	218-251 C	3.42cst@ 25C	<0.1 mm Hg@20 C	1	2	0	• prolonged or repeated exposure to skin could lead to irritation and dermatitis
Exxon **613 Drilling Fluid**	EMO	0.009%	85 C	238-247 C	2.1 cst@38C	<1mm Hg at 25 C	1	2	0	• aspiration hazard • eye irritant • high vapor concentrations (>700 ppm) will irritate eyes and respiratory tract • prolonged or repeated exposure to skin could lead to irritation and dermatitis
MI Drilling Fluids **LAO 14/16**	LAO	0	110 C							
MI Drilling Fluids **IO 16/18**	IO	0	130C							

[1]H: health; F: flammable; R: reactive
[2] 0: minimal; 1: slight; 2: moderate; 3: serious; 4: severe
[3] Polymerized material made from olefins and other materials, then fully hydrogenated, similar to low molecular weight PAO.

Table 17 (cont). Material Safety Data Sheet (MSDS) hazard data for SBMs and EMO base fluids.

COMPANY Base Fluid	Base Fluid Type	% aromatics	Flash Point	Boiling point	Viscosity	VP	HAZARD			
							H	F	R	HAZARD[1,2]
MI Drilling Fluids **Novasol II**	PAO	0	150C		1.8-2.8 cst @100 C					
Schlumberger Dowell **Ultidrill**	LAO									
Shell **Neodene**	IO	0	>200F	515-693F		<0.01 mm Hg220C	2	1	0	• aspiration hazard • eye irritant • skin irritant with prolonged or repeated contact

[1] H: health; F: flammable; R: reactive
[2] 0: minimal; 1: slight; 2: moderate; 3: serious; 4: severe

Table 18. Material Safety Data Sheet (MSDS) hazard data for SBM muds.

COMPANY DRILLING SYSTEM (Base Fluid)	Base Fluid Type	% aromatics	Flash Point	HAZARD[1,2]			
				H	F	R	HAZARD
Baroid **PETROFREE Mud** (PETROFREE)	Ester	0	>200 F	1	1	0	• may cause eye irritation • no skin irritation likely with short exposure • may cause irritation to the lungs if inhaled in high concentrations
Baroid **PETROFREE LE Mud** (PETROFREE LE)	Blend	0	>200 F	1	1	0	• irritating to the eyes • prolonged or repeated exposure to the skin may result in defatting and drying leading to irritation and dermatitis
Baroid **XPO7 Mud** (XPO7)	EMO	<0.05%	>95 F				• vapors formed at elevated temperatures may cause systemic effects • mist/aerosols may irritate the eyes or respiratory tract • may cause irritation of the intestinal system, nausea and vomiting if ingested • may cause skin irritation and dermatitis
Schlumberger Dowell **Ultidrill Mud** (Ultidrill)	LAO	0	235 C				• eye irritant, may cause pain, redness, discomfort • skin irritant, may cause pain, redness, dermatitis • no inhalation effect expected, prolonged or repeated exposure may cause mild irritation • on ingestion, may cause pain or discomfort to mouth, throat and stomach

[1]H: health; F: flammable; R: reactive
[2] 0: minimal; 1: slight; 2: moderate; 3: serious; 4: severe

8 OCCUPATIONAL RISKS FROM ACCIDENTS

Accidents associated with the use of OBMs that may be avoided if SBM/EMO cuttings discharge is allowed include those associated with the loading of cuttings boxes, transportation of cuttings to shore, and handling of waste materials at a landfill, landspreading or injection site onshore.

8.1 Accidents During Load Transfers

Loading or unloading a supply vessel or barge is risky, and injuries and fatalities occur during these operations.

On rigs used in deeper waters, cuttings are stored and transported in cuttings boxes. Cuttings boxes are transferred to and from supply vessels using cranes. Cuttings are usually transferred in 25-barrell boxes, and full boxes may weigh five to eleven tons. Spent drilling muds are pumped from the rigs to tanks located on the deck or within the hull of the supply vessel. During transfer of the cuttings boxes, the supply vessel must stay in position under the crane, and crew members move the load into position and disconnect it from the crane. This is a dangerous operation because the supply vessel is in motion and the crew must make physical contact with the load. The procedure is more hazardous when seas are rough. When seas are very rough, transfer of the cuttings becomes impossible, which can result in drilling delays.

In shallow water (depths less than 25 feet), barge mounted rigs must be used. Barge mounted rigs have limited deck space, and cuttings boxes cannot be used for storing and transporting cuttings. Cuttings barges are used to handle cuttings during drilling. Because of the shallow water conditions, boats and barges that are not designed for heavy seas must be used, and in the Gulf of Mexico the seas can be rough even in shallow coastal areas. Recent fatalities in shallow waters in the Gulf of Mexico underscore the risks associated with the transfer of cuttings to a barge. In 1993 a barge drilling crew member was crushed between two barges alongside a drilling rig.

Use of SBM/EMOs and onsite discharge of cuttings would reduce the potential for personnel casualties associated with the handing of drilling waste. Fatalities and injuries have occurred when cuttings barges were used to handle cuttings in shallow waters, but no quantitative data are available to estimate the rates of accidents associated with this practice. Most SBM/EMO discharges will be offshore in deeper water, and the increased number of casualties that may occur are primarily associated with the use of cranes to load and offload cuttings boxes. If SBM/EMO cuttings can be discharged and replace OBMs, the number of crane lifts, amount of cargo to be transported and the number of trips by supply vessels would decrease.

It is difficult to quantify the number of accidents associated with handling of cuttings, because operators and regulatory agencies do not report accidents in the categories necessary for such an analysis. Available data does suggest, however, that accidents associated with handling of drilling waste do occur on offshore rigs, and it is clear that reducing the need for shipping of cuttings onshore will result in fewer accidents.

US Coast Guard Data

SAIC (1993) summarized data available from the U.S Coast Guard CASMAIN data base for casualties that occurred on mobile offshore drilling units (MODUs) and offshore supply vessels (OSVs) for the years 1981 through 1990. The Coast Guard database reports only injuries in the following categories:

- A death
- Injury to five or more persons in a single incident
- Injury causing any person to be incapacitated for more than 72 hours.

These casualties included only those that were identified as being injuries that could have resulted from the handling of drill cuttings (Table 19):

- Struck by object or by falling, flying or moving object
- Struck by vessel
- Bumped fixed object
- Cargo handling
- Line handling
- Caught in lines
- Pinched/crushed
- Unknown
- Not Classified

Table 19. Personnel casualties on mobile offshore drilling units and offshore supply vessels (SAIC, 1993)[1].

Year	Mobile Offshore Drilling Units		Offshore Supply Vessels	
	Number of Injuries	Number of Deaths	Number of Injuries	Number of Deaths
1981	34	2	6	2
1982	102	2	19	1
1983	87	2	25	2
1984	227	4	19	1
1985	165	9	27	1
1986	69	0	18	1
1987	44	1	18	0
1988	65	2	31	1
1989	36	3	12	2
1990	28	1	20	0

[1] Data from U.S. Coast Guard CASMAIN database, casualties that may have resulted from the handling of drill cuttings.

SAIC concluded that most of the accidents were caused by human factors related to safety practices and procedures. SAIC also concluded that the limited data reviewed did not allow prediction of the effect of transportation of drilling waste on the number of personnel casualties. SAIC did not review the actual injury report forms, and the actual number of casualties resulting from the handling of drill cuttings is not known.

Walk, Haydel and Associates (1989) reviewed the US Coast Guard 3692 forms for the years 1985-1987 to identify incidents that involved use of a crane. Forty-two incidents were identified, that resulted in 42 injuries and 3 deaths. Most injuries were due to unsafe practices by the injured or another, equipment failure or improper loading and storage. Walk Haydel (1989) concludes that zero discharge requirements for drilling waste would increase the probability of fatalities and injuries by increasing the number of crane lifts, amount of cargo to be transferred and vessel traffic. The rate of injuries specifically associated with handling drilling waste was not estimated.

American Petroleum Institute Data

Table 20 summarizes accident statistics reported to API (API 1996) for four companies drilling offshore in 1995. Rates are reported as fatalities, injuries or illnesses per 200,000 hours worked, or for approximately 100 full time workers per year.

These data are more useful than the Coast Guard data because they are reported as rates per man-hour, but they represent only a small percentage of employees working on rigs offshore, and do not identify accidents associated with the handling of drilling waste.

Table 20. Accident rates for drilling operations in 1995 (API, 1996). Incidence rates per 200,000 hours worked or 100 full time workers per year.

Company	Average Number of Employees	Hours Worked (thousands)	Reportable Cases			Incidence Rate per 200,000 man-hours
			Injuries	Illnesses	Fatalities	Total Cases
Exxon Co. USA	50	99	1	0	0	2.02
Marathon Oil Co.	7	14	0	0	0	0
Shell Oil Co.	203	421	0	0	0	0
BP America	8	18	1	0	0	11.11
Total	268	552	2	0	0	0.72

International Association of Drilling Contractors Data

The International Association of Drilling Contractors (IADC) annually reports safety and accident information for the drilling industry. The data cannot be directly used because there is no category identified as "handling drilling waste", but the percent of accidents are reported for various occupations, locations on the rigs, accident type, equipment type and operation. Accident rates for 1997 as reported by 20 companies operating in US waters, based on a total of 41,222,488 man-hours (IADC, 1997) are given in Table 21. Table 22 gives the percentage of these accidents (lost time incidents, including fatalities) broken down by occupation, equipment, and accident type (IADC. 1997).

These accident percentages cannot be translated to incidence rates per man-hour, because the percent of the total category (e.g. occupation) represented by each type (e.g. roustabout) is not known.

Accident rates per 200,000 man-hours reported by IADC and API are similar (0.79 and 0.74, respectively). Based on the data given in Table 22, it can be assumed that the accident rate for the time spent loading and unloading cuttings boxes will be higher than this number.

Table 21. Accidents in the offshore drilling industry, 1997 (IADC, 1997), total man-hours: 41,222,488.

	Number	**Incidence rate per 200,000 man-hours**
Medical Treatment Incidents	556	2.70
Restricted Work Incidents	251	1.22
Lost Time Incidents	155	0.75
Total Fatalities	8	0.04
Lost Time Incidents + Fatalities	163	0.79

8.2 Accidents Involving Offshore Supply Vessels

The impact on Offshore Supply Vessel (OSV) traffic associated with the use and non-use of SBMs must also be considered in a comparative assessment. From 1969 to 1989 the accident rate for OSVs in U.S. ports in the Gulf of Mexico was 2.6 per thousand trips. Accidents include collisions, groundings, fire, explosions and capsizing (EPA, 1993b). Spills from on and off-loading are also of potential concern. Reducing trips associated with drilling waste will result in fewer OSV accidents. EPA (1993a) estimated that transporting drilling waste ashore from a well subject to zero discharge would require, on average, 5 to six service vessel service trips per year.

Table 22. Percent of Lost Time Incidents (163; includes fatalities) (calculated from data in IADC, 1998).

LTIs by Occupation	%	LTI by Equipment	%	LTIs by Operation	%	LTIs by Accident Type	%
Roustabout	33.6	Tongs	5.9	Tripping in/out	11.2	Struck by	30.3
Floorman	37.5	Elevators	3.9	Making connection	1.3	Struck against	4.6
Derrickman	9.2	Slips	3.3	Routing Drilling operations	7.2	Caught between/in	19.7
Driller	1.3	Spinning chain	0.0	Running casing	1.3	Slip/fall; same level	9.9
Toolpusher	0.7	Iron roughneck, etc.	0.0	Laying down/picking up	11.8	Slip/fall; different level	11.2
Electrician	1.3	Rotary	0.7	Material handling/manual	10.5	Strain overexertion	15.8
Motorman	2.0	Pipes, collars, tubulars	14.5	Material handling	7.9	Contact with chemicals/fluids	0.7
Mechanic	2.0	Cathead/drawworks	1.3	Rigging up/down	5.9	Electric shock	0.0
Crane Operator	3.3	Ropes/cables/chains/ slings	10.5	B.O.P. install/maintenance	2.6	Flame/heat/steam	1.3
Barge Engineer/Ballast	0.7	Hand tools: manual	2.6	Rig repairs/maintenance	13.8	Debris	0.0
Superintendent/ other	0	Handtools: power	0.0	Mud mixing/pumping	2.0	Cut	0.7
Truck Driver	0	Motors/pumps/ machinery	2.0	Cementing	0.7	Exposure to weather	0.0
Rig Helper	2.0	Vehicles/ transportation	0.7	Special operations	0.7	Jump	1.3
Truck Helper	0	Kelly bushing	0.0	Walking	4.6	Exposure to Gas	0.0
Welder	2.0	Stairs/ladders/decks	3.9	Training	0.0	Vehicle	0.0
Other	6.4	B.O.P.	2.6	Other	18.5	Other	4.5
		Material	7.2				
		Pressure hoses/lines	2.0				
		Crane	3.9				
		Other	35.0				

8.3 Accidents During Onshore Disposal Operations

Fatality rates for the major operations in landfilling operations involved in landfilling operations have been compiled (Table 23) and can be used to evaluate the hazards associated with the onshore disposal of cuttings.

These labor and fatality rates can be combined with estimates of the volumes of drilling waste that will not have to be disposed of onshore if SBM cuttings can be discharged to estimate the number of accidents associated with the disposal of OBM waste.

Injection of drilling wastes, both onsite and at onshore disposal facilities will also involve occupational accidents.

Table 23. Labor and fatality rates for landfilling and restoration operations (EPA, 1995).

LABOR RATES	FATALITY RATES (fatalities/hour)
soil excavation 0.051 hrs/m^3	soil excavation 1×10^{-7}
backfilling and terrain restoration 0.017 hrs/m	backfilling and restoration 1.38×10^{-7}
volume reduction 0.229 (hrs/m^3)	volume reduction 5×10^{-8}
	truck transportation 3.1×10^{-9}
	rail transportation 4.8×10^{-8}

9 PUBLIC HEALTH IMPACTS: INGESTION OF CONTAMINANTS IN EDIBLE FISH AND SHELLFISH

9.1 Introduction

Sportfishing in the Gulf of Mexico is concentrated around oil and gas platforms. Recreational fishermen may ingest contaminants in drilling fluids bioaccumulated by edible fish and crustaceans living close to the cuttings discharge. Risks to recreational fishermen from both WBMs and SBM/EMOs are expected to be small, but WBMs will present a higher potential risk because of the larger volumes of barite that will be discharged along with the cuttings and used drilling fluid. Concentrations of metals discharged are also limited by the current ELG limits for concentrations of cadmium and mercury in the stock barite (3 mg/kg and 1 mg/kg), respectively, that are also expected to limit concentrations of other metals in drilling fluid. Because OBMs are not discharged offshore, no risk to recreational fishermen is presented by the use of OBMs.

Information needed to assess this potential risk include the extent of bioaccumulation in edible fish and shellfish species of contaminants discharged with SBM and EMO cuttings and the amounts of fish ingested by recreational fishermen. Because OBMs and OBM associated cuttings (both diesel and mineral oil based) are assumed not to be discharged offshore, the following discussion focuses on the potential for bioaccumulation and subsequent risks to human health from components in WBMs, SBM, and EMOs.

9.2 Bioaccumulation

There are few data available to assess the bioaccumulation potential of SBM base fluids but the chemical composition of the materials suggest that they do not present a serious bioaccumulation potential (Avanti, 1997b). In addition, because these fluids contain little or no aromatics or priority pollutants, the potential for risks to human health associated with ingestion of these chemicals in fish and crustaceans is probably small. Of more concern in terms of potential ingestion by recreational fishermen are the metals used in additives for both SBM and WBM drilling fluid formulations. However, metals in drilling discharges are generally present in highly insoluble chemical forms that limit bioavailability.

Bioaccumulation of SBM/EMO Base Fluids

Bioconcentration (equilibrium partitioning between organisms and the surrounding water) has been measured for only a few of the SBM base fluids. For organic chemicals, it is common to rely on extrapolation from the logarithm of the 1-octanol/water partition coefficient (log P_{ow}). Log $P_{ow.}$ values can be determined experimentally, or calculated from solubility, molecular weight and other data.

This approach works because the lipid tissue of fish is the principal site for bioaccumulation of organic compounds, and 1-octanol is a surrogate for lipids. Linear correlations are usually observed between log BCF and log P_{ow}. The usual interpretation of log P_{ow} values is as follows:

- No significant bioconcentration (BCF<100) for log P_{ow}<2.7-3
- Highly accumulating, additional testing needed for log P_{ow} between 2.7-3 and 6
- Log P_{ow}>6 and molecular weight greater than 600 are modestly accumulating

Other characteristics of organic compounds that affect their tendency to bioaccumulate include their water solubility, molecular weight, and chemical structure. Increasing molecular size results in a higher partition coefficient, a decline in water solubility, and an increase in the potential for bioaccumulation. However, at certain molecular sizes, molecular surface areas and molecular volumes a decline in bioaccumulation occurs, possibly related to the reduced fat solubility of higher molecular weight compounds and their inability to penetrate biological membranes (Table 24).

Table 24. General characteristics of organic chemicals that exhibit bioaccumulation (from Connell, 1990).

Characteristic	Features Giving Bioaccumulation
Chemical structure	High capacity: high proportion of C-C (aliphatic), C-C (aromatic) C-H and C-halogen bonds Limited capacity: low proportion of the bonds above with the presence of a variety of functional groups
Molecular weight	>100 giving a maximum capacity at about 350, then declining to a very low capacity about 600
Molecular dimensions	Cross section width <9.5 A, molecular surface area between 208 and 460 A2, molecular volume between 260 and 760 A3
Stability	Resistant to degradation reflected in soil persistence in the order of years
Log P_{ow}	>2 giving a maximum capacity of about 6 and a decline to very low capacity at about 10-12
Water solubility (mole m-3)	<18 giving a maximum at about 0.002 with declining capacity of lower values
Degree of ionization	Very low

Assessing the bioaccumulation potential of the SBM and EMO base fluids has proved difficult. Higher log P_{ow} values reported for SBMs result from their low solubility in water. Low water solubility, however, does not necessarily result in bioaccumulation – the base fluids used in SBMs may not be bioavailable. Table 24 summarizes available P_{ow} values for SBM and EMO base fluids.

Several studies have been done to determine bioconcentration factors (BCF) using mussels (*Mytilus edilus*) to determine if SBMs are actually taken up by organisms (Table 25). Determination of BCFs is a more useful and relevant way to assess the potential for bioaccumuation than calculating octanol water partition coefficients. Little BCF data are available for SBM/EMOs, but most results suggest that the base fluid is not accumulated by shellfish. Additional data for bioaccumulation of SBM and EMO base fluids by fish, from both water and sediment are needed to eliminate this pathway completely. EPA will be conducting tests to better characterize the bioaccumulation potential of SBMs.

Table 25. Bioaccumulation potential of SBM and EMO base fluids.

COMPANY	BASE FLUID	BASE FLUID TYPE	Log P_{ow}	Log BCF *Mytilus edulis*
Amoco Chemical	AmoDrill 1100 Synthetic Olefin	LAO	>7.75	
Amoco Chemical	AmoDrill 1000 Synthetic Olefin	IO	>8.75	
Baroid	PETROFREE	Ester	1.69	
Baroid	LE BASE	Ester	>6	
Baroid	XPO7	EMO	>8	equilibrium 10 day 3.86 dry weight 5.08 lipid weight
Exxon	ESCAID 110	EMO	>6**	
Exxon	ESCAID 240	EMO	>6**	
Exxon	613 Drilling Fluid	EMO	>6**	
Exxon	EXXDRILL S 175	PAO*	>6**	
MI Drilling Fluids	LAO 14/16	LAO	7.82	
MI Drilling Fluids	IO 16/18	IO	8.57	0.7
MI Drilling Fluids	Novasol II	PAO	11.19	2.1
Schlumberger Dowell	Ultidrill	LAO	>6.43	4.8

* Polymerized material made from olefins and other materials, then fully hydrogenated, similar to low molecular weight PAO.

** calculated using the EPA ASTER model

Bioaccumulation of Metals

There is concern that metal contaminants in the stock barite used in SBM/EMO formulations may bioaccumulate in fish and shellfish (the same way they may for WBMs already discharged offshore). Volumes of metals discharged with SBM/EMO cuttings will be significantly smaller than for WBMs, because the drilling fluid itself is recycled.

Most of the metals of concern in barite are natural constituents of sea water and sediment, and are also present in the tissues of organisms that have not been exposed to drilling waste. Most of the metals discharged in the cuttings and spent drilling fluid (WBM, SBM, EMO) are in insoluble chemical forms and exhibit limited availability. Trefrey et al. (1986) assessed the leaching of soluble metals from high and low trace metal barite at pH 5.0 and 7.8. At the pH most representative of seawater (pH 7.8), negligible amounts of As, Cd, Pb and Hg were leached into the water (Neff, 1991).

Organisms living near platforms will be exposed to only very small concentrations of metals from barite in drilling fluids and cuttings. As drilling muds settle through the water column, the metals that are easily leached from the particles in the barite will move into the water column. These metals in the water column will be diluted rapidly to background concentrations (Neff et al., 1989). The barite that settles on the bottom will have equilibrated with seawater and will not contain the rapidly leached portion of metal contaminants (Neff et al., 1989), reducing the potential for exposure of organisms.

Elevated concentration of barium, and less frequently arsenic, cadmium, copper, chromium, zinc, lead, nickel and mercury have been reported in the sediments near offshore drilling platforms. There have been several laboratory and field studies of the bioaccumulation of metals from drilling fluids.

Laboratory studies have generally found that metals in drilling mud are not available to organisms. Neff et al., (1988a) studied bioaccumulation of barium and chromium from drilling fluid settable solids in seven species of benthic marine animals in flow through systems. The maximum bioaccumulation factors from sediment were in the range of 0.004 - 0.80 for barium and 0.1 - 0.36 for chromium. Neff et al (1988b) studied bioaccumulation of mercury, cadmium, copper, lead and arsenic from both high and low trace metal barite samples using four species of benthic marine animals. The authors concluded that the metals associated with drilling muds are virtually non-available for bioaccumulation by marine organisms.

Field studies have generally confirmed the low levels of metal bioaccumulation observed in laboratory studies. Results suggest only minimal accumulation of metals in drilling fluids, including Ba, Cd, Cu, Fe, Ni, Pb, and V. This accumulation has not been consistently reported. Some field studies have reported elevated metals in organisms near drilling platforms (Boothe and Presley, 1985; EG&G, 1982; Tillery and Thomas, 1980), but other studies report no elevated metals concentrations in biota (Crippen, Hold and Greene, 1980; Boehm et al., 1990). Bioaccumulation has also been reported primarily for benthic invertebrates, and not for the more mobile, demersal fish that are the primary targets for recreational fishermen. Levels that are statistically significantly elevated above background levels are often difficult to show because of variations in background levels and analytical constraints. Avanti (1993) reviews the major field studies for drilling mud impacts on marine organisms.

Recent studies at platforms where soluble metals are discharged in produced water have also found only limited bioaccumulation (OOC, 1997; CSA, 1997).

When sufficient field data are not available for a risk assessment, bioaccumulation factors that relate the equilibrium concentration of contaminants in organisms to the concentration in the water column. Only limited data are available for BCFs for metals in saltwater organisms. BCFs available in the literature should be reviewed in the context of their relevance and appropriateness for application to a specific organism and specific circumstance. Generic values are often used in screening-models (Strenge and Peterson, 1989; Napier *et al.,* 1980; Strenge *et al.,* 1986, Versar Associates, 1992)

Modeling of bioaccumulation is sometimes necessary to performing a risk assessment. When the data are so uncertain and so variable, worst case assumptions may be used to develop an estimate of risk and to bound the problem. Risk estimates developed in this way should not be used to represent reasonable estimates of human health risk. When a conservative modeling analysis suggests a potential human health risk, additional data should be collected and a risk assessment based on measured concentrations of contaminants in edible organisms done.

9.3 Fish Ingestion Rates by Recreational Fishermen

Available estimates of fish consumption rates by recreational fishermen vary because of differences in survey methods, water bodies, and the kinds of consumers surveyed (Ebert *et al.*, 1994). A number of surveys of fish consumption in the United States have demonstrated that fish consumption rates differ regionally and within specific subpopulations (NMFS, 1992).

The United States Environmental Protection Agency (EPA, 1997a) suggests values for fish consumption by recreational fishermen based on field interviews performed by the National Marine Fisheries Service (NMFS, 1993) (Table 26). The surveys used field interviews with marine anglers on area and mode of fishing, fishing frequency, species caught, weight of fish caught, and whether the fish were intended for consumption. EPA derived intake rates by assuming that 2.5 consumers would eat each fisherman's catch, and that half of the weight of the catch was edible. The amount of fish caught during the day of the interview was multiplied by the fisherman's self-reported fishing frequency to estimate the total amount of fish caught intended for consumption by each fisherman's family and friends.

These values are recommended by EPA to represent consumption rates for recreational fishermen in an area with widespread contamination. No specific values are recommended for small water bodies or for areas of localized contamination, because the amount of fish consumed from small areas is likely to be only a percentage of the total amount of self-caught fish eaten by a recreational fishermen.

Previous risk assessments for radium discharged in produced water found that the variability of fish ingestion rates for recreational fishermen in the Gulf of Mexico contributed a large amount of uncertainty to the final risk estimates (Meinhold *et al.,* 1995).

Table 26. Recommendations for ingestion rates of self-caught marine finfish by marine recreational fishermen (EPA, 1997a).

Study Location	Mean Intake (g/day)	95^{th} Percentile (g/day)
Gulf	7.2	26.0
Atlantic	5.6	18.0
Pacific	2.0	6.8

To provide data specifically for the Gulf of Mexico, a new survey of fishermen in Louisiana and Texas was done as part of a USDOE Study titled "Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations" (Steimle & Associates, 1995; Schultz et *al.*, 1996). Meinhold and Holtzman (1998) used the data collected in this survey to derive ingestion rates for recreational fishermen in the Gulf of Mexico. These data and analyses are summarized below.

Recreational and commercial fishermen were surveyed by personal interview from May through November 1993 to determine: categories of seafood taken over the previous three months; types of license(s) held; and information on the number, gender and ages of individuals in the household and their seafood consumption habits. Respondents were also interviewed about locations fished, estimated distances from oilfield structures, and species caught. Intercept surveys were done at docking areas located in 9 zones along the Louisiana and Texas Gulf Coast.

A total of 894 surveys were completed for Texas and Louisiana. Ninety percent of these were based on the intercept method (fishermen were interviewed at the dock, multiple visits were made to each location, and fishermen were re-interviewed if encountered more than once). Five percent of the surveys were done at Sports Club meetings, and 5% were re-interviews by telephone of fishermen who had previously been surveyed by the intercept method.

The data reported below is based only on results of the intercept surveys. These data are biased in the sense that the probability of being sampled in an intercept survey is not the same for all members of the target population (i.e. marine recreational fishermen in Louisiana and Texas). Fishermen who fish frequently will be oversampled (Price *et al.*, 1994). To correct for this bias, the individual survey responses were weighted by the inverse of the individual's fishing frequency.

Forty-six percent of respondents reported fishing offshore (3-10 miles) at least some of the time; 33% fish offshore exclusively. Twenty-nine percent of respondents fish exclusively near structures (≤1000 ft), 53% fish exclusively away from structures (>1000 ft), and 18% fish in both locations.

Individual survey responses for the number of times per week self-caught fish were eaten were weighted by the inverse of the individual's fishing frequency. This distribution was based on responses for fishermen who reported fishing inshore, offshore, and both inshore and offshore; close to and away from structures; and in Texas and Louisiana. Estimates based on these groups were not significantly different from the distribution for all fishermen in the data set.

Data that describes the size of a fish meal are needed, in combination with these data on meals per week, to estimate intake rates. This analysis used the distribution of meal sizes for adult males, age 19-34 derived by Pao et al. (1982) from the USDA Nationwide Food Consumption Survey 1977-78 (USDA, 1983) to represent the meal size distribution for adult recreational fishermen.

The ingestion rate distribution for recreational fishermen was derived as follows:

$$I_{fish} = \frac{M \times MS}{7d \times week^{-1}}$$

where:
I_{fish} = ingestion rate (g/d)
M = meals per week
MS = meal size

The ingestion rate (g/d) was calculated using the distributions described above for meals/week and meal size, in a Monte Carlo analysis. The resulting distribution of intake (g/d) is shown in Table 27. Intakes for adult recreational fishermen derived from the DOE survey are approximately four times larger than the intakes for the entire population of recreational fishermen and their families suggested by EPA (Table 27).

Table 27. Summary statistics, ingestion rate distribution for adult recreational fishermen in the Gulf of Mexico.

	Ingestion rate (g/d)
Mean	29
Median	20
Standard deviation	33
5th percentile	0
95th percentile	87

9.4 Approaches to Risk Assessment for Metals Ingestion

EPA (1993a,b) assessed the risks to human health from bioaccumulation of metals in shrimp and finfish caught near platforms in the Gulf of Mexico to quantify benefits associated with the Offshore ELGs. This analysis did not use field or laboratory data for metals in drilling wastes, but relied on modeling of contaminant concentrations in the water column and in fish and shrimp (using BCFs) to estimate population-level effects of lead and exceedances of water quality. Human health risks were determined for the consumption of commercially caught shrimp by the general population, and recreationally caught finfish by fishermen and their families.

Levels of contaminants in recreational fish were estimated by combining average effluent concentrations of pollutants with transport and fate modeling analyses to estimate pollutant concentrations in the water column and in sediment pore water within 100 meters of the discharge. Chemical-specific leach factors were used for metals to determine available, soluble levels of metals. Fish tissue concentrations were then estimated using chemical-specific bioconcentration factors.

The impacted shrimp harvest was estimated by deriving impact areas (51 m^2 for exploration wells and 267 km^2 for development platforms). All of the annual loadings of pollutants were considered to be uniformly mixed in these areas to estimate incremental sediment levels of pollutants from drilling fluids and cuttings.

Health benefits for carcinogens and most systemic toxicants were calculated based on individual consumption patterns, including both average individual risks and the high-end consumer risks. For lead, health benefits were calculated using a harvest-mass balance distribution of exposures for fish and shrimp consumption. Standard dose-response data were used to calculate the reduced levels of health risk associated with the estimated reduction in exposure.

The impacted shrimp harvest was allocated across the estimated 50 million Americans who consume shrimp. The impacted finfish harvest was allocated across the estimated 17 million individuals consuming recreationally caught finfish from the Gulf of Mexico.

This analysis found significant risks associated with ingestion of lead in shrimp from drilling fluids and cuttings, and significant benefits to the proposed ELGs. Risks from ingestion of lead in finfish were not significant. Marine water quality criteria based on human health (fish ingestion only) for arsenic and mercury in the water column and in sediment pore water quality were exceeded for both the baseline situation and the proposed ELGs, depending on the leach conditions assumed (see EPA, 1993 , Avanti, 1993).

This same approach could be used to quantify the risks associated with the discharge of metals in SBM cuttings. The problem with this kind of analysis is that small increments of metals modeled in fish and shellfish that have never been actually measured, are multiplied by a large number of consumers, resulting in the prediction of impacts that probably never occur. This analysis is an estimation of population risks, and not individual risks, and cannot estimate risks associated with most of the metals discharged with cuttings because they have a threshold for effects on human health.

A more reasonable way to assess risks associated with the discharge of metals in drilling waste is to use site-specific data collected in field studies in an assessment of the risk to individual recreational fishermen and their families. With the exception of lead, the metals of concern all have threshold levels for toxic effects in humans, and estimated intakes for recreational fishermen eating fish caught near the sampled platforms and away from the platforms can be compared to USEPA reference doses to determine the potential for an intake with a potential for human health impacts. A separate risk assessment for lead intake can be done that adds average intakes of lead in air, food and water for children, to levels that may be ingested in impacted and non-impacted fish and shrimp caught in the Gulf of Mexico.

This kind of analysis can be done making reasonable, but conservative assumptions, but would use available field data and not rely completely on modeled impacts. Even for field studies where the number of samples and variation in contaminant concentrations measured in organisms makes distinguishing an impact from drilling wastes difficult, a risk assessment using the total concentrations measured in edible fish will give some information about the potential magnitude of the problem.

If an estimate of total population risk is needed for the regulation, the analysis should:

- Compare risks associated with potential increases in contaminant concentrations in edible fish to risks associated with background levels of the contaminants; and
- Clearly describe the uncertainties associated with the analysis and assumptions.

10 PUBLIC HEALTH IMPACTS FROM AIR EMISSIONS AND ONSHORE DISPOSAL

10.1 Air emissions

Estimating emissions saved

Air emissions associated with the use and non-use of SBMs can be evaluated using the approach employed by EPA in assessing the non-water quality impacts associated with the Offshore Effluent Limitation Guidelines (EPA, 1993a, 1993c). The air emissions that would be avoided if SBM cuttings were discharged instead of shipping OBM cuttings ashore include those created by the supply ships that ship the cuttings to shore, the cranes needed to transfer the cuttings boxes to and from the supply boats, and the equipment needed to handle the waste at the landfill.

Air emissions resulting from operation of boats, cranes, trucks and earth-moving equipment involved in the onshore disposal of drilling wastes were estimated using emission factors. Emission factors relate the production of air pollutants to the length of time equipment is operated, and the amount of fuel consumed (EPA, 1993c; Table 28).

EPA (1993c) estimated emission factors for both controlled and uncontrolled sources. Uncontrolled emissions are those from a source that does not have add-on control technologies to reduce emissions of specific pollutants. Controlled emission factors are for sources that have implemented some means of control to reduce specific emissions. Controlled emission factors are appropriate for drilling in the California region, while uncontrolled emission factors are appropriate for the Gulf of Mexico.

EPA (1993c) developed the following assumptions for the use of boats, cranes, trucks and earth moving equipment.

Supply Boats: EPA (1993a) assumed the following for supply boats:

- 6 dedicated supply boat trips would be needed per well (average supply ship, 12 25-barrell cuttings boxes).
- 2,500 horsepower diesel engine
- Fuel throttle fuel consumption 169 gallons/hour
- Speed and distance: 100 miles round trip, at 10 knots.
- Maneuvering Fuel Consumption: 15% of full throttle
- Maneuvering time: 1 hour per trip
- Idling time: 4 hour s per trip
- Time inport: 24 hours per trip, auxiliary generator used for power, 120 HP, 50% load, 6 gallons diesel fuel per hour.

Table 28. Uncontrolled (Gulf of Mexico) and controlled (California) emission factors used to calculate air emissions from onshore disposal of drilling waste. (EPA, 1993a).

Source	Supply Boats (lb/1000 gallons)		Cranes (g/bhp-hr)	Trucks (g/mile)	Wheel Tractor (lb/hr)	Track-type Dozer (lg/hr)	Auxiliary Generator (g/bhp-hr)
	Idle	Transit					
Nitrogen Oxides (NO_x)							
Uncontrolled	419.6	391.7	14.0	11.44	1.269	0.827	14.0
Controlled	335.7	313.4	11.2	NA	NA	NA	NC
Total Hydrocarbons (THC)							
Uncontrolled	22.6	16.8	1.12	2.53	0.188	0.098	1.12
Controlled	24.9	18.5	1.232	NC	NA	NA	NC
Sulfur Dioxide (SO_2)							
Uncontrolled	28.48	28.48	0.931	NA	0.090	0.076	0.931
Controlled	7.12	7.12	0.23	NA	NA	NA	NC
Carbon Monoxide (CO)							
Uncontrolled	59.8	78.3	3.03	8.67	3.59	0.201	3.03
Controlled	65.8	86.1	3.33	NA	NA	NA	NC
Total Suspended Particulates (TSP)							
Uncontrolled	33.0	33.0	1.0	NA	0.136	0.058	1.0
Controlled	NC	NC	NC	NA	NC	NC	NC

NC: no controls
NA: not available

Cranes: Cranes are used to load and offload cuttings boxes at the drill site and inport. EPA (1993a) assumed:

- 170 horsepower operating at 80% of rate load
- Fuel consumption is 67 gallons of diesel fuel per hour.
- Lift capacity: 10 lifts per hour, minimum of 2.4 hours to unload 12 empty cuttings boxes and load 12 full cuttings boxes on the supply boat.

Trucks and Barges: Some disposal sites are located at marine transfer stations and may not require transportation by truck or by barge. In some cases wastes will be transferred from the supply vessels to barges which transport the drilling waste to the disposal sites on waterways. Trucks may also be used to transport drilling waste. EPA (1993a) estimated air emissions from truck traffic only, and assumed it would also approximate emissions from barge traffic.

- Truck capacity: 5,000 gallons (119 barrels) of cuttings
- Fuel consumption: 4 miles per gallon of diesel fuel.
- Distance: Average round trip between marine transfer station and disposal facility (Gulf of Mexico) is 100 miles.

Land Disposal Equipment: Landspreading equipment at the disposal site will also result in air emissions. EPA (1993a) based emissions on drilling waste volumes and capacity of the equipment (EPA, 1993a).

Wheel tractor: Wheel tractors are used for grading. Drilling waste from one well was assumed to require 8 hours of tractor operation. Fuel consumption is 1.67 gallons of diesel fuel per hour.

Track-type dozer/Loader: Track-type dozers are used for landspreading. EPA assumed that 16 hours of dozer operation are required to spread drilling waste generated from one well. Fuel consumption is 22 gallons of diesel fuel per hour.

Impacts on Human Health

Air emissions associated with drilling waste disposal include nitrogen oxides, sulfur dioxide, particulates, hydrocarbons, and ozone (created in the atmosphere from interaction of nitrogen oxides and VOCs).

These air pollutants have human health impacts that include asthma and respiratory illness, bronchitis, effects on pulmonary function, and mortality. EPA (1997b) estimated the human health benefits of air pollution reductions resulting from the Clean Air Act, in the process developing dose- response relationships for major health impacts associated with exposure to the criteria pollutants (Table 29). In this report EPA developed estimates of the number of fewer individuals that are likely to experience an adverse health effect per unit change in air quality. The dose-response relationships and their bases are given in detail in EPA (1997b).

Table 29. Health effects of air pollutants quantifed by EPA (EPA, 1997b)

Pollutant	Effects
Ozone	Mortality Respiratory symptoms Minor restricted activity days Respiratory restricted activity days Hospital admissions Asthma attacks Changes in pulmonary function Chronic sinusitis and hay fever
Particulate matter/TSP/sulfates	Mortality Bronchitis: chronic and cute Hospital admissions Lower respiratory illness Upper respiratory illness Chest illness Respiratory symptoms Minor restricted activity days All reduced activity days Days of work loss Moderate or worse asthma status (asthmatics)
Carbon monoxide	Hospital admissions Congestive heart failure Decreased time to onset of angina
Nitrogen oxides	Respiratory illness
Sulfur dioxide	In exercising asthmatics: Change in pulmonary function Respiratory symptoms Combined responses of respiratory symptoms and pulmonary function changes

Modeling the impact of small reductions in air quality is a difficult and time-consuming process. Emission reductions have to be estimated for specific locations in the Gulf of Mexico, and air transport models used to calculate exposure to specific populations. The analysis must also model the creation of ozone through the interaction of nitrogen oxides and VOCs, as well as the contribution of gaseous SO_2 and NO_x to ambient concentrations of particulates. The methods and models for this analysis have been developed and were used in EPA's report to Congress on the costs and benefits of the Clean Air Act.

Air emissions avoided by use of SBMs in place of OBMs may be significant in terms of total pounds of pollutants saved, but represent only a small percentage of the total air emissions associated with offshore exploration and production in the Gulf of Mexico (EPA, 1993c). Because the emissions sources are located offshore, actual exposures to people and associated adverse impacts avoided will be small. The effort and resources involved in modeling the risk reduction associated with the reduction in emissions that will be realized if SBM cuttings an be discharged offshore is probably not justified by the small human health benefit expected. An estimate of the total pounds of pollution saved, and a qualitative description of the small health benefits associated with this reduction is adequate for decision-making purposes.

10.2 Landfill impacts

Pollutants associated with OBM waste cuttings that will be landfilled include organic contaminants and PAHs from the mineral oil base fluid, as well as the metals from the stock barite. Use of SBMs would eliminate the oil hauled to shore in the cuttings, and the need for disposal in landfills onshore.

Landfill impacts are primarily a resource issue. Landfill space is expensive and limited. There is currently enough permitted capacity in the Gulf of Mexico region to handle drilling waste (EPA, 1993a). It is, however, difficult to permit land disposal facilities, and citizen opposition and poential liabilities associated with landfill operations make use of landfills an option.

Disposal of potentially hazardous material in a landfill also present the small but reasonable potential for groundwater contamination and other public health problems associated with onshore waste disposal. Because OBMs are now primarily based on mineral oil, the toxic components of the cuttings generated present less of a concern than those generated using OBMs. Current technologies for land treatment and disposal and regulations controlling landfilling will minimize any public exposure to contaminants in soil, air or water.

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APPENDIX A

EPA Definition of Enhanced Mineral Oil and Synthetic Material From (Coastal Effluent Limitations Guidelines, FR 61)

"The term *enhanced mineral oil* as applied to enhanced mineral oil-based drilling fluid means a petroleum distillate which has been highly purified and is distinguished from diesel oil and conventional mineral oil in having a lower polycyclic aromatic (PAH) content. Typically, conventional mineral oils have a PAH content on the order of 0.35 weight percent expressed as phenanthrene, whereas enhanced mineral oils typically have a PAH content of 0.001 or lower weight percent PAH expressed as phenanthrene.

The term *synthetic material* as applied to synthetic-based drilling fluid means material produced by the reaction of specific purified chemical feedstock, as opposed to the traditional base fluids such as diesel and mineral oil which are derived from crude oil solely through physical separation processes. Physical separation processes include fractionation and distillation and/or minor chemical reactions such as cracking and hydro processing. Since they are synthesized by the reaction of purified compounds, synthetic materials suitable for use in drilling fluids are typically free of polycyclic aromatic hydrocarbons (PAHs) but test sometimes report levels of PAH up to 0.001 weight percent expressed as phenanthrene. Poly (alpha-olefins) and vegetable esters are two examples of synthetic materials used by the oil and gas extraction industry in formulating drilling fluids. Poly (alpha olefins) are synthesized from the polymerization (dimerization, trimerization, tetramerization, and higher oligomerization) of purified straight-chain hydrocarbons such as C6-C14 alpha olefins. Vegetable esters are synthesized from the acid-catalyzed esterification of vegetable fatty acids with various alcohols. The mention of these two synthetic fluids base materials is to provide examples, and is not meant to exclude other synthetic materials that are either in current use or may be used in the future. A synthetic-based drilling fluid may include a combination of synthetic materials."