

Effects of Oil and Chemically Dispersed Oil in the Environment

Health and Environmental Sciences Department

API PUBLICATION NUMBER 4693

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CAPE CHARLES, VIRGINIA

MAY 2001

BACKGROUND ON THIS BOOKLET SERIES

Beginning in 1994, the Marine Spill Response Corporation (MSRC), and later the Marine Preservation Association (MPA), sponsored a study to examine the reasons for the apparent differences between expert and non expert perceptions of dispersant use and the ecological effects of dispersant use. Using a prescribed risk communication methodology, this study compared the mental models (an individual's thought processes in making a decision regarding a particular issue) of US dispersant decision-makers and other stakeholders to an expert model (expert consensus of the relevant decision concepts that might be used), specifically looking at the fate and effect of spilled oil in comparison to chemically-dispersed oil. Through a series of interviews and written questionnaires, a number of dispersant misperceptions were identified. These misperceptions were translated into topics for booklets that would provide dispersant information in a concise and reader-friendly format. For more information on the MSRC/MPA study, please see Bostrom et al., 1995, Bostrom et al., 1997, and Pond et al., 1997.

As a result of the MSRC/MPA work, in 1996, the American Petroleum Institute (API) commissioned the preparation of three dispersant-related booklets:

- Fate of Spilled Oil in Marine Waters: Where Does It Go? What Does It Do? How Do Dispersants Affect It? An Information Booklet for Decision Makers.
- A Decision-Maker's Guide to Dispersants: A Review of the Theory and Operational Requirements.
- Effects of Oil and Chemically Dispersed Oil in the Environment.*

*This booklet is the third in the series. In the previous two booklets it was referenced by a draft title - "Defining the Links Between Fate and Transport Processes with Exposure and Effects of Oil and Chemically Dispersed Oil in the Environment."

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OVERVIEW

- The American Petroleum Institute commissioned the preparation of three booklets to help bridge the gap in the understanding of dispersant use, effectiveness, and effects.
- This third booklet focuses on exposure and effects of untreated oil and chemically dispersed oil in the marine environment.
- Crude oil is a complex, highly variable mixture of hydrocarbons and other trace compounds. Exposure may cause a variety of adverse effects, including narcosis, slowed growth, reduced reproduction, and death.
- Dispersants are mixtures of chemicals known as solvents and surfactants. Solvents reduce the viscosity of both the oil and the dispersant, and help surfactants penetrate into the oil. The surfactants then help the oil break up and disperse into the water column.
- Toxicity is the “inherent potential or capacity of a material (in this case, oil or dispersed oil) to cause adverse effects in living organisms”.
- To be toxic, oil components must be bioavailable to the organisms being exposed. Many of the components in oil are considered toxic, but have limited bioavailability in the environment. Toxic effects depend on the duration of exposure, and the concentration of the chemical(s) involved.
- Concentrations of chemicals and oil are often measured in parts-per-million (ppm) or parts-per-billion (ppb). To quantify toxicity data, endpoints are often expressed in terms of the concentration necessary to kill 50% of the test organisms over a specified time period (LC_{50}) or the concentration necessary to cause a particular effect in 50% of the test organisms over a specified period of time (EC_{50}).
- Toxic effects can be lethal (causing death) and sublethal (e.g., disorientation, reduced growth and reproduction).
- Toxic effects can also be acute (caused by short-term exposure) or chronic (caused by long-term exposure).
- The amount of oil exposure an organism will experience depends on many factors, including:
 1. Oil type
 2. Spill volume
 3. Shoreline type
 4. Tide stage
 5. Weather conditions

- There are four main routes of exposure for organisms during a spill:
 1. Direct contact - an organism contacts or becomes coated with a substance.
 2. Ingestion - an organism eats or drinks a substance.
 3. Inhalation - an organism inhales a substance in the form of a vapor, mist, or spray.
 4. Absorption - an organism absorbs a substance directly through its skin or respiratory membranes.
- After oil is spilled, it typically undergoes eight main fate and weathering processes, which may all occur simultaneously in different degrees:
 1. Spreading and advection - When spilled, oil spreads out on the surface of the water. This increases the surface area of the oil, thus increasing the potential for exposure by all routes.
 2. Evaporation - Many components of oil evaporate. This creates a vapor that can lead to inhalation of toxic compounds as they pass from the water surface to the atmosphere.
 3. Dissolution - Some components of the oil will go into solution in the surrounding water. This increases the chance of exposure through direct contact, ingestion, or absorption for water column resources.
 4. Natural dispersion - Oil breaks up into droplets in the water beneath the slick and may float away. As a result, water column resources can be exposed through direct contact, ingestion, and absorption.
 5. Emulsification - Oil and water combine to form a mousse. Exposures can result from direct contact or ingestion.
 6. Photo-oxidation - Sunlight transforms some oil components into new by-products, which may be more toxic and water-soluble than the original components. Water surface and water column resources can be exposed to the by-products through inhalation, direct contact, absorption, and ingestion.
 7. Sedimentation and shoreline stranding - Oil washes ashore and also sinks after sticking to particles in the water. Exposure can occur through direct contact and ingestion of stranded or sunken oil.
 8. Biodegradation - Oil is slowly broken down by resident bacteria into H_2O and CO_2 . Biodegradation is a slow process, with little effect on exposures.
- Different resources are at varying risk of exposure to untreated oil and chemically dispersed oil. These resources are discussed in the following groups:
 1. Surface-dwelling resources - This typically includes birds, marine mammals, and reptiles. These resources are at high risk of exposure to oil floating on the surface during a spill.
 2. Water column (pelagic) resources - This group includes fish and plankton. They are typically at lower risk of exposure to oil during a spill. Dispersion can temporarily increase the risk of exposure to these resources.

3. Bottom-dwelling (benthic) resources - This includes all resources that live on, or in, the bottom. Typical examples are many species of crabs, bivalves, and plants. They are usually at lower risk of exposure during a crude oil spill and are most affected by sinking oil.
 4. Intertidal resources - These resources live in the areas that are exposed to air during low tides, but submerged during high tides. They also include many species of crabs, bivalves, and plants. If a spill reaches the shore, these resources are at high risk of exposure, as successive layers of oil can be put down by tides and winds.
- Bioaccumulation and biomagnification of hydrocarbons are not believed to be of great concern to vertebrates (fish, mammals, etc.) since they are able to metabolize them. Some invertebrates, however, have limited, if any, capability to metabolize hydrocarbons (e.g., shellfish). Long term contaminated shellfish may be able to eliminate (depurate) hydrocarbons over time if they can be placed in uncontaminated waters. The effects (if any) of oil on these organisms have not been clearly established.
 - Tainting (the presence of an “off-taste” or smell in seafood) is a concern after a spill. Tainting cannot be easily tested. Tainting will cause the greatest problems in shellfish, which have a limited, if any, ability to metabolize hydrocarbons. Finfish can metabolize the oil within several days after exposure ends.
 - Field tests and spill studies on dispersant use have generally found that the use of dispersants has some drawbacks and may increase adverse effects to some resources in the short-term. However, this can be outweighed by the immediate and longer-term beneficial effects to other resources that can result from dispersant use.
 - Dispersants and chemically dispersed oil will affect different resources in different ways, depending on the exposure conditions and the manner in which the dispersants are used. The potential environmental benefits and impacts of dispersant use tradeoffs among resources should always be carefully weighed.
 - To minimize adverse effects on water column resources, dispersant use in waters less than 10 meters deep, in bays, or in areas with low flushing rates has historically been avoided. However, dispersant use need not be ruled out automatically. In these areas, dispersant use should be examined and compared to other response options in order to determine the optimal response in terms of net environmental benefit. The response method providing the greatest net environmental benefit should be the determining factor in these areas.
 - Ecological risk assessments enable the methodical comparison of ecological tradeoffs of various response methods. Ecological risk assessments should be part of pre-spill planning activities to speed the decision-making process for possible dispersant use during actual incidents.

INTRODUCTION

Consider this scenario – an oil tanker has been involved in an accident near mangroves and a large salt marsh. Some of the tanker’s cargo has been released in the accident. One member from the team of decision-makers is assigned the responsibility of recommending countermeasure options. While dispersants are one option, he is concerned about their possible effect on resources in the area, including all resident plants and animals. Many papers are available which provide information on the different effects of chemically dispersed oil on biological resources. However, applying the findings from numerous scientific experiments to a real-world emergency is not easy. What this person wants is a concise booklet that in layman’s terms explains the general effects of oil and chemically dispersed oil on various biological resources. Such a booklet would have made preparing for, and now dealing with, dispersant use issues less time consuming, while making the information more comprehensible. This booklet was designed to fill that planning need. Ideally, it should be read along with other reference material as part of pre-spill planning activities, not just during a response emergency.



PURPOSE OF THE BOOKLET

This booklet has been developed as a reference document for oil spill response decision-makers, to provide an accurate summary of exposure and effects of oil and chemically dispersed oil in the marine environment. During both pre-spill planning and actual response, decision-makers are faced with many questions concerning exposure and effects. For instance:

- What will the oil do to a particular biological resource, both to individuals and the entire population?
- Is dispersant alone likely to cause adverse effects?
- Will adding chemical dispersants change the way oil affects plants and animals?
- Would it be better to expose one resource to the oil so that another resource could be protected?

These are the types of questions addressed in this booklet.

Part One of the booklet provides a general, background discussion on concepts necessary for understanding the potential sources of oil and dispersed oil contamination that can cause adverse effects. This infor-

mation provides the foundation for understanding oil chemistry, toxicity, and exposure. **Part Two** focuses on the effects of undispersed oil and **Part Three** discusses how chemically dispersing oil changes exposure and effects to marine animals and plants. Resources are discussed in groups, according to their distribution in the environment and their likelihood of exposure to oil and chemically dispersed oil (i.e., surface-dwelling, water column, bottom-dwelling, and intertidal). **Part Four** provides information on the tradeoffs of various decisions and information on conducting an ecological risk assessment.

This booklet also identifies and explains specific terms associated with oil that may be used by technical experts during planning or response operations. The first time a new technical term is used within this booklet, it will appear in an ALL CAPS format; this signifies that a more detailed explanation or definition is present in the right or left margin near where the word(s) is first used within the main text.

PART I: SOURCES OF CONTAMINATION AND INJURY

The type of oil spilled is a key variable in determining its impact on a biological resource. The composition of crude oil is different from refined products, and both compositions can vary greatly. For instance, one crude oil may have many components that evaporate quickly into the atmosphere, whereas, another crude oil may be composed of many heavy components that can persist in the environment for a long time. General oil properties are reviewed below. A more detailed discussion on oil chemistry can be found in the first booklet in this series, “Fate of Spilled Oil in Marine Waters: Where Does It Go? What Does It Do? How Do Dispersants Affect It?: An Information Booklet for Decision-Makers.”

Purpose of Part I, Section I

To review oil composition and properties.

Hydrocarbons are chemical compounds composed solely of carbon and hydrogen atoms. In crude oils, hydrocarbons are the most abundant compounds—up to 85 percent of the overall mixture (Gilfillan, 1993).

SECTION I: WHAT IS OIL?

HYDROCARBONS are the most abundant organic compounds in crude oil (NRC, 1989; Gilfillan, 1993). There are essentially three groups of hydrocarbon components in every crude oil type:



1. Lightweight components (low molecular weight)

- contain 1 to 10 carbon atoms (C1 to C10);
- evaporate and dissolve more readily than medium or heavy-weight components, and also leave fewer residual weathering compounds (often called residue) than medium or heavy-weight components;
- are thought to be more BIOAVAILABLE to animals (readily absorbed by an organism) than medium or heavyweight components; and
- are potentially flammable and readily inhaled, so, are of concern for human health and safety.

Examples: Benzene, Toluene, Ethyl-benzene, Xylene, ALKANES (see the first booklet in this series for more information).

Because lightweight components are biologically available to organisms and can be readily inhaled, their potential TOXICITY to animals and humans is of concern.

2. Medium-weight components (medium molecular weight)

- contain 11 to 22 carbon atoms (C11 to C22);
- evaporate or dissolve more slowly, over several days, and may leave behind some residual weathering compounds which can appear as a coating or film;
- are sometimes regarded as more toxic than the lightweight components; and
- are not as bioavailable as lower-weight components, resulting in lower chemical toxicity to animals.

Example: POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) (see the first booklet in this series for more information).

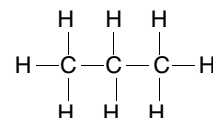
3. Heavyweight components (high molecular weight)

- contain 23 or more carbon atoms ($\geq C_{23}$);
- undergo little to no evaporation or dissolution;
- can cause long-term effects via smothering or coating by residual weathering compounds. These residuals may remain in the water column and sediments indefinitely (Helton, 1996); and
- are not very bioavailable, resulting in lower chemical toxicity to animals when compared to light or medium-weight components.

Example: Asphaltenes (see the first booklet in this series for more information).

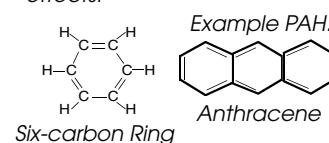
To be **Bioavailable** is to be in a form that is conducive to uptake by organisms. Bioavailability is the tendency of a substance (in this case, individual oil components) to be taken up by a biological organism (Rand and Petrocelli, 1985).

Alkanes are petroleum hydrocarbon compounds, also called normal paraffins and isoparaffins. Alkanes are characterized by branched or unbranched chains of carbon atoms with attached hydrogen atoms and contain only single carbon-carbon bonds (no double or triple bonds between carbon atoms).



Toxicity represents the degree of danger a substance poses to animal and plant life. The words "toxic" and "poisonous" have, essentially, the same meaning. Therefore, it can be said that something with high toxicity is highly poisonous, and vice versa.

Polycyclic Aromatic Hydrocarbons (PAHs) are a class of hydrocarbons characterized by multiple rings with six carbon atoms each. PAHs are considered to be the most acutely toxic components of crude oil, and are associated with chronic and carcinogenic effects.



Persistence refers to an oil's or refined product's tendency to remain in the environment for a long period of time following a discharge. Persistent oils are those crude and refined oil products that may not be completely removed from an affected environment as a result of weathering processes or cleanup operations. When reading persistence measurements, higher numbers mean greater persistence.

Non-persistent oils and products will be rapidly and completely removed from the affected environments through natural weathering processes. They are largely composed of light-weight components. Only short-term effects are expected from non-persistent oils.

Pour point is the temperature above which an oil begins to flow.

Crude oils are composed of various combinations of compounds in each of the three component categories. When comparing crude oils, the concentration of the larger molecular-weight compounds (medium and heavyweight) relative to the amount of lightweight components within the oil affects PERSISTENCE. Oils with greater concentrations of medium and heavyweight components will typically have greater persistence. Because oils with greater persistence remain in the environment longer, they lengthen the period of time during which organisms are at risk of exposure. Oils composed primarily of the lightweight components are usually considered NON-PERSISTENT.

For purposes of illustration, Table 1 lists some of the differences in common petroleum products. For more information on this topic, a full discussion of the properties of different oil types can be found in the first booklet, "Fate of Spilled Oil in Marine Waters: Where Does It Go? What Does It Do? How Do Dispersants Affect It?: An Information Booklet for Decision-Makers."

Table 1. Comparison of oil properties for several commonly used refined oil products.

Oil Type	Components	Relative persistence*	POUR POINT (average)	Boiling Point Range
Gasoline	Mostly lightweight (<10 C atoms)	1	NA (<0° F)	104-302° F
Fuel oil #2 (diesel)	Light- and medium-weight (10 to 20 C atoms)	8	0° F	93-365° F
Fuel oil #6 (bunker)	Mostly heavy-weight (25 to 50 C atoms)	400	60° F	615-826° F

* Relative persistence values were calculated by Markarian *et al.* (1993), and are based on the persistence of the product in the environment, divided by the persistence of the least persistent oil product (gasoline), which has a persistence value of 1.

The effects of oil depend on the chemical composition of the oil itself. To be harmful, oil components must be bioavailable to the organisms. Some components which are considered harmful (i.e., alkanes in the C1 to C10 range) have a high volatility. This means that, unless the concentration of oil is very high, they will usually evaporate before becoming bioavailable to organisms in the water column. Other oil components are also considered harmful, but their molecules are very large, making them less soluble in water. Because these components are less soluble,

they are also less biologically available to organisms in the water column. The two classes of oil components thought to be the most bioavailable, and, thus, most dangerous for water column organisms, include the alkanes in the C12 to C24 range and the two and three-ring polycyclic aromatic hydrocarbons (PAHs) (NRC, 1985; 1989; Gilfillan, 1993; Neff and Sauer, 1995). Potentially hazardous levels of bioavailable oil components such as these usually exist in the water column for only a short period of time after a spill. According to Neff and Sauer (1995), "potentially toxic concentrations of (dissolved) petroleum hydrocarbons, if they are attained at all, probably persist in the water column for only a few days or weeks." This time period is considered to be even shorter by other researchers.

SECTION II: WHAT IS A DISPERSANT?

Chemical dispersants are mixtures that contain "surface-active" chemicals (SURFACTANTS) and SOLVENTS. The surfactants actually cause the oil to "disperse" into tiny droplets that remain suspended in the water column. As the saying goes, oil and water do not mix...without surfactants. In simple terms, surfactant molecules have one end that sticks to oil and another end that sticks to water. This means that the surfactant will work to lightly attach water and oil molecules together, allowing the oil to mix in with the water as small droplets. More information about the action and chemical composition of dispersants can be found in the second paper in this series "A Decision-Maker's Guide to Dispersants."

PART II: TOXICITY AND EXPOSURE

SECTION I: TOXICITY

WHAT IS TOXICITY?

Rand and Petrocelli (1985) define toxicity as the "inherent potential or capacity of a material [in this case oil or dispersed oil] to cause adverse effects in a living organism." Adverse effects are responses outside the "normal" range for healthy organisms and can include behavioral, reproductive, or physiological changes, such as slowed movements, re-

Purpose of Part I, Section II

To review the basic composition and properties of dispersants.

Surfactants are naturally occurring and chemically manufactured molecules often referred to as surface active agents or "detergents." Surfactant molecules contain both water-seeking (hydrophilic) and oil-seeking (oleophilic, or hydrophobic) portions that orient themselves at the oil-water interface so that the oil-seeking portion of the molecule attaches to the oil and the water-seeking portion of the molecule faces outward into the surrounding water.

Solvents are chemical compounds that are included in dispersants to assist the surfactants in penetrating the oil.

Purpose of Part II, Section I

To define toxicity and explain how it is typically measured.

Exposure is contact of an organism with a chemical, physical, or biological agent (e.g., oil). Exposure increases with the amount of time an agent is available for absorption at the exchange boundaries of the organism (e.g., skin, lungs, digestive tract).

Technically, exposure to a toxin equals dose plus concentration. The dose is the actual quantity of an agent an organism is in physical contact with and the concentration is the amount of the toxin in a given volume of that agent.

Solubility is the capability of a substance to be dissolved in a liquid, such as water. Technically, it is the equilibrium concentration of the product (e.g., components of oil) when in contact with the solution (e.g., water).

Vapor Pressure is the pressure at which a liquid (oil components) and its vapor are in equilibrium at a given temperature.

Salinity is the salt content of the water. Salinity of typical seawater ranges from 32 to 35 parts per thousand.

Parts-per-million (ppm) is one part chemical (e.g., oil) per 1,000,000 (10^6) parts of the medium (e.g., seawater) in which it is contained. For water, the ratio commonly used is milligrams of chemical per liter of water, $1\text{ mg/L} \cong 1\text{ ppm}$.

Parts-per-billion (ppb) is one part of chemical (e.g., oil) per 1,000,000,000 (10^9) parts of the medium (e.g., seawater) in which it is contained. For water, the ratio commonly used is micrograms of chemical per liter of water, $1\text{ ug/L} \cong 1\text{ ppb}$.

An **LC₅₀** (also written as LC50), or median lethal concentration, is the concentration of a chemical required to cause death in 50 percent of the exposed population when exposed for a specified time period, and then observed for a specified period of time after the exposure ends.

An **EC₅₀** (also written as EC50), or median effective concentration, is the concentration of a chemical in water to which test organisms are exposed that is estimated to be effective in producing some sublethal response in 50 percent of the test organisms.

duced fertility, or death. Toxic effects are a function of both the duration of EXPOSURE to the chemical and the concentration of the chemical. In the aquatic environment, the concentration of a chemical, as well as its transport, transformation, and fate, are controlled by: 1) physical and chemical properties of the compound (such as a compound's SOLUBILITY or VAPOR PRESSURE); 2) physical, chemical, and biological properties of the ecosystem (such as SALINITY, temperature, or water depth); and 3) sources and rate of input of the chemical into the environment (Rand and Petrocelli, 1985; Capuzzo, 1987; Gilfillan, 1992).

HOW IS TOXICITY MEASURED?

The objective in measuring toxicity is to estimate the range of chemical concentration that produces some selected, readily observable, and quantifiable response during a given time of exposure (Rand and Petrocelli, 1985). This is referred to as a dose-response relationship and is usually measured in PARTS-PER-MILLION (ppm) or PARTS-PER-BILLION (ppb).

Often, toxicity data are expressed as LC₅₀ or EC₅₀. For LC₅₀, the END-POINT is mortality over a specified time. Length of exposure is usually 24 to 96 hours and chemical exposure usually remains constant over the entire time period. In some tests, the endpoint is not mortality, but a non-lethal response such as immobility, developmental abnormality, etc. In these cases, results are expressed as EC₅₀, where a significant, defined effect is seen in 50% of the population over a specified time period, usually 24 or 48 hours (Rand and Petrocelli, 1985). Although these tests can be used to produce a numerical measure of a substance's toxicity and provide us with important information about the effects of oil, they cannot accurately reproduce the different types of exposures organisms experience during actual oil spill. During an actual incident, organisms may see exposures of much longer time periods as well as exposures that vary greatly over time; as tides change or currents shift exposures may increase, decrease, or even stop, only to start again hours later.

There are some complicating factors that one should keep in mind when looking at toxicity data. Markarian *et al.* (1993) cautions that use of the term "LC" or "LETHAL Concentration" is inappropriate for testing with oil products. This is because an LC₅₀, for example, should measure the lethal concentration of a *single* compound. However, oil is a mix of compounds and often the exact mixture is not known. Seeing an LC₅₀ result for oil does not immediately indicate how the measured concentration was developed. This can make comparisons of oil difficult.

because various approaches can provide different results, which are of different scientific relevance (Markarian *et al.*, 1993).

Another complicating factor for those reading toxicity tests with oil products is how the concentration is expressed. Concentrations expressed as the total oil per unit volume (nominal concentration) are misleading because much of the oil is not soluble in the water and, therefore, not bioavailable to water column organisms. Using this nominal concentration will produce overestimates of exposure concentrations and toxicities (NRC, 1989; Lewis and Aurand, 1997). More realistic testing methods measure concentration based on the water-accommodated fraction (WAF) of the oil, which is the fraction of an oil product that remains in the water phase after mixing and settling (CONCAWE, 1983).

Although different species may react to toxic substances in unique ways, animal testing can be used to produce some basic categorizations about the toxicity of substances. Table 2 provides general guidance to the relative toxicity of substances.

Table 2. Relative toxicity of substances (from USFWS, 1984; Hunn and Schnick, 1990). See sidebar for conversion to ppm.

Toxicity Rating	Aquatic 96-hour LC ₅₀	Avian Oral 96-hour LD ₅₀ (mg _{substance} /Kg _{bird})	Mammalian Oral 96-hour LD ₅₀ (mg _{substance} /Kg _{animal})
Practically Nontoxic	100-1,000 mg/L	> 5,000	>15,000
Slightly Toxic	10-100 mg/L	1,000-5,000	5,000-15,000
Moderately Toxic	1-10 mg/L	200-1,000	500-5,000
Highly Toxic	0.1-1.0 mg/L	40-200	50-500
Extremely Toxic	< 0.1 mg/L	<40	5-50

SECTION II: EXPOSURE

WHAT IS EXPOSURE?

Exposure refers to the amount of contact an organism has with a chemical, physical, or biological agent. When assessing toxicity, it is necessary to know the exposure. The most significant factors are the kind, duration, and frequency of exposure, as well as the concentration of the

An **Endpoint** is an observable or measurable biological or chemical event used as an index of the effect of a chemical on a cell, tissue, organ, organism, etc.

Lethal means resulting in death. (e.g., lethal effects).

LD₅₀ is the lethal dose required to kill 50% of the animals tested. "Dose" means that the substance is ingested directly by the animal, not mixed in the surrounding water, as is the case with a lethal concentration.

mg/L can usually be converted directly to ppm (i.e., 1 mg/L $\cong$ 1 ppm) for rough approximations.

Here is a general explanation of the math involved: One mg of water is 1 millionth of a liter (1 ppm). If a substance has the same density as water, the conversion is completely accurate. For substances with slightly different densities, such as oil, this conversion provides a quick estimation.

Purpose of Part II, Section II

To explain what exposure is and how it may be affected by dispersant use.

chemical (Rand and Petrocelli, 1985). NOAA's Damage Assessment Center summarized the factors to be considered when assessing exposure to subtidal and intertidal organisms along shorelines (NOAA, 1996):

- **Oil type** – physical and chemical characteristics of the oil.
- **Spill volume** – size of the discharge and/or amount in shoreline area.
- **Shoreline type** – high energy shorelines may reduce the chance for long-term aquatic exposure, but may also result in the oil being deposited along or above the high tide line. Sediment grain size will also affect exposure, with coarse-grained sediments allowing for more rapid and deeper penetration.
- **Tide stage** – subtidal organisms are at less risk than intertidal organisms, since they won't come in contact with the floating oil.
- **Weather conditions** – floods or storm-driven tides may strand oil in places it would not normally go. Weather conditions can also accelerate or retard oil weathering.

Acute refers to an effect in which the organism of interest is exposed to the contaminant (e.g., oil) for only a small portion of its life cycle (i.e., generally equal to, or fewer than, 4 days). Typical effects endpoints include mortality or immobility.

Chronic refers to an effect in which the organism of interest is exposed to the contaminant (e.g., oil) for a significant stage of its life cycle or the entire life cycle (i.e., generally weeks to years, depending on the reproductive life cycle of the test organism). Typical effects endpoints include non-lethal reproduction, growth, or developmental impairment as well as behavioral changes.

Toxic effects can be produced by ACUTE (short-term) or CHRONIC (long-term) exposure. Acute exposure occurs when an organism is in contact with a chemical for a brief time period. Toxicity testing for acute effects usually involves effects that occur within a four-day period (96 hours) or less. In the case of oil spills, negative effects from acute exposure are usually seen early in the spill. This is because the oil, including the light and medium-weight components which may evaporate, is most concentrated during the first few days. Alternatively, chronic exposures are longer duration (weeks to years), and generally involve daily exposure to smaller amounts of oil or residual weathering compounds from oil.

CHANGES IN EXPOSURE WITH DISPERSANT USE

When dispersants are applied during a spill, they act to break up the oil into droplets, moving it from the surface and moving downward into the water column. As a result, dispersants will increase oil exposure to some organisms while reducing it for others. When dispersants are applied, exposure to oil will typically decrease for surface-dwelling and intertidal resources, but increase for water column and bottom-dwelling resources. This is one reason that dispersants are not usually applied to a spill directly over a shallow coral reef. Without dispersant application the oil may stay on the surface and not contact the reef, whereas with dispersant application the reef may be exposed to large numbers of oil droplets.

SECTION III:

ROUTES OF EXPOSURE

Following a spill, resources can be exposed to oil through four different routes:

1. Direct Contact – This is the most visible route of exposure to an observer. When a plant or animal comes into direct contact with oil, it may only become lightly oiled. It could also become completely coated with oil, making it unable to move, function, or survive. Once an organism is physically coated with oil, the chances of exposure through ingestion, inhalation, and absorption will increase dramatically.
2. Ingestion – Both direct and indirect. Direct ingestion occurs when an organism eats food coated with oil or even ingests the oil itself. Direct ingestion of oil may occur accidentally, such as when a bird attempts to clean oil from its feathers. Indirect ingestion occurs when an organism eats prey or food tainted with oil. This food is not necessarily coated with oil itself, but has been exposed to it previously. For example, an eagle could ingest oil indirectly by eating an animal which swallowed oil during a spill the week before.
3. Inhalation – Inhalation may occur when animals breathe in evaporating oil components or oil mists from storm and wave action. Inhalation usually occurs when animals on the surface (e.g., seabirds, otters, seals) breathe while swimming within a slick. It may also occur when an animal along the shore breathes after getting its head and face coated with oil from feeding or swimming.
4. Absorption – This occurs when an organism absorbs the oil, or toxins from the oil, directly through its skin or outer membranes. Typical examples of organisms to which this could apply are benthic or intertidal molluscs, worms, fish, and plants.

As the oil slick WEATHERS and various oil components are transported into the water column and air, the degree of exposure and, consequently, the impact on living resources, will change. Each weathering process is briefly described below along with a discussion of how the process influences exposure. The reader is reminded that, although the processes are discussed separately, many occur simultaneously. For a detailed explanation of each process, the reader is referred to the first booklet in this series, “Fate of Spilled Oil in Marine Waters: Where Does It Go? What Does It Do? How Do Dispersants Affect It?”

Purpose of Part II, Section III

To discuss the ways organisms can be exposed to oil and how natural changes in spilled oil can affect exposure.

*To **Weather** or "**Weathering**" is the combination of physical and chemical changes in oil composition over time, as it is exposed to the environment. It may result in the removal of oil from the water's surface to the atmosphere, water column, sediments, and shorelines.*



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SPREADING AND ADVECTION

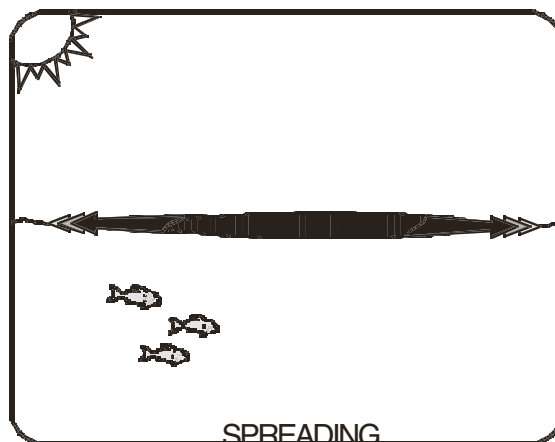
Viscosity is a fluid's internal resistance to flow. A highly viscous oil will not flow easily. This physical property of the oil or refined product is important to understand, as it helps determine the oil's behavior during a spill.

Surface Tension is an attractive force exerted between the molecules of a liquid. For example, water sticks together in droplets due to surface tension. In general, surface tension hinders the spreading of a slick.

A **Current** is a stream of ocean or river water moving continuously in about the same path, and distinguished from the surrounding water through which it flows mainly by temperature and salinity differences.

Spreading is just that, the actual spreading out of oil on the surface of the water. Oil spreads on water much like a glass of liquid would when poured on a table. Oil spreading occurs because of the effects of gravity, inertia, friction, VISCOSITY, and SURFACE TENSION. On

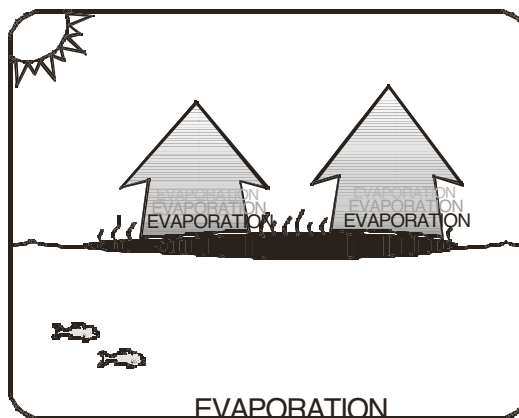
calm water, spreading occurs in a circular pattern outward from the center of the release point (CONCAWE, 1983). Advection is a type of spreading caused by the influence of overlying winds and/or underlying CURRENTS (NRC, 1985). Due to the effects of advection, spreading is not uniform, and can result in large variations in oil thickness within the slick (ITOPF, 1987). Since spreading increases the surface area of the slick, it also increases the probability that any biological resource on the surface of the water will be exposed to the oil through direct contact (e.g., birds diving through the slick).



EVAPORATION

Evaporation is the preferential transfer of light and medium-weight oil components from the liquid phase to the vapor phase (into the atmosphere) (Exxon, 1985). The oil slick is physically and chemically altered as these components evaporate.

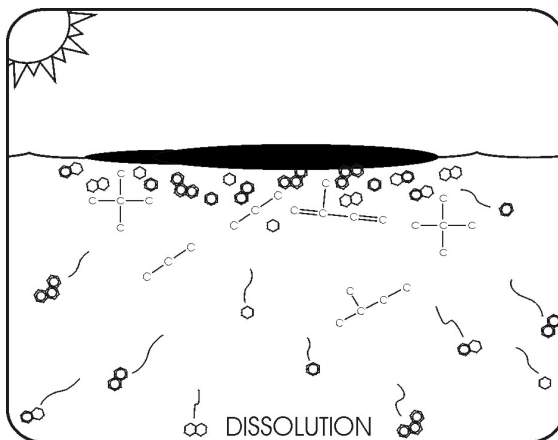
Some of these components are highly VOLATILE and fairly toxic (Lewis and Aurand, 1997). Evaporation influences exposure by creating a vapor which can lead to inhalation of toxic compounds as they pass from the water surface into the atmosphere. Time of such exposure is relatively short, due to rapid air dispersion.



Volatile describes a state of matter; oil will "give off" or lose components of its original makeup through evaporation when exposed to the atmosphere. The more volatile the component, the faster it evaporates. The components that volatilize are rapidly removed from the original product (e.g., the oil).

DISSOLUTION

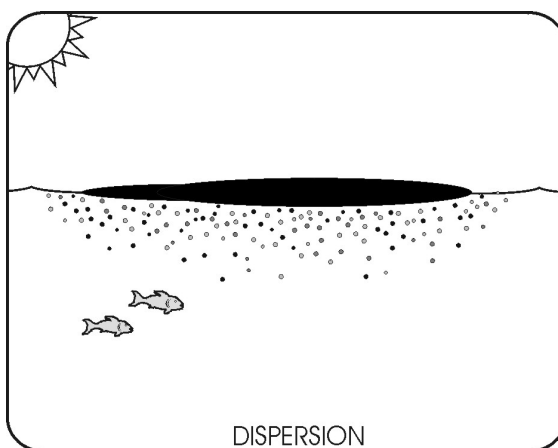
is the preferential transfer of oil components from a slick on the water's surface into solution in the water column (Exxon, 1985). Certain lighter-weight components of the spilled oil tend to be the most soluble and, therefore, the ones that dissolve into the water column.



However, many soluble components are also volatile, with evaporation occurring 10 to 1,000 times faster than dissolution (CONCAWE, 1983; ITOPF, 1987; Lewis and Aurand, 1997). Consequently, only a slight fraction (2 to 5%, at most) of the spill is removed by dissolution (Neff, 1990). Although concentrations of dissolved components are usually very low, water column resources can be exposed to them through direct contact, direct and indirect ingestion, and absorption through the body surface.

NATURAL DISPERSION

Natural dispersion is the process of forming small oil droplets that become incorporated into the water column in the form of a dilute oil-in-water suspension (CONCAWE, 1983; Exxon, 1985). This process occurs when breaking waves mix the **WHOLE OIL** into the water column.



Large droplets (greater than 0.1 mm in diameter) that are formed when mixing occurs tend to “coalesce, rise rapidly, and concentrate near the water surface. Small droplets (typically less than 0.1 mm in diameter) break away from the main mass and become dispersed in the water column” (Neff, 1990). A simple demonstration can be done with a bottle of oil and vinegar salad dressing; although the bottle starts out with separate oil and vinegar layers, when it is shaken the oil is dispersed throughout the vinegar. However, after a few minutes most of the oil coalesces and rises to the top again.

Whole Oil is a reference to the oil itself. When referencing the “whole oil”, we are NOT referring to the individual components of the oil; however, the “whole oil” will continue to change in composition over time as weathering processes act on it.



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