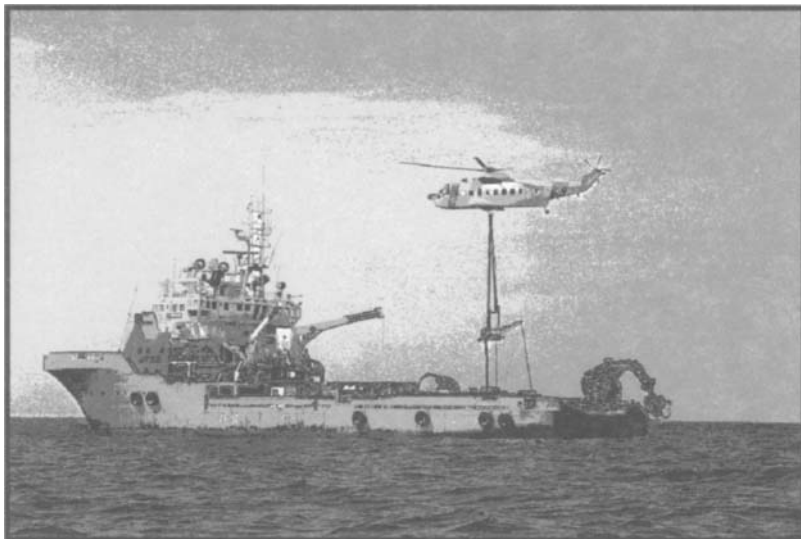


PUTTING DISPERSANTS TO WORK: OVERCOMING OBSTACLES



An Issue Paper Prepared for the 1997 International Oil Spill Conference

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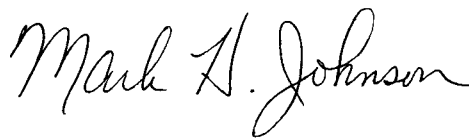
PREFACE

The 1997 International Oil Spill Conference sponsors, American Petroleum Institute, US Coast Guard, US Environmental Protection Agency, International Maritime Organization, and International Petroleum Industry Environmental Conservation Association, commissioned issue papers covering three topics of special importance to the oil spill community. The sponsors assigned responsibility for general management and oversight, scope definition, peer review, and publication of these issue papers to the Program Committee.

The goals of these papers are to stimulate open discussion of complex and controversial issues, and balance diverse positions of stakeholders. Each topic addresses varying scientific/technical and sociopolitical concerns. Therefore, each paper differs as to depth of study and breadth of conclusions. The views and opinions presented are those of the authors solely and do not represent the views, opinions, or policies of the International Oil Spill Conference or its sponsors.

During the 1997 Conference, each of the three issue paper topics will be the subject of a special panel session. Publication of these issue papers as separate companion documents to the Conference Proceedings continues the International Oil Spill Conference Technical Report Series. The Technical Reports are published biennially in conjunction with the International Oil Spill Conference.

It is the Program Committee's hope that each issue paper topic furthers substantive discussion and serves as a catalyst for solutions to the topics discussed.



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ABSTRACT

Oil spill dispersants are one of the possible responses to oil pollution at sea. Some countries have found dispersant use to be an effective way of limiting the environmental damage that may be caused by an oil spill, while other countries favor the use of alternative response methods. The debate has been especially protracted in the United States. In many respects, the issues raised in a recent workshop in Leesburg, Va. (SEA, 1995) reflect international issues in areas where dispersant use is controversial. Factors cited in that report include:

- fear that the addition of dispersant to spilled oil may increase the potential for environmental stress;
- uncertainty about the performance of dispersants;
- lack of understanding and/or familiarity with existing data on effectiveness and aquatic toxicity for dispersants;
- over-confidence in the adequacy of mechanical measures;
- failure to examine and balance the toxicity and effectiveness of dispersants against the toxicity and effectiveness of alternative response techniques (mechanical measures, no action, etc.); and
- fear of making a poor decision. There is a widespread feeling that if only more information were available about the effectiveness and ecological impacts of dispersants added to a spill, versus that of the spilled oil alone, a more defensible decision could be made.

The report concluded, "Consequently, opportunities for employing techniques which might improve spill response have probably been missed." While such reluctance persists, dispersants will not be generally available as a response option in the event of a major spill. The important consideration in any oil spill response is that the action taken is the most effective in limiting the overall damage to resources (environmental, ecological, amenity, or financial) that will be caused by an oil spill. Decisions regarding dispersant use must be made well in advance of a spill. There will be no time to plan or implement an effective dispersant response when a spill occurs.

This paper summarizes the information on issues concerning dispersant use: the obstacles (general and specific) to dispersant use, the key issues of the environmental debate, and the operational requirements for effective dispersant use. The aim of the paper is to identify the key elements of these complex issues and to stimulate professional debate so there can be further policy development in this area. This paper expands on Canevari *et al.* (1986) and IPIECA (1993) by emphasizing:

- the complex nature of oil and the role of specific components in toxicity;
- the use of formal ecological risk assessment protocols to aid in pre-spill planning;
- the importance of pre-planning for logistics; and
- the need for flexibility in identifying incident-specific operational and monitoring parameters.

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FOREWORD

This paper was commissioned by the 1997 International Oil Spill Conference to examine the following premise: While the use of dispersants requires careful analysis, the current situation is more restrictive than necessary based on existing scientific information. This is related to misconceptions about the ecological effects of spilled oil relative to the effects of cleanup, difficulties in using and interpreting available scientific data, and unrealistic expectations for oil spill response operations in general.

The authors summarize previous efforts to address dispersant use issues as background to their recommendations for moving beyond the debate over whether or not dispersants should be used and toward implementation of practical strategies for dispersant deployment.

Review of existing dispersant literature indicates that:

- the knowledge base influencing decision-makers worldwide is highly inconsistent and often poorly applied, especially regarding environmental factors;
- dispersant use is not uncommon; and
- dispersants often are a better option than allowing oil to strand on shorelines or enter sensitive habitats.

When an oil spill occurs, the public often feels that the only acceptable response is total, and preferably immediate, removal of the oil and restoration of the environment. Since this option is never achievable, public expectations are never met. Inappropriate or unrealistic perceptions about the effectiveness of oil spill response options in general, combined with a lack of understanding of the potential net environmental benefit of dispersants, are major obstacles to dispersant use. A major factor in the controversy is the sheer volume of often contradictory information. It is difficult, if not impossible, for participants in the decision-making process to read all the relevant literature on the subject and reach their own conclusions.

The best option for resolving these concerns is to conduct a Net Environmental Benefit Analysis (NEBA) to coordinate and improve risk communication and ecological risk assessment. Using NEBA focuses pre-spill planning on appropriate issues,

helps clarify misconceptions, and avoids the use of inappropriate data by forcing participants to explain their concerns in at least a semi-quantitative manner. The resulting exchange among response planners, environmental advocates, responders, and the academic community is very beneficial to the planning process in general and dispersant use in particular.

Once a risk assessment is complete, effectively communicating the results to the response community and the public is essential. The most effective approach is a cooperative, interactive, long-term program of information dissemination, rather than a series of sporadic attempts at issue resolution. Regulators should play an important communication and education role, and are especially well suited to integrate ecological risk assessment protocols into the planning process.

It is apparent that the research and response communities have not effectively educated the public about the limitations and advantages of various spill cleanup strategies. However, industry representatives should recognize that they are the best source of information about response options. Non-partisan, objective information should be prepared and aggressively distributed to the entire response community.

After a dispersant use strategy is approved, contingency planners should determine what materials, equipment, and personnel are necessary for the operation. Effective use of dispersants requires planning, training, and practice. Critical actions include:

- alerting the responder to the location of the spilled oil and tracking the slicks as they drift;
- providing sufficient dispersant to treat the quantity of spilled oil;
- locating and treating the areas of thickest oil within a slick;
- accurately spraying dispersants before oil viscosity increases to a level at which dispersants become ineffective; and
- monitoring the effectiveness of dispersant application.

Everyone involved in spill response has the same goal — to minimize the effects of the spill on the environment. The improvements discussed here, particularly the implementation

of NEBA, offer an opportunity for the response community to significantly expand appropriate application of dispersants to protect the environment.

This paper is intended to provide an up-to-date, comprehensive summary of the complex issues regarding dispersant

use, including a review of essential information and related references. The aim of the authors is to stimulate professional debate to allow for further policy development on the use of dispersants.

CHAPTER 1 – OVERVIEW AND BACKGROUND

by Alun Lewis and Don Aurand

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SECTION 1

THE DEBATE CONCERNING DISPERSANTS IN OIL SPILL RESPONSE

1.1 INTRODUCTION

When an oil spill occurs, the public often feels that the only acceptable response is total, and preferably immediate, removal of the oil and restoration of the environment. Since this option is never achievable, their expectations are never met. Inappropriate or unrealistic perceptions about the effectiveness of oil spill response options in general, combined with a lack of understanding of the potential net environmental benefit of dispersants, are major obstacles to dispersant use. Much of the controversy over dispersants appears to be a result of the way information has been presented to, and interpreted by, the various participants in the decision process. The basic issues have remained essentially the same for the last 25 years: "Do they work?" and "Are they environmentally acceptable?" The prolonged, and at times acrimonious, dispersant debate itself has been an

obstacle to dispersant use. A major contributor to the controversy is the sheer amount of seemingly contradictory information. It is very difficult, if not impossible, for the participants in the decision-making process to read all the relevant literature on the subject and reach their own conclusions.

Opponents of dispersant use argue that it has proved unsuccessful in the past and that concrete, quantifiable proof of dispersant effectiveness is difficult to obtain. Proponents counter those objections by stating that, while the *Torrey Canyon* was a disaster, there is a long history subsequent to that of successful dispersant operations which opponents appear to ignore. Proponents suggest that dispersion can be a valid and effective response option and that objections to it are based on a narrow view of only a subset of relevant facts. The issue is synopsized simply as shown in Table 1, below.

TABLE 1.
DISPERSANT DEBATE SYNOPSIS

Opponents argue:	Proponents counter:
• It is better to remove spilled oil from the sea, rather than force it into the sea. The use of dispersants "hides" the problem of the spilled oil instead of "solving" the problem. They are an attempt by industry to avoid the expense of "better" response options. • Addition of chemicals into the environment is undesirable. Dispersants are toxic, or their use causes the oil to have greater toxic effects. • The oil will disperse naturally, given enough time. Dispersants are an unreliable response technique because they do not always work.	• Environmental damage, whether on the water surface, in the water column, or on the shoreline, is caused by exposure to spilled oil. Rapid and total removal of the oil by mechanical means is not feasible at a spill of any significant size. Dispersants can produce a net environmental benefit by rapidly removing oil from the sea surface and preventing or minimizing surface and shoreline impacts. Dispersion accelerates biodegradation and inhibits sedimentation of the oil. • Modern dispersants have low toxicity and when combined with oil do not add measurably to the environmental effects caused by the oil alone. • Natural dispersion is slowed or even stops altogether when oil emulsifies. Emulsified oil persists in and poses long-term hazard to the environment. Dispersant use speeds up the natural dispersion process and retards or prevents emulsification. Like every other response technique, dispersant use cannot be guaranteed to be effective in all circumstances.

1.2 PURPOSE OF DISPERSANT USE

The function of an oil spill dispersant is to greatly enhance the rate of transfer of spilled oil from the water surface into the water column. Effective application of dispersant to an oil that is dispersible will achieve this result. The main concerns about dispersant use are that the temporary increase in oil concentration and the potential for higher concentrations of toxic water-soluble oil components will cause environmental damage. These concerns are described and discussed in detail in Chapter 2.

Dispersion is the conversion of spilled oil from a coherent slick floating on the surface of the sea into very small oil droplets, estimated as about 70 μm in diameter or less (Lunel, 1993), by the prevailing wave energy. These oil droplets are nearly neutrally buoyant due to their small size, and they remain dispersed into the water column until the majority of the oil is eventually biodegraded. The rate of dispersion depends on the oil's properties, principally viscosity, and the prevailing wave energy. Low viscosity oils disperse faster than higher viscosity oils and dispersion is faster in rough seas than in calm conditions.

Dispersion occurs naturally and can proceed at a rapid rate in rough conditions with some low viscosity oils, such as No. 2 heating oil (North Cape incident (OSIR, 1996)), or Gullfaks crude oil (*Braer* incident (Harris, 1995)). The effective use of dispersants allows the responder to transfer the oil into the sea at a time and location that will cause less overall environmental damage than allowing the oil to drift toward more sensitive resources or eventually impact the shoreline.

1.3 HISTORICAL REVIEW

The history of dispersants, at least in the public's mind, begins with the wreck of the *Torrey Canyon* off the coast of Cornwall, UK in 1967, resulting in the loss of 95,000 tons of Kuwait crude oil (GESAMP, 1993; Advanced Technology, Inc. and Continental Shelf Associates, Inc., 1990). As part of the response, chemicals were used to remove oil from the shoreline. Although these chemicals are often referred to in the literature as dispersants, they bear little resemblance to modern chemicals developed for this use. Instead, they were degreasing agents containing 60 percent or more of aromatic solvents; their intended use was to clean oily residues from tanker compartments, not to respond to marine oil spills (Exxon, 1994). Their improper application, including direct shoreline application, resulted in extensive mortality of intertidal organisms (NRC, 1985; Exxon, 1994). According to Southward and Southward (1978), approximately 14,000 tons of weathered oil ultimately came ashore in Cornwall, and a total of 10,000 tons of chemicals were applied to remove it. The oil, most of which was at sea for a week before stranding, was highly weathered and not particularly toxic by the time it reached the shore. The stranded oil was sprayed with chemicals and then removed by hosing down the area. In some locations multiple treatments were applied. While organisms were certainly killed by direct

contact with the oil, almost all of the observed impacts were due to the chemical applications. Animal mortality near or in chemical-treated areas was nearly total and many algae were killed or damaged.

Despite its notoriety, this was not the first use of chemicals on a major spill. Just the year before (1966), the Norwegian tanker *Anne Mildred Brovig* collided with the British MV *Pentland* in the vicinity of the Elbe Estuary in the North Sea. Approximately 450 bbls of a variety of dispersants were applied from workboats. Most was applied to oil escaping from the wreck or used to prevent the formation of large integrated oil slicks. In this case, no ecological damage was attributed to the use of the dispersants (Exxon, 1994). In the three years after the *Torrey Canyon*, dispersants were used seven times on major spills: three in 1968, one in 1969, and three in 1970 (Appendix). In none of these events was a significant ecological impact attributed to the use of dispersants observed. At one of the United States cases in 1969 dispersants were used during the Platform A blowout in the Santa Barbara Channel, Calif. Despite the notoriety of this spill and its significant influence on environmental legislation in the United States, the use of dispersants apparently attracted little attention and reportedly did not contribute to the ecological consequences. The use of dispersants was not extensive and did not prevent stranding (NOAA, 1992; Kallman and Wheeler, 1984).

As summarized in the Appendix, dispersants have been successfully used in a variety of situations, including several large incidents in recent times. Dispersants were a critical part of the response to the *Sea Empress* spill in February 1996 (Lunel, 1996). Through mid-1996, 80 documented uses of dispersants on spill events have been identified in the literature, and dispersants were used on many more small spills that did not receive international attention. Most spill reports indicated (usually anecdotally) that the dispersant use appeared effective. Except for the *Torrey Canyon*, dispersant use at spill events has never been reported to cause any additional environmental damages beyond that due to the oil. In many instances, dispersant use was credited with preventing shoreline damage or contamination of sensitive habitats.

1.4 THE LEGACY OF THE *TORREY CANYON*

Despite the fact that it was an aberrant event, authors writing about dispersant use often introduce the topic with a reference to the effects of the *Torrey Canyon* response. Depending upon the intent, this is either presented as a cautionary tale or an event of no current significance. Whichever way it is presented, the wreck of the *Torrey Canyon* has cast a 30-year shadow over the use of dispersants, and it was clearly the impetus for new dispersant formulations and expanded scientific research on the ecological consequences of dispersant use. As a result, proposals for dispersant use are given more scrutiny and are required to meet more stringent effectiveness and effects criteria than any other response option.

THE EVOLUTION OF DISPERSANT FORMULATIONS

Concerns about the toxicity of dispersants are often expressed by opponents to their use. As stated previously, early dispersant products were derived from engine room degreasers, and many were very toxic. Efforts to develop less toxic, more effective formulations began in the early 1970s and resulted in modern dispersants that are significantly improved in both areas. Modern dispersants are specifically formulated to have a low toxicity (see Chapter 2).

Dispersants can be divided into three types:

- hydrocarbon base—the earliest and least effective type;
- water-dilutable—for use from ships; and
- modern concentrate—for use from aircraft.

Modern dispersants contain one or more nonionic surfactants (15 to 75 percent of the total formulation) plus an anionic surfactant (5 to 25 percent of the formulation) and one or more solvents. The purpose of the solvent is to dissolve any solid surfactant and reduce the viscosity so that the dispersant can be sprayed effectively. In most modern dispersants the major solvent is a glycol ether and the surfactants are similar to those used in many industrial detergents (Gilfillan, 1993).

CONTINUING CONCERNS OVER THE FATE AND EFFECTS OF DISPERSANTS AND DISPERSED OIL

From an industry perspective, the currently available products are cost-effective, efficient, and safe for the environment when properly used. To their opponents, they represent an attempt by industry to avoid the expense of “better” response options and decrease the visibility of the environmental consequences of oil spills through the introduction of yet another chemical into the environment. The US National Research Council (NRC) report in 1989 (NRC, 1989), the UK Ministry of Agriculture, Fisheries and Food (MAFF, 1995), and SEA (1995) examined the role of dispersants and alternative responses in detail and confirmed that the careful and controlled use of dispersants is a fully justified and effective oil spill response method under appropriate conditions. Despite these conclusions, planning for the use of dispersants is still controversial in many parts of the world.

THE CHALLENGE FOR DECISION-MAKERS

It is the job of regulators and oil spill response planners to decide on the best way of dealing with oil spills. They need to have good information to enable them to make valid decisions and rely on experts to provide it. They also need to be able to justify their decisions to a wide cross-section of society.

The currently available information on dispersant use can be difficult to interpret, confusing, and contradictory. It is possible to make a superficial case for either not using dispersants or for using dispersants by considering only selected information or focusing on specific topics. Historically, this has been cast as the “fish versus birds” debate; use of dispersants favors sea birds whilst threatening fish. This is an oversimplification, and there is much more at stake than just birds or fish. A structured mechanism is needed to facilitate the discussion, and this is the function of ecological risk assessment (or Net Environmental Benefit Analysis), as discussed in Chapter 3.

An examination of the experience of different national authorities is unlikely to offer a universal solution. Different countries have very different attitudes toward dispersant use. In some countries dispersants are banned and in other countries, notably the UK, aerial spraying of dispersant is the major method of oil spill response. Many countries have taken an intermediate attitude. Practical considerations need to be taken into account. Countries with relatively long coastlines that are subject to vigorous weather, such as the UK or France, accept carefully controlled use of dispersants as an integral part of their national contingency plan (NCP). Nations with much shorter coastlines in more sheltered waters, such as the Netherlands, have adopted mechanical recovery as their primary oil spill response method.

The current situation in many countries appears to be more restrictive than is necessary based on the existing scientific information. This appears to be related to misconceptions about ecological effects of spilled oil relative to the effects of oil spill countermeasures (especially dispersants), difficulties in using and interpreting the available scientific data, and unrealistic expectations for oil spill response operations in general. The element of uncertainty in estimating the environmental consequences of dispersant use, coupled with the concern that it has the potential for making the situation worse, tends to make decision-makers very conservative and adopt the least controversial response option, mechanical recovery. However, experience from actual spill incidents, especially larger oil spills, has demonstrated that no single response method can deal completely with a spill. The decision to use or not use dispersants cannot be made in isolation; it should be made on the basis of limiting the overall environmental damage that might be caused by the oil spill. This judgment requires knowledge about many aspects of the consequences of a spill and the potential for response. The purpose of this issue paper is to offer some suggestions as to the accomplishment of this task and to provide an overview of required information.

SECTION 2

THE CHARACTERISTICS AND BEHAVIOR OF SPILLED OIL

2.1 INTRODUCTION

Before the questions “Will dispersants work with a particular oil?” and “What are the environmental consequences of dispersant use?” can be answered, the likely behavior of spilled oil should be assessed. When any oil is spilled on the sea, its physical and chemical properties change. There are hundreds of crude oils, and many attempts have been made to classify them into groups on the basis of physical parameters. Viscosity and pour point are typically used as key indicators of whether a given oil is amenable to dispersion. Very light and very heavy oils — classified as Group I and Group V oils on the basis of viscosity by ITOPI (1987) and the US Coast Guard — are not considered to be amenable to dispersion. Intermediate oils (Groups II, III, and IV) are generally considered to be dispersible. However, their dispersibility is variable and declines over time due to weathering.

2.2 OIL WEATHERING

The changes in chemical composition and physical properties caused by the prevailing temperature and wind are known as “weathering.” These changes have been described in detail in other reports (Daling *et al.*, 1990) and vary in degree and extent with oil type (Strøm-Kristiansen *et al.*, 1993). In order to understand the ecological issues related to oil spills, the influence of weathering must be clear. Important weathering mechanisms include:

- spreading
- evaporation
- dissolution
- formation of emulsions
- dispersion in the water column
- sedimentation
- biodegradation

Figure 1 is a typical representation of the processes that occur in the marine environment. While it is a useful

FIGURE 1.
SCHEMATIC OF OIL WEATHERING PROCESS

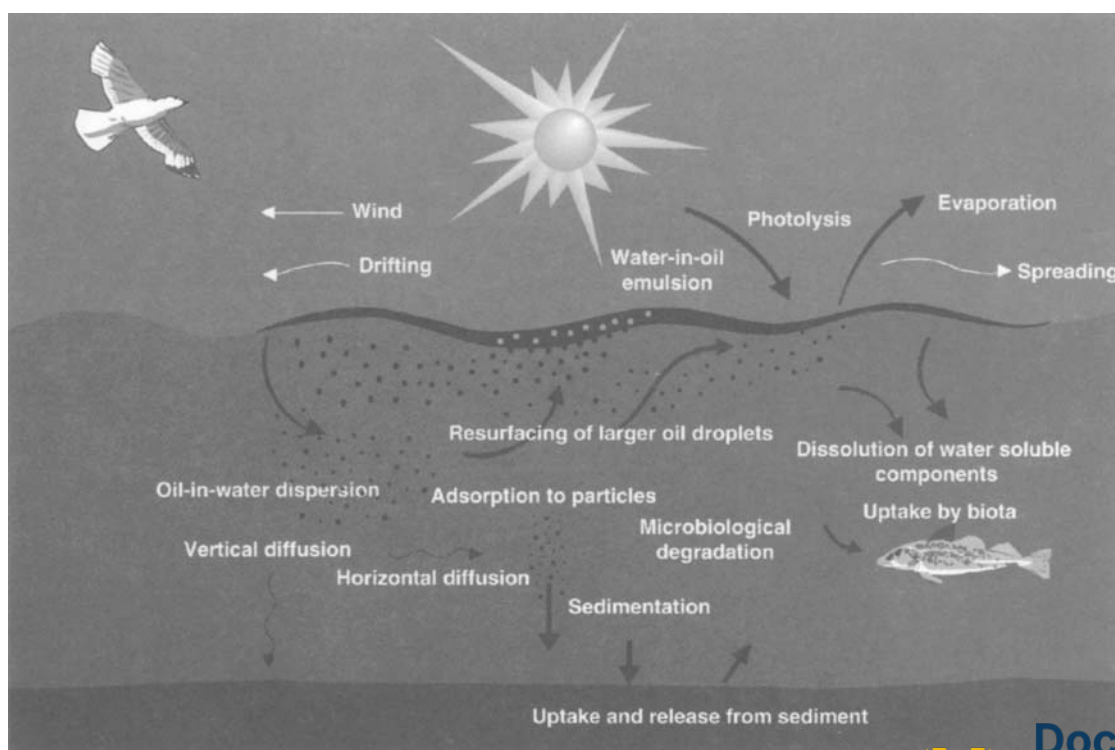
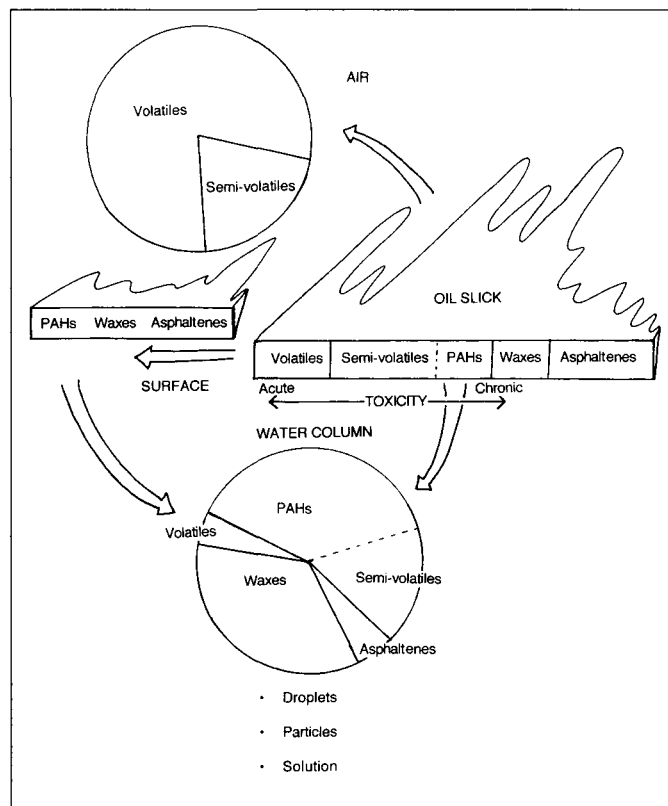


FIGURE 2.
MODIFICATION OF THE CLASSICAL FATE DIAGRAM
FOR SPILLED OIL



visualization, it can give the impression that the materials in the various components are all oil, in the sense of the material originally spilled. This impression is incorrect, but nevertheless influences the way many people perceive oil weathering.

Crude oil is neither a chemical nor a compound. It is a complex mixture of thousands of different compounds that begin to separate as soon as they enter the environment.

Their potential effects in the various media differ. A key concern in clarifying the environmental effects of oil is to overcome this hurdle in communication. Figure 2 represents a modification of the classical fate diagram to attempt to clarify this issue. The major processes important when considering dispersant use are briefly described below.

SPREADING OF SPILLED OIL

Oil spreads rapidly on the sea. Initially, the rate of spreading is controlled by gravity and viscous drag forces (Fay, 1971). The wind exerts a powerful influence as the slick is propelled at about 3.5 percent of the wind speed, leaving a trail of sheen behind it that is caused by the resurfacing of temporarily dispersed oil droplets (Reed *et al.*, 1995; Elliot *et al.*, 1986).

A slick has two distinct regions:

- (i) A large area of thin oil or sheen, 1 micron thick or less, which contains very little of the total volume of oil, typically less than 5 percent.
- (ii) A much smaller area that contains the majority (95 percent or more) of the total oil volume in the form of emulsion that is several millimeters or more thick. If the oil is not capable of forming a stable emulsion, this area will be thinner.

The difference in these areas is not easy to see from a ship in or near the slick because of the oblique viewing angle and the large size of a slick, but may be visible from the air under suitable viewing conditions.

Under the influence of wind and currents, the thickest areas of the slick line up as a series of thin parallel patches called "windrows" (Cormack, 1983). At a later stage in an oil spill incident, the slicks of the thickest oil and water-in-oil (w/o) emulsion will break up into progressively smaller pieces by changing currents and winds. The oil that was released as a single coherent slick becomes a collection of smaller and smaller patches of w/o emulsion spread out over an increasingly large area of sheen or open water (Figure 3).

FIGURE 3.
BROKEN PATCHES OF W/O EMULSION AFTER EXTENSIVE OIL WEATHERING



EVAPORATION

As spilled oil rapidly spreads on the water, the lighter components of the oil evaporate at a rate determined by temperature and wind speed (Stiver and Mackay, 1984). Evaporation is by far the most important process in the first few hours or days after an oil spill. Most crude oils will lose 20 percent to 40 percent of their volume by evaporation. While this reduces the volume of pollution, the residue that remains has a higher viscosity than the original oil (Daling *et al.*, 1990). Evaporation rapidly removes many of the compounds of most concern with respect to toxicity. Components up to C_8 can be expected to be gone after five hours (Betton, 1994) and 50 percent to 70 percent of the amount that will ultimately be lost evaporates within the first 12 hours (McAuliffe, 1989). No. 6 bunker fuel oil only loses a small proportion of its volume by evaporation (Ostazeski *et al.*, 1995) because it contains a much smaller proportion of volatile components.

DISSOLUTION

A small proportion of the components in crude oil is partially water soluble. Dissolution, as a mechanism to remove compounds from an oil slick, is in competition with evaporation. The loss of volatile hydrocarbons to the atmosphere, which proceeds much more rapidly, is a major factor in preventing the buildup of dissolved hydrocarbons in the water column (McAuliffe, 1989). Harrison *et al.* (1975) predicted evaporative rates for aromatic hydrocarbons that were 100 times faster than their rates of solution. The evaporative rate for alkanes was 10,000 times faster. This is supported by the low level of dissolved hydrocarbons present under experimental slicks, where values are generally in the ppb range (McAuliffe, 1989; Brandvik, 1996). Water column concentrations of PAHs in Prince William Sound during the *Exxon Valdez* incident were in the ppb range (Neff and Stubblefield, 1995). Although only a very small proportion of oil components dissolve in the sea, the dissolved components bring toxic hydrocarbons into contact with marine organisms in a bioavailable form (Neff, 1990), albeit in a very limited area and for a brief period of time.

WATER-IN-OIL EMULSIFICATION

Droplets of water can become incorporated into the oil due to the mixing action of the sea. As evaporation proceeds, wax and asphaltene components that were originally in solution in the oil may precipitate in the form of very fine solid particles. These particles are capable of stabilizing in w/o emulsions formed by the incorporation of water into the body of the oil residue that remains after evaporation (Bobra *et al.*, 1992; Walker *et al.*, 1993). The formation of such emulsions is assisted by the presence of natural surfactants in the oil.

The consequences of w/o emulsification are a large increase in pollutant volume (typically by a factor of nearly three compared to the original oil) and more importantly, a very large increase in viscosity, by a factor of 100 or more (Fingas *et al.*, 1995). The stability of the emulsion formed — its resistance to separation into its oil and water constituents — is of immense importance in oil spill response. Some oils produce very stable

emulsions that do not break down under the influence of standing, shearing, heating, or treatment with chemicals. Other oils produce weak emulsions which easily revert to the oil residue and water (Lewis and Walker, 1993; Fingas *et al.*, 1995).

EFFECT OF OIL WEATHERING ON NATURAL DISPERSION

Once a slick has been reduced by evaporation, natural dispersion becomes the most important weathering process (Neff, 1990). Natural dispersion (the conversion of an oil slick into permanently dispersed oil droplets) occurs in the initial stages of spills of low viscosity oils and proceeds rapidly and to a large extent if the sea conditions are very rough. With higher viscosity oils, or in calmer conditions, the rate of natural dispersion is lower and may not proceed significantly before it is slowed or stopped by the effects of oil weathering. The rate of natural dispersion depends on the wave conditions. Breaking waves plunge through the oil film and produce oil droplets of a wide range of sizes (Delvinge *et al.*, 1987). The viscosity of the oil is the crucial factor resisting dispersion (natural or chemically enhanced). As crude oils weather, the viscosity increases due to evaporative loss. A large rise in viscosity caused by the formation of stable w/o emulsions provides a resistance to the break up of the slick by the waves. A lower proportion of small oil droplets is produced by each breaking wave, and the overall rate of natural dispersion rapidly drops. Only the smallest can be considered to be permanently dispersed (Lewis *et al.*, 1985; Lunel, 1993; Fraser and Wicks, 1995). The larger oil droplets resurface. The exact size of droplet where this may occur depends upon the level of turbulent energy near the sea surface. Payne and McNabb (1985a) suggested a limit of 0.1 mm (100 μ m), while Lunel (1995a) defined dispersed droplets as less than 50 μ m and suspended droplets as greater than 70 μ m, which he considered to be the critical size for permanent dispersion.

BIODEGRADATION AND SEDIMENTATION

Ultimately, biodegradation becomes the dominant weathering factor in the environmental compartments where the oil or its constituents are deposited. The hydrocarbons and other compounds found in crude oil are all natural materials and represent a potential energy source for organisms, and all but the most refractory can be degraded by biological processes, especially microbial action. A comprehensive review of biodegradation of petroleum was prepared by Bartha and Atlas (1987). Biodegradation occurs in the water column, in slicks, on the shoreline, and in the sediments. All compounds degrade simultaneously, but the rates for the various components vary considerably. Estimated rates from the literature reported by Neff (1990) ranged from 1 to 10 mg/m³/day in open-ocean waters to 50 mg/m³/day on the intertidal zone of the Brittany coast. Degradation rates in sediments, either subtidal or intertidal, are strongly influenced by temperature and by the availability of oxygen. In very cold, very hot, or anaerobic environments, refractory compounds can remain for decades. While studies of this duration are rare, biodegradation

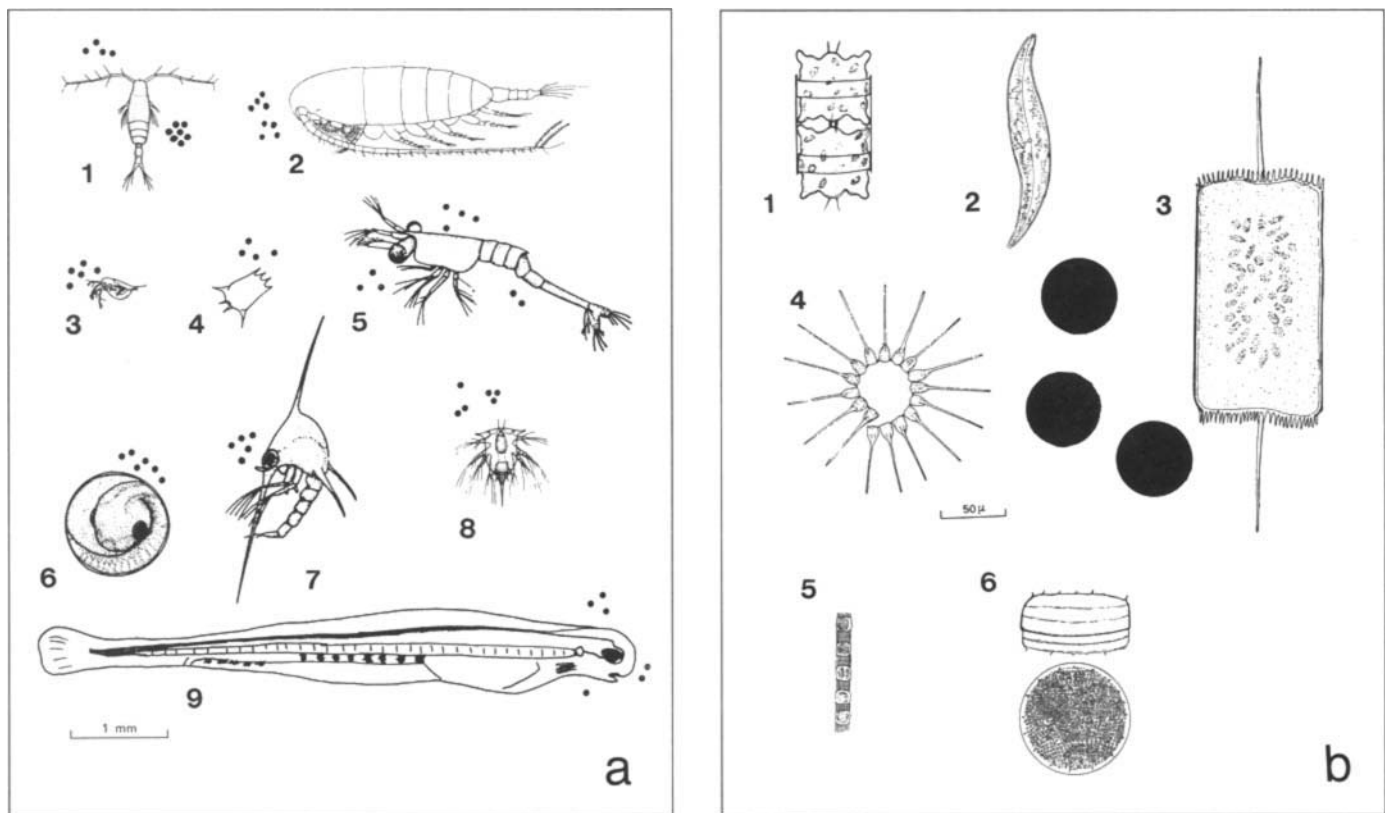
of oil residue has been demonstrated in the Canadian sub-arctic (Owens *et al.*, 1993), a boreal salt marsh in Chile (Sell *et al.*, 1995), a salt marsh in Massachusetts (Teal *et al.*, 1992), and beaches in Saudi Arabia (Hayes *et al.*, 1993). Under most other circumstances, however, the various compounds will steadily be removed from the environment.

Oil adsorption to particles, followed by advective transport, can be a very significant weathering process, depending upon circumstances. Suspended particles (including biological particles such as microscopic organisms) in the water column interact with dispersed oil droplets by physical collision and adherence, or by adsorption of dissolved hydrocarbons from the water phase (Neff, 1990). Figure 4 compares the size of some common planktonic organisms to that of dispersed oil droplets. The affinity of a particle for oil depends upon its chemical and physical properties, as well as those of the oil. Clay and similar-sized particles have a high affinity for oil. The adsorption process is most significant in areas with a high suspended particulate matter load in the water column, or after oil has stranded on the shoreline. Where oil actually strands, the adsorption process in the intertidal zone far out-

weighs any adsorption occurring in the water column. Bragg and Yang (1995) did extensive studies on clay-oil flocculation in Prince William Sound after the *Exxon Valdez* spill, and concluded that stable oil-mineral fines-water complexes were created and stabilized by glacial flour (particles of clays, quartz, and feldspar 1 to 100 μm in diameter). The presence of these aggregates encouraged the removal of oil from the shoreline.

Once oil has been adsorbed onto a particle it may settle to the bottom of the water column, or, if the adsorption occurred as a result of stranding, it may be transported to subtidal sediments. Very heavy (Group V) oils may sink directly to the bottom, as was the case at the *Morris J. Berman* spill involving No. 6 fuel oil (Burns *et al.*, 1995). The ultimate fate of the contaminated particles depends on local conditions. In most instances, oil does not accumulate to any great degree in subtidal sediments in the vicinity of oiled shorelines. This was the case in both Prince William Sound (Bragg and Yang, 1995; Page *et al.*, 1995), and in the area of Saudi Arabian coastline heavily oiled in the Iraq-Kuwait War (Michel *et al.*, 1993).

FIGURE 4.
COMPARATIVE SIZES OF COMMON MICROSCOPIC PLANKTON
AND DISPERSED OIL DROPLETS



ZOOPLANKTON

1. *Acartia* sp. 2. *Calanus finmarchicus* female 3. *Daphnia* sp.
4. *Brachyonus calyciflorus* 5. Peneaid decapod larva 6. Fish egg
7. Decapod zoea larva 8. Nauplius larva 9. Early herring larva

Source: Based on Day *et al.*, 1989; Newell and Newell, 1963.

PHYTOPLANKTON

1. *Biddulphia aurita* 2. *Pleurosigma* sp. 3. *Asterionella japonica*
4. *Ditylum brightwelli* 5. *Skeletonema costatum* 6. *Coscinodiscus excentricus*

SECTION 3

EFFECTIVE DISPERSANT USE

3.1 DEFINITION

The definition of “effectiveness,” when related to dispersant use, means different things to different people. At one level, “effective” dispersant use can be defined as a response that substantially reduces the environmental impact of a spill, compared to that which would have occurred if dispersants had not been used. Dispersant “effectiveness” is also used in more restricted senses; dispersant effectiveness in laboratory tests refers to the proportion (or percentage) of test oil that is dispersed and retained in a water sample under carefully specified (though not necessarily realistic) conditions.

Operationally, effective dispersant use must relate to the degree to which the dispersant use achieves its intended purpose. This is to rapidly remove the spilled oil from the surface of the sea into the water column, with the intention of reducing the overall damage caused by the oil spill. Effective dispersant use, from the operational point of view, is therefore rapid removal of oil from the sea surface. This will occur if the correct amount of dispersant is accurately applied to the oil before weathering reduces the dispersant’s effectiveness.

3.2 EFFECT OF OIL WEATHERING ON CHEMICALLY ENHANCED DISPERSION

Dispersants reduce an oil’s resistance to dispersion by the prevailing wave action by two mechanisms:

- (i) Reducing the interfacial tension (IFT) between the oil and water (Canevari, 1985). Reducing the IFT to a very low level permits the waves to produce a greater proportion of very small (permanently dispersed) oil droplets, providing that the oil is of low enough viscosity, or the sea is rough enough.
- (ii) Breaking emulsions, especially those that are not particularly stable, even though the emulsion may be of high viscosity (Lewis *et al.*, 1994). The increase in viscosity caused by emulsification can be slowly reversed by the addition of dispersant.

Laboratory tests are used as a guide to the dispersibility of a crude oil and how this changes with time. If the viscosity of an oil is high or if the oil is semi-solid, for example heavy bunker fuel oils or waxy crude oils at low temperature, the reduction in IFT will not be sufficient to cause an enhanced rate of dispersion. Many attempts have been made to define a

common limiting viscosity for successful dispersion (Cormack, 1983). Values of around 2,000 cP are often quoted, but cannot be generally applicable to all oil types because of the complicated flow behavior of many oils (Mackay *et al.*, 1993) and of all w/o emulsions (Buist *et al.*, 1994). The composition of each crude oil is different, and each behaves in a different way. Some viscosity limits have been derived using laboratory tests that do not simulate all aspects of the dispersion process that happens at sea. The limits are therefore not accurate.

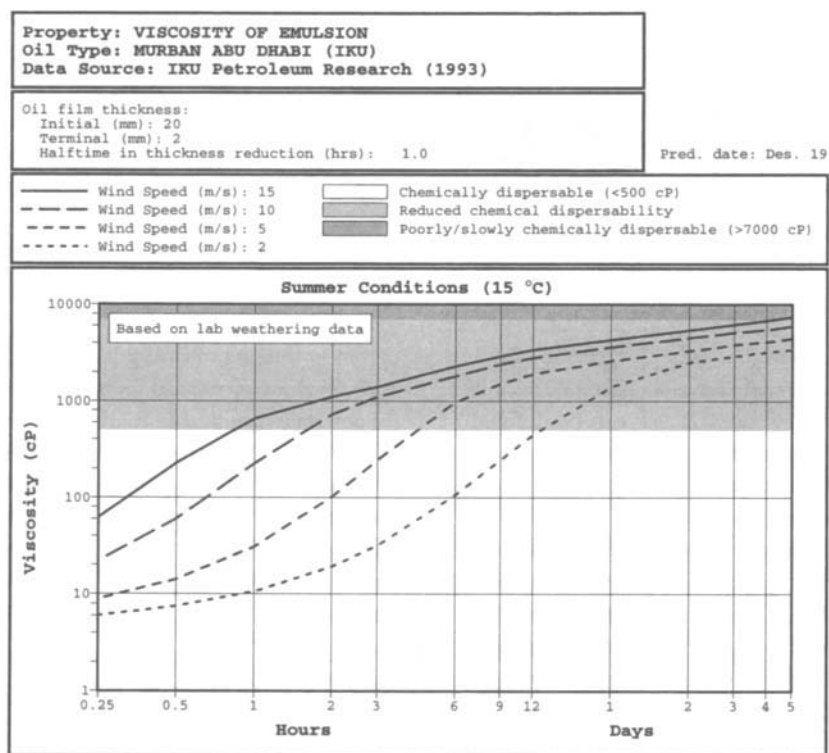
3.3 THE WINDOW OF OPPORTUNITY FOR DISPERSANT USE

Practical experience at oil spill incidents and evidence from extensive laboratory test work has shown that oils that are initially amenable to dispersants become more difficult to disperse as the oil weathers. It has always been acknowledged that dispersants are more effective if they are used promptly. However, it is not possible to determine a precise time limit that is relevant to all oils and all dispersants. There is a window of opportunity for the use of dispersants that varies with oil type (Nordvik *et al.*, 1995; Daling *et al.*, 1990). Some oils become difficult to treat very rapidly, while others remain amenable for much longer.

Figures 5 and 6 illustrate the windows of opportunity at a range of wind speeds for the use of a particular dispersant on Murban crude oil at 15°C and Bonny Light crude oil at 5°C. Bonny Light crude oil becomes non-dispersible within hours, yet Murban crude oil is easily dispersible for a long time and “of reduced dispersibility” for days.

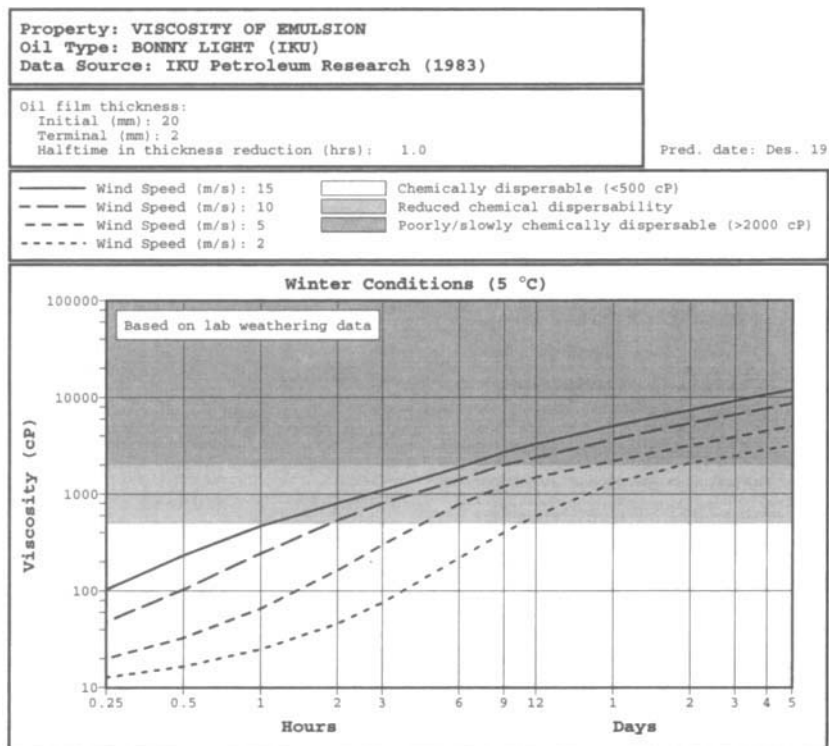
The dispersibility limits, as measured in the laboratory for the particular oil and dispersant combination, are superimposed on the predicted increase in w/o emulsion viscosity caused by the combination of all the weathering processes. The potential effectiveness of dispersants is divided into three categories — “easily dispersible,” “of reduced dispersibility,” and “poorly or slowly dispersible.” Accurate application of dispersant while the oil is in the “easily dispersible” condition will produce rapid dispersion (within a few minutes). If applied when the oil is “of reduced dispersibility” the dispersant will produce slower, but effective dispersion. These limits are derived from laboratory tests and are known to be conservative (Lewis *et al.*, 1994). The information is intended to

FIGURE 5.
CHANGE IN W/O EMULSION VISCOSITY AND DISPERSIBILITY OF MURBAN CRUDE OIL AT 15°C



Source: IKU Petroleum Research.

FIGURE 6.
CHANGE IN W/O EMULSION VISCOSITY AND DISPERSIBILITY OF BONNY LIGHT CRUDE OIL AT 5°C



Source: IKU Petroleum Research.

be used as a guide in oil spill contingency planning, i.e., to decide whether or not dispersants are a feasible response option. It is therefore better to err on the side of caution rather than indicating that dispersants will work when they may not. The information is not intended to dictate operational dispersant spraying. Observations, preferably measurements from monitoring, should be made in the field.

Weathering begins as soon as the oil is released onto or into the sea. For a rapid or nearly instantaneous spill (catastrophic rupture of tanks on an oil tanker following a collision, for example) almost all the oil weathers at the same rate. However, with a slower rate of oil release (a pipeline leak, a blow-out, or oil escaping at a slow rate from a damaged tanker, such as occurred at the *Sea Empress* incident) the starting point of the window of opportunity for dispersant use is from when the oil is released — not from when the incident occurred. This has important implications for dispersant use strategy. Success is more likely if dispersants are used on relatively “fresh” oil that has recently spilled, rather than on highly weathered oil.

3.4 PLANNING FOR DISPERSANT USE

The use of mechanical recovery versus dispersants is often discussed as an either/or option. When allocating effort, time, and money to an oil spill contingency plan, the possibility should be considered of using outside resources with different response philosophies. Dispersants and mechanical recovery can be used in combination, although not simultaneously in the same area of the slick.

Dispersants are one of several responses to an oil spill, along with containment and recovery using booms and skimmers, *in-situ* burning, etc., which should be evaluated during the oil spill contingency planning process (IPIECA, 1991). Typically this planning process will consider the environmental consequences of no response action to establish a damage baseline which is then compared to the consequences of alternative response actions. The aim of any response is to reduce the total environmental, amenity, or economic resource damages caused by the oil spill.

THE QUESTION OF RISK AND SCALE

Massive oil spills can overwhelm the resources available to respond to them. It is not possible to plan for the total loss of a super tanker at all the possible locations where it might occur. The planned response effort must be proportional to the perceived risk. The majority of NCPs are not capable of dealing with the very biggest oil spills that have occurred. Most NCPs can deal with spills of 5,000 to 15,000 tonnes of spilled oil. Very large oil spills are rare; only eight have involved over 100,000 tonnes in the last decade (ITOPF, 1996), and significant impact on the coastline only arises if the bulk of the oil is carried ashore by currents or wind. The majority of oil spills are small (<7 tonnes) and caused by routine operations such as loading, discharging, and bunkering. Incidents involving collisions and grounding of tankers generally give rise to oil spills of ≥ 700 tonnes. Dispersion may be an even more acceptable response option to small and medium ($\leq 1,000$ tonnes) spills. The amount of oil transferred into the water column is limited, and the potentially undesirable effects are confined to a small area. The desirability of dispersion on a very large scale has often been questioned, although there is no evidence that the very large amount (84,000 tonnes) of oil that was naturally dispersed at the *Braer* incident will have unacceptable environmental consequences (ESGOSS, 1994). As explained in Chapter 3, spill size has serious logistical implications that may dictate the ultimate decision of whether and how to employ dispersants.

ACCEPTABILITY OF DISPERSANTS

The rationale for using oil dispersants must be based on the judgment that dispersing the oil has greater net environmental benefit than leaving it to come ashore at a later stage (Baker, 1995). The use of ecological risk assessment is crucial to this judgment. Whether the use of dispersants is desirable or appropriate in a particular spill scenario needs to be addressed with respect to likelihood of success, alternative response techniques, and environmental consequences. This issue needs to be thoroughly investigated before the operational aspects of dispersant use are contemplated in the planning process.