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International
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Dispersants: surface application

Good practice guidelines for incident management and emergency response personnel

IPIECA

The global oil and gas industry association for environmental and social issues

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Dispersants: surface application

Good practice guidelines for incident management and emergency response personnel

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USDA; Oil Spill Response Limited; US Air Force

Preface

This publication is part of the IPIECA-IOGP Good Practice Guide Series which summarizes current views on good practice for a range of oil spill preparedness and response topics. The series aims to help align industry practices and activities, inform stakeholders, and serve as a communication tool to promote awareness and education.

The series updates and replaces the well-established IPIECA 'Oil Spill Report Series' published between 1990 and 2008. It covers topics that are broadly applicable both to exploration and production, as well as shipping and transportation activities.

The revisions are being undertaken by the IOGP-IPIECA Oil Spill Response Joint Industry Project (JIP). The JIP was established in 2011 to implement learning opportunities in respect of oil spill preparedness and response following the April 2010 well control incident in the Gulf of Mexico.

The original IPIECA Report Series will be progressively withdrawn upon publication of the various titles in this new Good Practice Guide Series during 2014–2015.

Note on good practice

'Good practice' in the context of the JIP is a statement of internationally-recognized guidelines, practices and procedures that will enable the oil and gas industry to deliver acceptable health, safety and environmental performance.

Good practice for a particular subject will change over time in the light of advances in technology, practical experience and scientific understanding, as well as changes in the political and social environment.

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Executive summary

The use of oil spill dispersants is one of several possible at-sea response techniques that remove floating spilled oil. Dispersant use can be an effective way of minimizing the overall ecological and socio-economic damage, by preventing oil from reaching coastal habitats and shorelines and enhancing the natural biodegradation processes that break down oil.

Dispersant use greatly enhances the rate and extent of natural dispersion and dilution of oil caused by wave action. The surfactants in dispersant allow the mixing energy of the waves to convert a greater proportion of the oil into small oil droplets. These droplets are pushed into the upper water column by wave action and maintained there by turbulence. The dispersed oil droplets are much more available to naturally-occurring hydrocarbon-degrading microorganisms compared to floating or stranded oil.

Like all techniques in the oil spill response toolkit, while dispersant use has some limitations, it has capabilities that make it particularly useful in responding to larger oil spills at sea. Most crude oils will be amenable to dispersant use, but the effectiveness of the dispersant will decrease with increased oil viscosity caused by oil 'weathering'.

In comparison with the other spill response tools, surface dispersant use can often be the most rapid and effective technique to remove floating oil:

- Spraying dispersants from aircraft enables large areas of floating oil to be dispersed into the sea within a relatively short time.
- Aerial application capability can respond to remote locations relatively quickly.
- There is reduced exposure and safety risk to response personnel.
- Dispersants can be used in sea conditions that are too rough for the effective use of either at-sea containment and recovery or controlled in-situ burning of oil.

Planning is an essential process for dealing effectively with potential oil spills. In order that dispersants can be a viable response option, they need to be available without delay. It is therefore important to consider the various aspects of dispersant use in oil spill contingency planning. Net environmental benefit analysis (NEBA) is part of the planning process and is used by the response community for making the best choices to minimize impacts of oil spills on people and the environment. The NEBA case for dispersant use on spilled oil in waters of depths greater than 10 or 20 metres is generally clear: the potential benefits are large and the potential for damage is very small, due to the rapid dilution of the dispersed oil in a large volume of water. Where spilled oil is in waters less than 10 or 20 metres deep, one should examine the suitability of dispersant use more closely.

Dispersant spraying using specially-equipped aircraft.


Oil Spill Response Limited

There is a potential risk of dispersed oil causing marine organisms inhabiting the upper water column to be briefly exposed to diffuse clouds of dispersed oil droplets and water-soluble oil compounds, to a greater extent than if dispersants were not used. This exposure to dispersed oil can potentially have toxic effects on marine organisms.

Oil Spill Response Limited

Dispersant spraying from a vessel-mounted spraying arm.

It is appropriate for countries to develop regulations regarding dispersant use. These normally consist of two parts:

1. **Dispersant product approval regulations:** these describe which dispersants would be approved for use in national waters, and ensure that these products are both effective and of relatively low toxicity compared to oil.
2. **Dispersant use authorization regulations:** these define where and when approved dispersant products may be authorized, including pre-authorization, for use on spilled oil in national waters.

Dispersant use is an established and proven technique which is part of the response toolkit and can make a major contribution to minimizing the ecological and socio-economic impacts of marine oil spills.

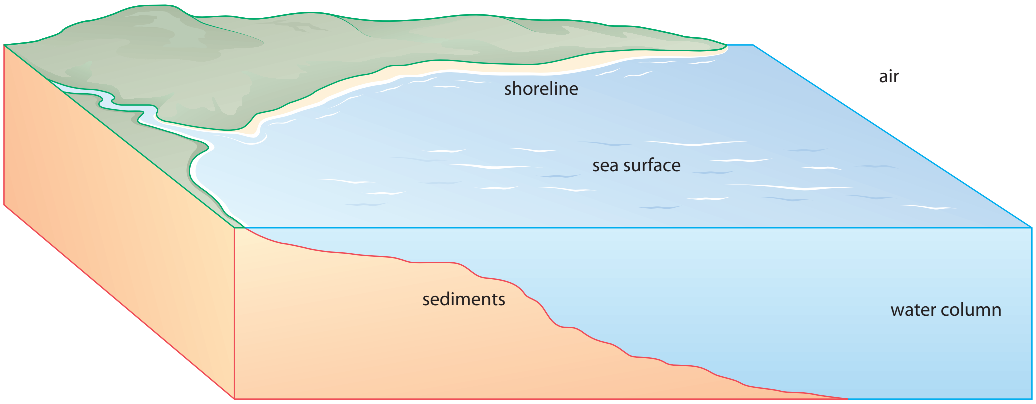
The role of dispersant use in oil spill response

The use of oil spill dispersants is one of several possible at-sea response techniques. Dispersant use can be a useful way of minimizing an incident's overall damage by removing oil from the sea's surface, preventing it from reaching coastal habitats and shorelines and enhancing the natural biodegradation processes that break down oil. Like all techniques in the response toolkit, dispersant use has some limitations, but also has capabilities that make it particularly useful in responding to larger oil spills at sea.

Fate of spilled oil in the environment

Oil spills often generate a great deal of concern about their potential effects on the environment. The environment that may be affected by spilled oil consists of several compartments: air, shoreline, sea surface, water column and sediments (see Figure 1).

Figure 1 *Environmental components at potential risk from spilled oil*



Each of these compartments, with the exception of air (which may have importance for responder and community exposure), may contain a variety of different habitats, each with its own populations of species and individuals.

Natural processes cause spilled oil, or its chemical components, to be transferred from one environmental compartment to another:

- Evaporation transfers the more volatile components from the oil into the air.
- The limited proportion of oil components that are water-soluble will dissolve into the water column.
- The action of breaking waves will transfer some oil from the sea surface into the water column as small oil droplets; this is known as natural dispersion.
- Spilled oil that is naturally dispersed into the water column in shallow water by waves in the surf-zone may become incorporated into near-shore sediments.
- Spilled oil on the sea surface will drift under the influence of the wind and current and may strand ashore.
- Oil can eventually become negatively buoyant by loss of volatile components, emulsification, biodegradation and interaction with sediments suspended in the water column, and sink to the seabed.

Potential effects of spilled oil

Oil spilled at sea can potentially have negative effects on a variety of ecological and socio-economic resources, depending on the environmental compartment in which it has been spilt. Further information is provided in the IPIECA-IOGP Good Practice Guides on marine and shoreline ecology (IPIECA-IOGP, 2015, 2015a).

Air

Oil compounds evaporating from a large spill of crude oil on the sea surface and into the air can pose a fire or explosion risk, but this diminishes quickly as the concentration of these components in the air is rapidly diluted. Exposure of responders to potentially harmful vapour from spilled oil can be controlled by using appropriate personal protective equipment (PPE), and/or reduced by the use of dispersants to remove the floating oil. See the IPIECA-IOGP Good Practice Guide on oil spill responder health and safety (IPIECA-IOGP, 2012).

Sea surface

Spilled oil floating on the sea surface poses risks to ecological resources such as seabirds and marine mammals. The plumage of seabirds that land in, or dive through, the oil will be contaminated with oil. This reduces the insulation properties and can lead to death by hypothermia. Floating oil may be persistent and serve as a long-term source of hydrocarbon contamination in the upper water column. Oil on the sea surface can foul fishing vessels and their equipment, supporting the need for a fishing ban and thus impacting the livelihoods of fishermen. Water recreation activities can be either prevented or disrupted by oil on the sea surface.

Water column

Water-soluble oil components and naturally dispersed oil droplets from a surface oil slick will move into the water column, where experience has shown that concentrations will decline rapidly in open water due to dilution caused by currents and tides. Oil slicks that spread over large areas and persist for significant periods of time, however, can continually transfer oil into the water column, and this may cause longer-term toxic effects and contaminate marine life. Economically-exploited marine life can become 'tainted', making it unsuitable for commercial and recreational purposes. Temporary fishing bans are often implemented when a large oil spill occurs, as a precautionary measure and to protect seafood market confidence. This has an impact on the incomes and livelihoods of fishermen.

Sediments

Naturally dispersed oil droplets that become incorporated into near-shore sediments can result in long-term exposure of the organisms that inhabit the mud and sediment.

Shoreline

Spilled oil on the sea surface will often drift into shallow water and ashore, and may contaminate coastal habitats including particularly oil-sensitive mud-flats and wetlands. Photos or video in the

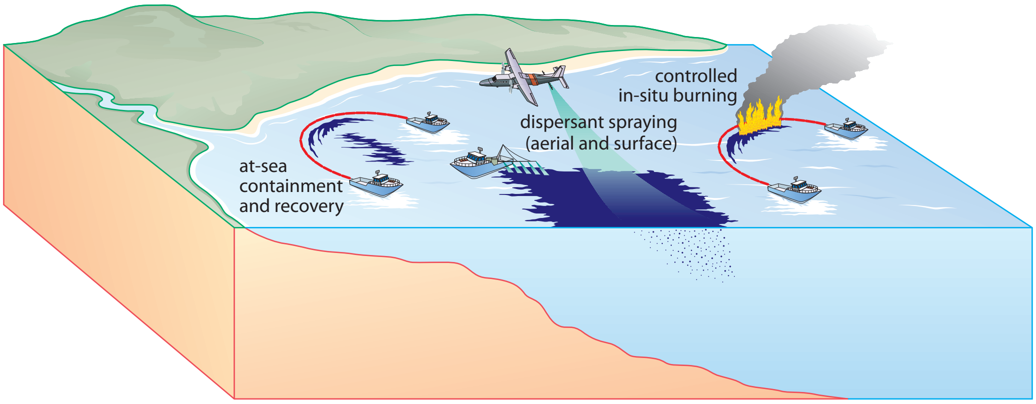
Above: examples of the wide range of ecological and socio-economic resources that may be affected by oil spills.

media of distressed and dying seabirds covered in oil that washed ashore are stark images of the effects of oil spills. Spilled oil can smother shoreline organisms. Oil trapped in shoreline substrates can be a source of long-term exposure to shoreline organisms and can be the cause of long-term toxic effects. Spilled oil drifting onto a tourist beach will render it unusable and this can have an impact on the income of those whose livelihoods depend on tourism. Shoreline economic features such as seawater intakes or ports and harbours can also be severely disrupted by oil drifting ashore. Stranded oil presents a potential oil exposure route for the community and responders involved in shoreline clean-up.

Response techniques

Deployment of any technique in the response toolkit should aim to minimize the damage that could be caused by spilled oil if no response was undertaken. The goal of offshore oil spill response techniques is to remove the floating oil, sometimes transferring it to another compartment, to reduce the potential damage from the spill.

Figure 2 *The three primary at-sea response techniques for responding to a surface oil spill*



The three primary at-sea response techniques for responding to a surface oil spill are containment and recovery, aerial and surface dispersant spraying and controlled in-situ burning (Figure 2).

- **At-sea containment and recovery of spilled oil with floating barriers (booms) and collection using recovery devices (skimmers):** recovered oil is stored for subsequent processing or disposal.
- **Controlled in-situ burning:** oil is corralled in fire-resistant booms and ignited. Controlled in-situ burning converts the floating oil into airborne combustion products (primarily as carbon dioxide and water vapour with small amounts of soot and other gases) which are rapidly diluted.
- **Dispersant application:** transfers the floating oil into the water column as small droplets. The dispersed oil is rapidly diluted to low concentrations in the water. The majority of the oil in these droplets will subsequently be biodegraded by hydrocarbon-degrading organisms. The ultimate fate of most of the oil is to be biologically converted to carbon dioxide and water.


USCG USCG MSRC

Examples of the three main offshore oil spill response techniques (left to right): containment using booms; controlled in-situ burning; and dispersant spraying.

The principle of the response is the same for each one of these techniques: to prevent or limit the contact of the spilled oil with the ecological and socio-economic resources that might be affected. In many cases, the most oil-sensitive ecological resources are those in coastal waters or on shorelines, and the aim of the response is to prevent or limit spilled oil from reaching these resources. A further consideration is to protect human health by minimizing the exposure of responders and local communities to oil. This is achieved by removing oil from the sea's surface and preventing it from reaching the shorelines.

Table 1 compares key operational features of the primary at-sea response techniques (see also *Capabilities and limitations* on page 18). Dispersant use can be the most rapid and effective response to remove floating oil during oil spills at sea because:

- spraying dispersants from aircraft enables large areas of floating oil to be treated and dispersed into the sea within a relatively short time (see *How dispersants are applied* on page 43); and
- dispersants can be used in sea conditions that are too rough for the effective use of booms and skimmers or controlled in-situ burning.

Table 1 *Key operational features of the primary at-sea response techniques*

Factor	Containment and recovery	Controlled in-situ burning	Dispersant use
Rate at which spilled oil can be encountered	Low	Low	High
Spilled oil removal rate	Low	High during burn	High
Limiting prevailing conditions	Possible up to wind speed of 20 knots and maximum wave height of 2.5 metres	Possible up to wind speed of 10 knots and wave height of <1 metre	Aerial application possible up to a wind speed of 35 knots and wave height of 5 metres
Oil type and properties	Need to match skimmer to changing viscosity	Oils that have lost lighter fractions and emulsified oils are difficult to ignite	High-viscosity oil may be challenging to disperse, plus possible pour point limitation

Right: a spill of marine diesel will naturally disperse and evaporate offshore without the need for intervention.


USCG

In some circumstances, no active response may be needed. A spill of a small amount of a non-persistent oil, such as marine diesel fuel, far out at sea will be naturally dispersed and will dissipate, and the response will be limited to monitoring.

Protective booming, the deployment of stationary booms close to threatened resources, is often used in addition to an oil spill response at sea. This recognizes that no response at sea is likely to remove all of the floating oil. It is inevitable that, in most incidents involving large volumes of oil, or oil spilled close to the coast, some oil will eventually drift ashore and will need to be cleaned up.

Each of the response techniques in the toolkit has strengths and weaknesses that make one or other more or less appropriate for the prevailing circumstances of a particular oil spill. It may be appropriate to use a variety of techniques simultaneously in different locations. Net environmental benefit analysis (NEBA) provides a systematic process for decision making and a basis for selecting the response technique, or combination of techniques, that will result in the lowest overall negative impact of spilled oil on threatened environmental and socio-economic resources. NEBA is discussed in more detail in the section on contingency planning on pages 36–42.

Dispersants and how they work

Two natural mixing processes, caused by the action of waves, can occur when spilled oil is on the sea surface. These processes are natural dispersion and the formation of water-in-oil emulsions; both are relevant to the behaviour of spilled oil and the effectiveness of all response techniques, including dispersant use.

Natural dispersion

A thin layer of spilled oil on the sea surface will be broken up as breaking waves pass through it. The oil layer in the wave-affected area will be converted into oil droplets with a wide range of sizes (Delvigne, 1985; Delvigne and Sweeney 1988). These oil droplets are pushed into the top few metres of the water column by the waves. The oil droplet size distribution produced depends on the:

- **energy of the wave:** this describes the power or strength and size of a wave;
- **viscosity of the oil:** this is oil's resistance to flow, a measure of how 'runny' the oil is; this property is temperature dependent (i.e. lower temperatures lead to higher viscosity); and
- **oil-water interfacial tension (IFT):** the IFT creates a contracting force (a tension) that minimizes the interfacial area between the oil and water, and therefore produces generally large oil droplets when the oil is mixed into water. Larger droplets have a smaller surface area per volume of oil than small droplets.

The majority of the oil droplets produced by the breaking wave action will have diameters of substantially more than 0.05 to 0.1 mm (50–100 microns) and float back up to the sea surface rapidly. Smaller oil droplets rise more slowly due to their lower buoyancy (Delvigne *et al.,* 1987). Breaking waves result in a low proportion of these smaller oil droplets (Lunel, 1995b; Daling *et al.,* 1990b). They tend to be retained in the upper water column by the turbulence that is produced beneath the waves in moderate sea states (Csanady, 1973). This oil is said to have been naturally dispersed into the water column.

Natural dispersion takes place in moderately rough seas with breaking waves and winds above 10 knots (circa 5 m/s). If the sea is very rough, natural dispersion can determine the fate of the majority of the spilled oil. For example, the severe storm conditions during the grounding of the tanker *Braer* off the Shetland Isles, UK in 1993 caused almost all of the 85,000 tonnes (630,000 bbls) of Gullfaks crude oil to be naturally dispersed with minimal shoreline impact (ESGOSS, 1994; Lunel, 1995; Davies *et al.,* 1997) and limited impact on the fisheries (Goodlad, 1996). Another example of natural dispersion is the grounding of the *North Cape* tank barge in the USA during 1996. Conditions were a wind speed of 60 mph (52 knots) and waves of 15–20 feet (3–5 metres). The incident resulted in a spill of 19,700 bbls (3,000 tonnes) of home heating oil (No. 2 fuel oil). This incident had a substantial impact on near-shore fisheries (Michel *et al.,* 1997).

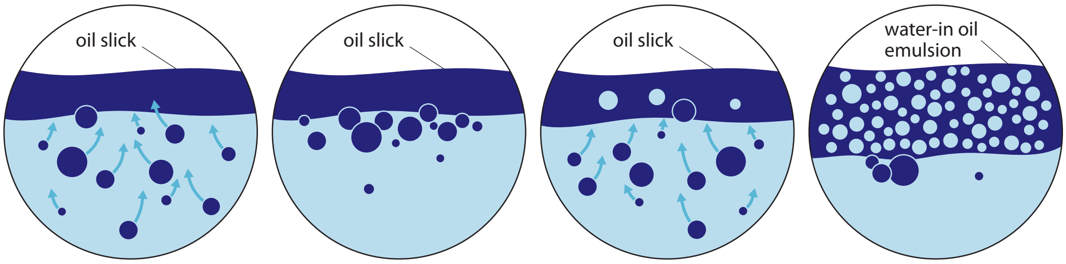
Severe weather led to the majority of the crude oil cargo from the Braer to be naturally dispersed.


RSPB

Water-in-oil emulsification

The flexing action of the waves on the floating oil layer and the resurfacing of the larger oil droplets that were only temporarily dispersed causes small water droplets to become entrained in the oil. The water droplets are stabilized and prevented from coalescing with each other by the precipitation of asphaltenes that are present in crude oils and residual fuel oils (but not in distillate fuels). The result is a water-in-oil emulsion (Bridie *et al.,* 1980; Bobra, 1991).

Figure 3 *Schematic illustration of the emulsification process*



Waves cause naturally dispersed oil droplets to resurface.

Resurfacing oil droplets trap seawater.

Subsequent waves bring more oil droplets to the surface; oil and trapped water begin to mix.

Numerous waves cause mixing of oil and water, which creates a water-in-oil emulsion.

Over a period of hours and days, the proportion of water entrained within the oil can rise to 75%, increasing the volume of water-in-oil emulsion by up to four times the original volume of oil alone (Sjoblom *et al.,* 2003). The viscosity of the emulsion formed will be much higher, by a factor of 100 or more, than that of the original oil. The formation of water-in-oil emulsions stops the natural dispersion process; the viscosity becomes too high for any small oil droplets to be formed by the action of breaking waves.

History of dispersants

At the time of the *Torrey Canyon* oil spill in the UK in 1967 there were no true oil spill dispersants. Very large quantities (approximately 11,000 tonnes) of industrial detergents were used to clean oil from sand and rocky shorelines. Some detergent was used offshore to try to disperse the oil into the sea. The effect was dramatic:

> '*The detergent used to treat the oil away from the coast was not noticeably injurious to marine life except in the extreme surface layers, where pilchard eggs and some phytoplankton were affected. The direct treatment of polluted shores, however, resulted in the death of a large number of shore organisms of many different kinds, and effects were also observed in the sublittoral (shallow costal water) zone.*'

Torrey Canyon Pollution and Marine Life, J. E. Smith (Editor), 1968.

The detergents were toxic to marine life on the shoreline (Corner *et al.,* 1968) and recovery was slow (Southward and Southward, 1978). The first true oil spill dispersants, with much lower toxicity, became available in the early 1970s. They were blends of 15 to 25% of surfactants (see Box 1 on page 15) in a solvent of low-aromatics ('odourless') kerosene. Compared to the dispersants available today, they were not very effective and had to be used at a high treatment rate of 1 part dispersant to 2 to 3 parts of spilled oil. This type of dispersant is now known as UK Type 1 dispersant, or 'hydrocarbon-based' dispersant. Such dispersants are not approved for use in many countries since they have been superseded.

All dispersant-spraying at that time was from boats or ships. Dispersant-spraying operations were relatively inefficient because of the high treatment rate of dispersant that was required. The spray gear available at the time could only spray low viscosity liquids and could not spray more concentrated (higher surfactant content), and therefore higher viscosity, dispersants. Spray-gear was developed that allowed the 'concentrate' dispersant (with up to 50% of surfactant) to be diluted with seawater just prior to spraying. The seawater was pumped through an eductor which draws and mixes in dispersant before the spray nozzle. These dispersants were used as 1 part of diluted dispersant (10% concentrate dispersant plus 90% seawater) to 2 to 3 parts of spilled oil. These are now known as UK Type 2 dispersants, or 'water-dilutable concentrate' dispersants.

During the mid- and late-1970s the capability to spray dispersants from aircraft, both helicopters and fixed-wing, was developed. Much more effective dispersants were formulated and suitable spraying systems developed. These modern dispersants were effective when used at 1 part of dispersant to 20 to 30 parts of spilled oil; they are at least 10 times more effective than the first true Type 1 oil spill dispersants. These are now known as UK Type 3, or 'concentrate' dispersants.

During the 1980s and 1990s new formulations of dispersant were developed. Some of these have demonstrated effectiveness on emulsified and heavier oils. All of these modern dispersants are far more effective and less toxic than earlier types.

Composition of modern dispersants

Surfactants in modern dispersants

The precise formulations of most dispersants are proprietary information. However, the formulation details may be shared, in confidence, to national regulators as part of the dispersant listing or approval process. Most dispersants consist of a blend of two or three nonionic surfactants (Brochu *et al.,* 1986) and sometimes include an anionic surfactant (Brandvik and Daling, 1998). Most modern surfactants used in dispersants are also widely used in household products, e.g. soaps, shampoo, detergents, etc.

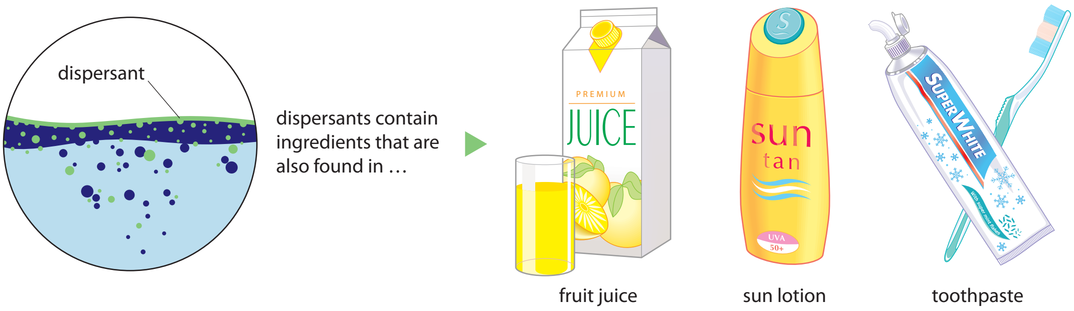
The ingredients list of the widely stockpiled COREXIT® dispersants has been published by their manufacturer, as shown in Table 2 on page 14.

Table 2 *Ingredients list of the widely stockpiled COREXIT® dispersants, as published by the manufacturer*

Chemical abstracts service number	Name	Generic name	Examples of common, day-to-day use
1338-43-8	Sorbitan, mono-(9Z)-9-octadecenoate	Span	Skin cream, body shampoo, emulsifier in juice
9005-65-6	Sorbitan, mono-(9Z)-9-octadecenoate, poly(oxy-1, 2-ethanediyl) derivatives	Tween	Baby bath, mouth wash, face lotion, emulsifier in food
9005-70-3	Sorbitan, tri-(9Z)-9-octadecenoate, poly(oxy-1, 2-ethanediyl) derivatives	Tween	Body/face lotion, tanning lotions
577-11-7	Butanedioic acid, 2-sulfo-, 1,4-bis(2-ethylhexyl) ester, sodium salt (1:1) [contains 2-Propanediol]	DOSS	Wetting agent in cosmetic products, gelatin, beverages
29911-28-2	Propanol, 1-(2-butoxy-1-methylethoxy)	Glycol ether solvent	Household cleaning products
64742-47-8	Distillates (petroleum), hydrotreated light	Hydrocarbon solvent	Air freshener, cleaner
111-76-2	Ethanol, 2-butoxy [NOT included in the composition of COREXIT® 9500]	Glycol ether solvent	Cleaners

Some of the most widely used non-ionic surfactants have a hydrophilic part based on sorbitan (derived from sorbitol, a sugar) and an oleophilic part based on a fatty acid (a vegetable oil) (Al-Sabagh *et al.,* 2007). These non-ionic surfactants have the generic trade name of 'Spans'. Other non-ionic surfactants used are generically known as 'Tweens', and these are ethoxylated sorbitan esters. Spans and Tweens have applications in the pharmaceutical, cosmetic, food and agrochemical industries. The anionic surfactant used in many modern dispersants is sodium diiso-octyl sulphosuccinate (sometimes referred to as DOSS). This surfactant is also used in many household products, such as cleaners and health products.

Figure 4 *Dispersants contain the same ingredients used in many household goods*



Box 1 *Surfactants*

Surfactants are surface active substances used in numerous cleaning applications. Surfactant molecules have two linked parts: a hydrophilic ('water-loving') part connected to an oleophilic ('oil-loving') part. Surfactants can be classified into various groupings such as anionic (with a negatively charged hydrophilic part), non-ionic (with a non-charged hydrophilic part), cationic (with a positively charged hydrophilic part) or amphoteric (combining cationic and anionic in the same molecule). There are thousands of commercially-available surfactants. They are the active ingredients in many household products such as soaps, shampoos, food additives, cosmetics, cleaners and detergents. No surfactants are manufactured specifically for use in dispersants.

The function of surfactants

The function of surfactants in most applications is to lower the interfacial tension (IFT) between two fluids. Surfactants used in common cleaners reduce the surface tension of the water (also called the air/water IFT) so the water can more effectively wet the fibres and surfaces to be cleaned. They loosen and encapsulate the dirt, which ensures that the dirt will not be re-deposited on the surfaces.

Surfactants used in dispersants reduce the oil/water IFT by becoming orientated at the oil/water interface. The oleophilic part of the surfactant molecule is in the oil and the hydrophilic part is in the water. The surfactant forms a 'bridge' between the oil and water. The interface between the oil and the water is now occupied by the surfactants and this reduces the oil/water IFT by around 30 times if a modern, well-formulated dispersant is used.

Solvents in modern dispersants

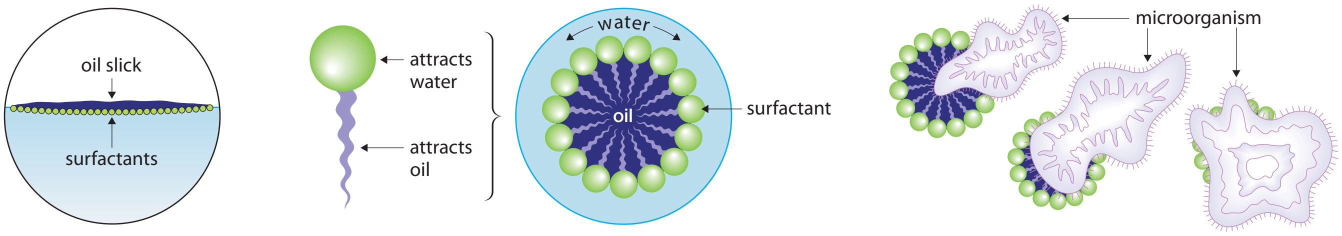
Solvents used in modern dispersants include glycol ethers, hydrocarbon and water (Fiocco *et al.,* 1995). A solvent is necessary to produce a liquid dispersant that can be easily sprayed. Many surfactants are high viscosity liquids and/or solids, so they need to be blended into a solvent to produce a dispersant of relatively low viscosity. The solvent also helps the surfactant to penetrate into the spilled oil.

Mechanism of dispersant action

Dispersant use enhances the rate and extent of natural dispersion caused by wave action (Canevari, 1969; Fiocco and Lewis, 1999; Lessard and DeMarco, 2000).

When dispersant is sprayed onto floating spilled oil the dispersant soaks into the oil. The surfactants in the dispersant migrate to the oil/water interface and orientate so that the hydrophilic part of the surfactant molecule is in the water and the lipophilic part of the surfactant molecule is in the oil. This surfactant orientation greatly reduces the oil/water IFT enabling the mixing energy from a breaking wave (or other energy input) to convert a much higher proportion of the dispersant-treated oil volume into small oil droplets. These oil droplets, with maximum diameters of 0.05 to 0.1mm (50 to 100 microns) or less (Mukherjee *et al.,* 2012), are pushed into the upper water column by wave action and are briefly visible as a light-brown ('café au lait') cloud in the water, if viewing conditions are suitable. The small droplets rise slowly back towards the sea surface and are pushed back into the water column by each successive breaking or non-breaking

Figure 5 *How dispersant products work*



Surfactants reduce the interfacial tension between oil and water so that oil slicks can break apart.

Surfactants are comprised of two parts; the molecules attract water on one end, and oil on the other.

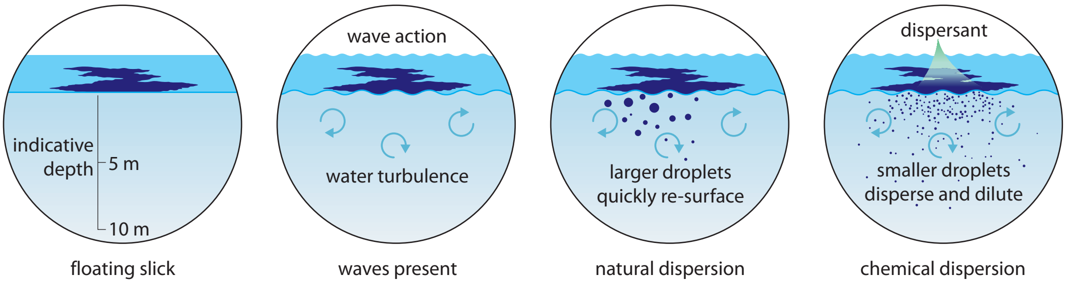
Microorganisms convert oil into mostly carbon dioxide (CO_2) and water (H_2O).

wave (Leibovich and Lumley, 1982; Robbins *et al.,* 1995; Varadaraj *et al.,* 1995; Lunel, 1995a). The cloud of dispersed oil quickly fades from sight as it is rapidly diluted to low oil concentrations by the turbulence in the upper water column (Cormack and Nichols, 1977; Mackay and Chau, 1986; Mackay, 1995).

The surfactants remain on the surface of the oil droplets dispersed in water. This very thin layer of surfactant prevents the oil droplets from coalescing should they come into contact with each other, although this is increasingly unlikely as the dispersed oil is rapidly diluted to very low concentrations in the water. The surfactants also prevent the dispersed oil droplets from sticking to solid surfaces such as a bird's feathers or shoreline substrates, such as sand, rocks or pebbles.

The small droplets of dispersed oil in the water column are readily available to naturally-occurring hydrocarbon-degrading microorganisms. A volume of oil in the form of small droplets has a surface (oil/water) area that is much higher than the same amount of oil present as a coherent slick on the sea surface. The formation of small oil droplets enables the microorganisms in the water to come into contact with much more of the oil, and this facilitates biodegradation.

Figure 6 *The different stages of oil dispersion*

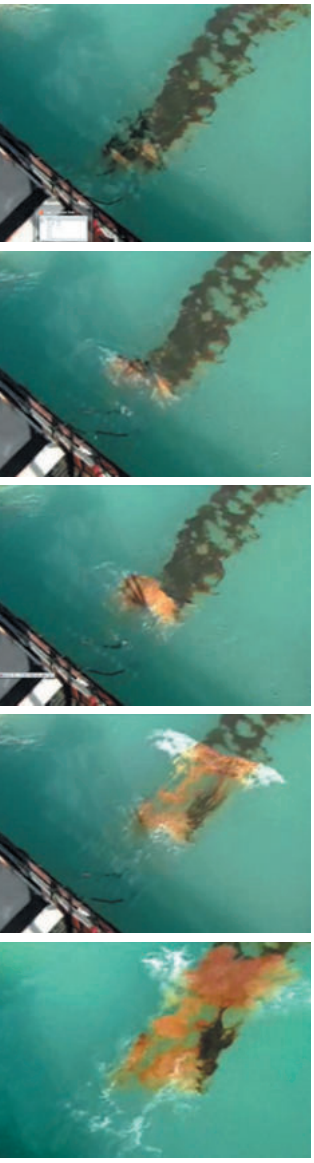


floating slick

waves present

natural dispersion

chemical dispersion



OHMSETT test performed by the USA government.

Left: these sequential images show the aerial view of a single wave passing through dispersant-treated oil; note the formation of the light brown cloud, indicating successful use of the dispersant.

Advantages and disadvantages of dispersant use

With thorough planning, dispersant use can be quickly deployed and can treat larger areas of floating oil significantly more rapidly compared to other response techniques. Effective application of dispersant has the following benefits:

- It minimizes long-term damage and disruption to sensitive wildlife, coastal habitats and socio-economic features that could occur if dispersant was not used and the oil either remained on the surface or reached coastal waters and shorelines.
- It increases the availability of oil for biodegradation and thereby speeds up its natural break-down and assimilation into the environment.
- It can reduce potentially harmful vapours in the vicinity of a spill and provide a safety benefit to any responders undertaking vessel-based activities in the immediate area, as well as minimizing the exposure of responders and local communities to oil in the wider context.
- The need for potentially large-scale and prolonged shoreline clean-up operations is removed.
- It avoids the creation of large volumes of waste material often associated with shoreline clean-up operations; such waste brings serious environmental challenges during its handling, storage and disposal.

However, there is a potential risk of dispersed oil causing marine organisms inhabiting the upper water column to be briefly exposed to diffuse clouds of dispersed oil droplets and water-soluble oil compounds, to a greater extent than if dispersants were not used. This exposure to dispersed oil can potentially have toxic effects on the marine organisms.

Evaluating the consequences of dispersant use are discussed in the context of net environmental benefit analysis (NEBA) in the section on contingency planning (see pages 36–42).

Capabilities and limitations

All oil spill response techniques have capabilities that may make them more suitable than others, or have significant limitations, depending on the circumstances of the oil spill. The choice of response techniques should not be based on pre-existing preferences, but on an understanding of which techniques are most capable of achieving the required outcome, i.e. to minimize the overall damage that could be caused by the spilled oil.

The common aim of all at-sea response techniques (at-sea containment and recovery, controlled in-situ burning and dispersant use) is to remove floating oil and reduce the amount of oil that threatens near-shore areas and which may contaminate shoreline habitats. The capabilities and limitations of these at-sea response techniques can be categorized as:

a) the rate at which floating oil can be removed;
b) the prevailing conditions under which the response is effective or feasible; and
c) oil type or physical property limiting factors and how these may limit the effectiveness of the response technique.

Oil removal rate

The rate at which floating oil needs to be removed to prevent or limit damage to a resource depends on the amount of oil spilled, the proximity to the threatened resource and the prevailing conditions of wind and currents. Logistics may also influence removal rate, as deployment times for some equipment may be extended in remote areas.

Any response technique needs to be put into action as soon as possible after the oil has been spilled. Most oils spread rapidly when spilled onto the sea, and can quickly cover a large area.

The response to relatively small oil spills of less than a few tonnes (tens of barrels) of oil in sheltered waters can often be reasonably effective using booms and skimmers to recover the oil. A response to larger oil spills at sea is more difficult, as the floating oil rapidly spreads out to cover a large area of sea surface. The oil thickness is often very uneven, with scattered areas of thicker oil separated by large areas of very thin oil (sheen) or clear water. This can make a response at sea difficult and requires aerial surveillance to identify the areas of thickest oil (see the IPIECA-IOGP Good Practice Guide on the aerial observation of oil pollution at sea—IPIECA-IOGP, 2015b). The 'encounter rate'—the rate at which floating oil can be treated by a technique—is low for both

The oil encounter rate of offshore booming systems can be low.

USCG

at-sea containment and recovery and for controlled in-situ burning because of the inherent limitations of booms that only permit their operation at low current speeds or when towed from vessels at slow speed (a maximum of a few knots even for 'fast water' systems). The encounter rate of dispersant use is by far the largest of any response technique. Spraying from larger fixed-wing aircraft can give high encounter rates as the response and transit times are generally much quicker than vessels. However in some scenarios vessels can remain 'on-station' for much longer and carry much more dispersant.

If the spilled oil is already very close to the resource that could be impacted, and the prevailing wind causes the oil to drift rapidly towards the resource, there may be insufficient time for any effective response at sea using any technique.

Limitations caused by prevailing conditions

Sea state

The prevailing sea conditions have a great influence on the effectiveness of response techniques.

The effectiveness of booms used to corral floating oil prior to recovery with skimmers or ignition in controlled in-situ burning is greatly reduced in rougher seas. Booms can be overwhelmed by waves, related to the size (draft and freeboard) of the boom as well as its buoyancy and ability to respond to, or ride on, waves. Even large sea booms can become ineffective at wave heights of approximately 1.4 to 1.8 metres and wind speeds in excess of around 20 knots. Many skimmers are limited by sea state, with some types becoming increasingly ineffective at wave heights greater than 0.6 to 1 metres.

Rapid dispersion of dispersant-treated oil begins at a wind speed of approximately 7 knots (3 m/s, a light to gentle breeze) with wave heights of 0.2 to 0.3 metres. However, dispersants can be sprayed onto floating oil in flat calm conditions, and dispersion will begin when appropriate sea conditions occur. Gale-force winds with speeds greater than 35 knots (18 m/s) and wave heights of 5 metres are generally the upper limits for spraying dispersant from aircraft, although dispersants have been applied from aircraft in winds greater than 50 knots (ESGOSS, 1994). Also, targeting the dispersant becomes challenging in high winds, and floating oil will be over-washed or temporarily submerged in rough seas. The limiting conditions for spraying dispersants from ships will be less for the same reasons.

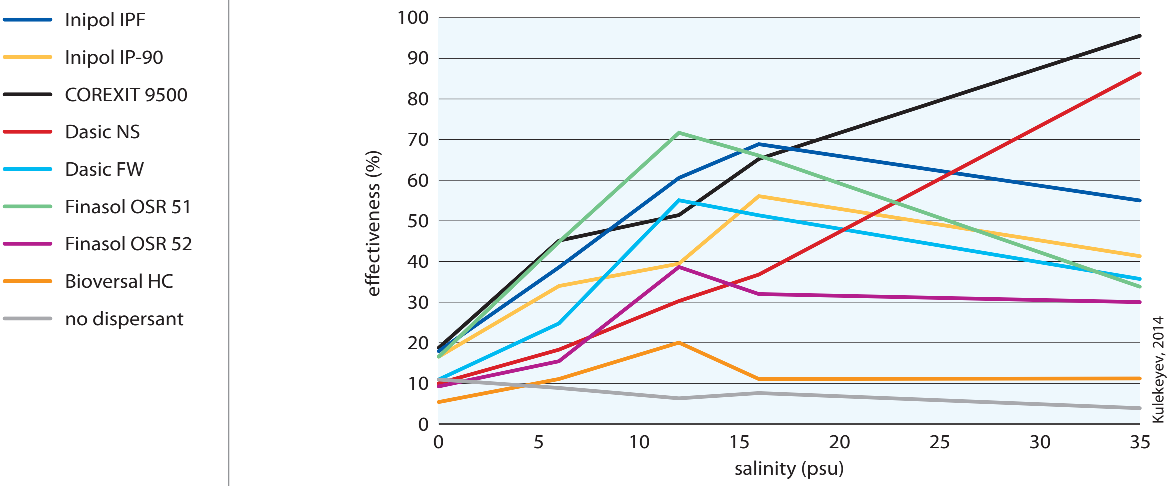
Extremely rough sea conditions may prevent any at-sea oil spill response. However, these conditions can cause extensive natural dispersion of lighter spilled oils.

Effect of water salinity on dispersant effectiveness

Most commercially available dispersants have been formulated to be most effective in seawater with a salt content (salinity) of 30 to 35 psu (practical salinity units) (Belk *et al.,* 1989; Georges-Ares *et al.,* 2001). The effectiveness of these dispersants will be decreased in brackish waters (salinity of 5 to 10 psu) and can be very low in fresh water (Kulekeyev *et al.,* 2014). (See Figure 7 on page 20.)

Although freshwater dispersants are available, the dispersion of oil into fresh water is not recommended in most circumstances because there is insufficient water volume in rivers and often in lakes to allow dilution of dispersed oil to low concentrations.

Figure 7 *Effect of salinity on dispersant effectiveness in a laboratory test using eight products*



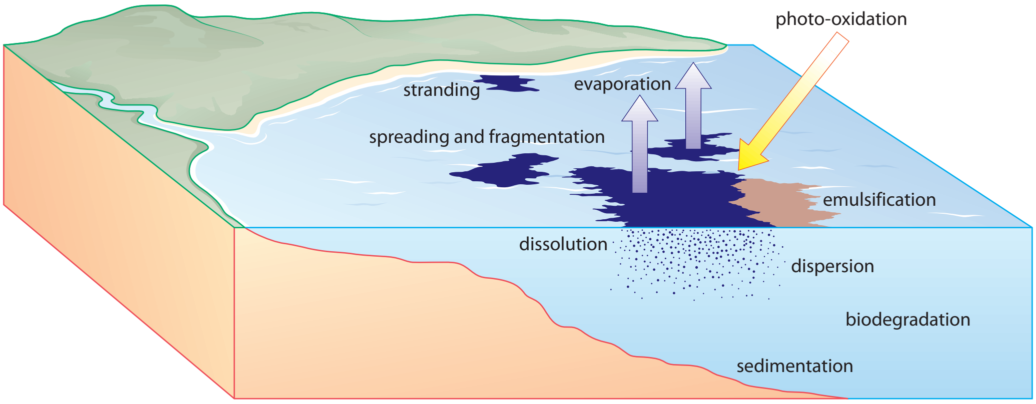
Kulekeyev, 2014

Oil type and physical properties

Many different types of oil and its products can be spilled at sea including crude oils, diesel fuel and heavy (residual) fuel oils.

The physical properties of spilled crude oils and heavy fuel oils change as they lose the volatile components by evaporation, and may form stable water-in-oil emulsions (Payne and McNabb, 1984; Daling *et al.*, 1990; Lewis *et al.*, 1995). These changes are collectively known as oil 'weathering' and are characterized by progressively increasing viscosity of the floating oil with

Figure 8 *The fate and natural weathering processes of spilled oil*



time. The rate of weathering is related to the prevailing sea-state, temperature, oil type and release conditions.

The physical properties of the oil that have a major influence on the effectiveness of all response techniques are density, pour point and viscosity. For oils that form stable water-in-oil emulsions, it is the viscosity of the emulsified oil, related to water content, that is the important factor.

Density

The density of an oil, measured as specific gravity (the weight in relation to fresh water) or degrees API, provides an overall categorization of oil type. Oils are commonly placed into four groups by their density. Group 1 oils are described as very light and are largely non-persistent. Group 4 oils are very heavy, with 2 and 3 being the intermediaries. In some classifications a fifth group of extremely heavy oils, with a propensity to sink, are defined. Knowledge of the oil density provides responders with a broad indication of how an oil may behave and which response techniques may be effective.

Pour point

Oil that is at a temperature significantly (10 to 15°C) below its pour point will be semi-solid and will not flow. This has implications for mechanical recovery devices and shoreline clean-up methods but also indicates that dispersant use is unlikely to be successful, as it cannot penetrate into a semi-solid oil and will be washed off.

Viscosity

This is an important property with implications for all response techniques. Very high viscosity oils can be corralled in booms, but some types of skimmer require that the oil flows towards them, and their effectiveness and efficiency can be low with high viscosity oils and emulsions. High viscosity oils can also be difficult to pump. Igniting oils that have lost their lighter fractions through evaporation may be challenging, particularly if the oil is emulsified (i.e. high water content), limiting the effectiveness of controlled in-situ burning.

The viscosity of spilled oil changes with time as it ‘weathers’, influencing the effectiveness of dispersants on floating oil (Canevari *et al.,* 2001; Clark *et al.*, 2005). As the viscosity of a floating oil increases with time, the probable effectiveness of dispersant use will decline. This is often known as the ‘window of opportunity’ for dispersant use. This window is temperature dependent.

Box 2 *Viscosity*

Viscosity is the resistance to flow (‘runniness’) of an oil and is measured in either cP (centiPoise—dynamic viscosity) or cSt (centiStokes—kinematic viscosity). The dynamic viscosity in centiPoise = the kinematic viscosity in centiStokes multiplied by the density of the oil. For practical oil spill response terms, kinematic and dynamic viscosity can be interchanged. Viscosity decreases markedly with increasing temperature.

There is no universally-accepted oil viscosity limit beyond which dispersants are deemed to be ineffective; this will depend on many factors such as the dispersant used, the nature of the oil and the prevailing conditions (Colcomb *et al.,* 2005). General guidelines on the probable effectiveness of dispersant and oil viscosity are shown in Table 3.

Table 3 *The impact of oil viscosity on dispersant effectiveness*

Oil type/viscosity	Dispersant effectiveness
Light distillate fuels (petrol, kerosene, diesel oil)	Dispersant use not advised These oils will evaporate and naturally disperse quite rapidly in most conditions.
Oils with viscosity up to 5,000 cSt	Dispersant use is likely to be effective
Oils with viscosity between 5,000 and 10,000 cSt	Dispersant use might be effective
Oils with viscosity above 10,000 cSt	Dispersant use is likely to be ineffective (though success is reported on oils with viscosity greater than 20,000 cP)

To assist with oil spill contingency planning and the choice of response techniques, specific information about a particular oil that might be spilled (for example, a crude oil from an offshore production facility) may be available, together with weathering and modelling studies that will have been undertaken previously.

Successful dispersion of weathered oils is possible under some circumstances. The picture shows Alaskan North Slope crude oil being dispersed during a North Sea trial after 55 hours weathering and a viscosity of 15,000–20,000 cP; the dispersed oil cloud is the light brown colouring in the water.

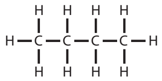
AEA Technology

Biodegradability and toxicity of oil

Transferring spilled floating oil into the water column in the form of small oil droplets by the use of dispersant makes the oil more biologically available to marine organisms. Dispersed oil will eventually be biodegraded to a large extent by naturally occurring microorganisms already present in the sea. Some of the chemical compounds in oils are water-soluble and are potentially toxic to marine organisms. The magnitude of any toxicity observed will depend on the exposure (concentration and duration) of marine organisms to dispersed oil and the water-soluble compounds from the oil. Some of these compounds will be transferred into the water column, whether or not dispersant is used.

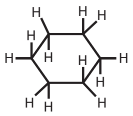
Chemical compounds in crude oils

Crude oils are composed of a large number of individual chemical compounds. Almost all of these are hydrocarbons, composed of only hydrogen and carbon. Hydrocarbons can be classified by molecular weight or carbon chain length; the majority of hydrocarbons in crude oil contain from 5 to 35 carbon atoms. Hydrocarbons can also be classified according to chemical type, i.e. alkanes (paraffins), cycloalkanes (naphthenes) and aromatic compounds (containing one or more benzene rings). The relative proportions of these chemical compounds differ between crude oils and are responsible for the range of physical properties that crude oils exhibit. The majority of hydrocarbons in most crude oils are alkanes and cycloalkanes and they can range from volatile liquids to non-volatile liquids or solids (waxes) depending on their size (number of carbon atoms) and the prevailing temperature.



$$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$$

alkane



cycloalkane

aromatic benzene

Interaction of marine organisms with dispersed oil

Many marine microorganisms (bacteria and yeasts) have the ability to metabolize and degrade chemical compounds in oils. Metabolism is the biochemical process that breaks down complex substances, such as the chemical oil compounds, to produce energy and waste matter (e.g. carbon dioxide and water, in the case of oil). Metabolism proceeds through a series of steps involving enzymes that convert the chemical compounds into intermediate compounds or metabolites. The consequences of this process depend on the chemical compound considered and the marine organism involved, i.e.:

- biodegradation of oil can be considered to be beneficial to the microorganisms as the metabolites are an energy source;
- however, there could be some toxic effects on various marine life caused by exposure to the partly water-soluble components transferring from the oil droplets and into the water, or by ingestion of the droplets by filter feeders which may be preyed upon by larger organisms. The severity of the toxicity effects is proportional to exposure and can range from sub-lethal effects (temporary narcosis, changes in reproduction or feeding) that are often reversible, up to lethality for some individuals in the affected population.

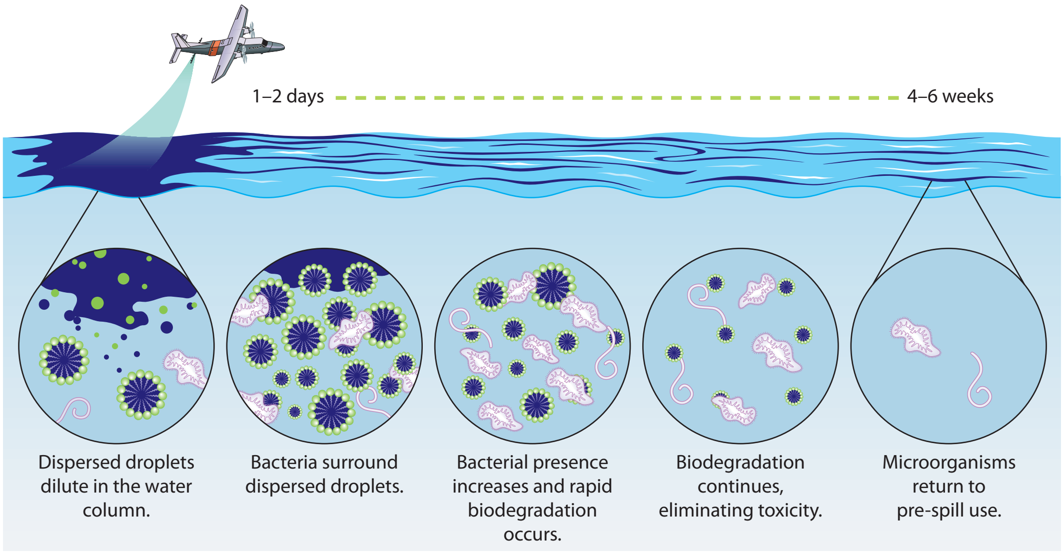
Biodegradability of oils

Biodegradation proceeds principally by biochemical oxidation (Leahy and Colwell, 1990; Atlas and Bartha, 1992; Atlas and Cerniglia, 1995; Prince, 1997; Prince *et al.,* 2013). The different chemical compounds in crude oils will be biodegraded at different rates and to different extents by naturally-occurring hydrocarbon-degrading microorganisms (Singer and Finnerty, 1984; Lindstrom and Braddock, 2002; Campo *et al.,* 2013). Linear chain alkanes will be most rapidly biodegraded, followed by the single-ring aromatic compounds and then by branched chain alkanes and cycloalkanes. Many complex branched, cyclic and aromatic hydrocarbons, which otherwise would not be biodegraded individually, can be oxidized through co-metabolism in an oil mixture due to the abundance of other substrates that can be metabolized easily within the oil (Heitkamp and Cerniglia, 1987). The ultimate fate of the majority of oil that is biodegraded is to be eventually converted into carbon dioxide and water (MacNaughton *et al.,* 2003). The oil compounds that are resistant to biodegradation are largely biologically inert and of low toxicity. Dispersants themselves are readily biodegradable and do not interfere with oil degradation, other than enhancing it by increasing the oil's availability as described below.

The rate of biodegradation also depends on the availability of the oil, and on both oxygen and nutrient availability. The availability of oxygen and nutrients is typically not a limiting factor in offshore waters, however, they may be limited where oil strands, particularly in soft sediments. The microorganisms colonize at the oil/water interface; small dispersed oil droplets have a surface area up to 100 times higher than equivalent oil volume as a floating slick, thus dispersion greatly enhances the rate of biodegradation. Biodegradation of oil that strands on shorelines may be retarded due to the increased thickness which reduces the available surface area. It may also be limited due to drying through exposure to the air in tidal areas. Furthermore, oil can become buried in sediment beaches and this can also retard biodegradation due to lack of oxygen.

The most favourable conditions for biodegradation to take place are when oil is dispersed offshore. The biodegradation process for oil droplets typically commences within 1–2 days and is completed in a few weeks. Areas exposed to oil through natural seeps and industrial pollution may already contain large numbers of active hydrocarbon-degrading microorganism communities. However, suitable microorganisms are present in all seas, and can rapidly adapt and expand their populations when oil becomes available, such as when a spill occurs.

Figure 9 *The typical biodegradation process for spilled oil*



Potential toxicity of dispersed oil

An essential element of toxicology is that the magnitude of the effect on an organism caused by a chemical compound is dependent on the exposure of the organism to the chemical compound. Exposure is a function of exposure route, concentration of the chemical to which the organism is exposed and the duration of exposure.

Potentially toxic chemical compounds in oil

Most alkanes and cycloalkanes have a limited potential to cause toxic effects on marine organisms due to their low water solubility. Aromatic hydrocarbons are the components of crude and fuel oils that are generally considered to be toxic to aquatic organisms (Anderson *et al.,* 1974; Di Toro *et al.,* 2007).

Exposure to oil, dispersed oil and water-soluble compounds from the oil

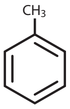
Once an oil spill has occurred, it is inevitable that some marine organisms will be exposed to elevated concentrations of naturally dispersed oil droplets and water-soluble compounds from the oil in the upper water column (González *et al.,* 2006). The one-ring aromatic compounds (or BTEX) will rapidly evaporate from floating oil into the air, and this alters the potential for toxic effects to be caused by the remaining oil (Neff *et al.,* 2000).

The main cause of acute toxic effects in marine organisms is exposure to 2-ring PAHs (substituted naphthalenes) in the water through absorption across the gills and other organs. The dispersion of oil as small droplets, either naturally or enhanced by dispersants, may increase the exposure of some marine life to these and other partly water-soluble compounds from the oil due to the increased oil/water surface area. However the dispersion process does not increase the oil's toxicity.

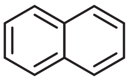
The uppermost water layer typically contains high densities of planktonic organisms, including the developing spawn (embryos and larvae) of some fish species. These early life stages are known to be sensitive to low concentrations of 2- and 3-ring PAHs in the water (Carls *et al.,* 2008). Plankton drift with the currents in the water and cannot avoid exposure to the compounds from the oil, but any effects on plankton would be localized and recovery by recruitment from outside of the affected area is rapid. Most oil spills are of limited area and short duration, and the impact, if any, would be limited and localized (Kingston, 1999).

In water more than 10 metres deep, the concentration of naturally dispersed oil and water-soluble compounds from the oil will be rapidly diluted to low levels in the underlying water. Adult fish can detect oil compounds in the water and are likely to avoid the contaminated area (Weber *et al.,* 1981). There is no recorded case of any massive fish-kill being caused by an oil spill in the sea.

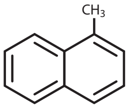
Fish swimming through water containing oil can absorb some of the water-soluble compounds (most usually the 2-ring aromatic compounds) from the oil into their tissues, but these compounds are quickly lost ('depurated') when the fish passes into clean water. Fishing bans or restrictions are often put in place as a precautionary measure to prevent fishing boats and their equipment being oiled, and to reassure the public and protect the reputation of the seafood markets.



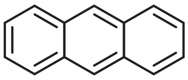
1-ring: toluene



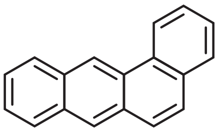
2-ring: napthalene



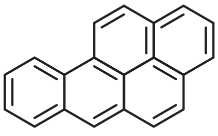
2-ring: 2-methylnaphthalene



3-ring: anthracene



4-ring: benzo(a)anthracene



5-ring: benzo(a)pyrene

Above: examples of aromatic compounds

Box 3 *Aromatic chemical compounds in oils*

- **One-ring aromatic compounds:** these are benzene, toluene, ethylbenzene and xylenes and are often referred to as BTEX compounds. Crude oils contain from about 0.5% up to 5% BTEX. Gasoline can contain up to 40% BTEX. BTEX compounds are relatively soluble in water, but they are also volatile and will rapidly evaporate into the air from spilled oil on the sea surface.
- **Two-ring aromatic compounds:** naphthalene and alkyl-substituted derivatives. Different crude oils contain from 0% to 0.4% of naphthalene and from 0% up to 1% or more of substituted naphthalenes. These compounds are less water-soluble than BTEX and of moderate volatility.
- **3-, 4- and 5-ring polycyclic aromatic hydrocarbons (PAHs):** crude oils contain from 0 ppm to several hundred ppm of the 3-ring aromatic compounds, but much less, typically 1 to 10 ppm, of the individual 4-ring and 5-ring compounds. These PAH compounds are not volatile, and the 3- and 4-ring compounds are slightly water-soluble.

Oil spilled in water less than 10 metres deep is more likely to cause toxic effects because aquatic organisms will be exposed to higher concentrations of naturally dispersed oil and water-soluble compounds from the oil for a longer duration (Claireaux *et al.,* 2013). In addition, the marine organisms present in shallow water that could be exposed to high concentrations of dispersed oil will include those that live either close to or in the seabed. These organisms would be at too great a depth to be affected in deeper water. This does not mean that dispersant use should always be avoided in waters less than 10 metres, rather that it requires more detailed consideration than in deeper waters (Le Floch *et al.,* 2014).

Effect of using dispersants

Dispersing more of the oil as small droplets in the water column by the use of dispersant will temporarily increase the exposure of all marine organisms in the upper water column (Singer *et al.,* 1998). The increase in oil/water surface area will enable more of the partially water-soluble chemical compounds to transfer into the water. They will also be rapidly diluted, as long as sufficient water depth is available (Law and Kelly, 1999; Bejarano *et al.,* 2013). The elevated concentrations of these compounds (the 2- and 3-ring aromatic compounds) in the water column have the potential to cause toxic effects, with the magnitude of the effect depending on the duration of exposure (Kelly and Law, 1998; Sterling *et al.,* 2003; Bejarano, 2014). If dispersants are used on spilled oil over water deeper than 10 or 20 metres the concentrations of dispersed oil droplets and water-soluble chemical compounds from the oil will initially increase, but then rapidly decrease as they are diluted into the surrounding water. Marine organisms will therefore be exposed to a brief 'spike' of elevated concentration of these compounds (Singer *et al.,* 1991; Bragin *et al.,* 1994; Clark *et al.,* 2001), typically reaching a concentration around 50 ppm and rarely exceeding 100–200 ppm in the top few metres and falling to >1 ppm within a few hours. The overall levels of exposure in the marine environment are much lower than those used in standard laboratory toxicity testing procedures (Pace *et al.,* 1995; Coelho *et al.,* 2013).

Exposure of marine organisms by ingestion of dispersed oil droplets

Marine organisms may also be exposed to the higher molecular weight PAHs through ingestion of food. Filter-feeding organisms that prey on plankton can ingest naturally or chemically dispersed oil droplets when they are of similar size to some plankton. Relatively simple organisms, such as bivalves, cannot biochemically process the higher molecular weight PAHs in the oil, and these PAHs can build up ('bio-accumulate') in some organs (Neff and Burns, 1996). These compounds will subsequently be lost by depuration into clean water. Predators that consume oil-contaminated bivalves can therefore be exposed to elevated concentrations of the higher molecular PAHs by this ingestion route. Organisms that possess livers, such as fish, can metabolize PAH, and some of these metabolites are harmful, causing lesions and other effects. The magnitude of toxic effects caused by this exposure route in most circumstances is likely to be low with only some individuals affected.

Box 4 *Toxicity concepts and terminology*

Toxicity is defined as the 'inherent potential or capacity of a material to cause adverse effects in living organisms'; aquatic toxicity is the effect of chemicals on aquatic organisms.

- The range of the **adverse effects** can be from the subcellular level to whole organisms to communities and whole ecosystems. Adverse effects may be reversible or irreversible, mild or severe. Many toxicity studies focus on mortality. Less severe, sublethal, effects include changes in behaviour, physiology (such as slowed movements) and effects on reproduction, feeding and other functions. Some organisms are much more sensitive to some substances than other organisms. Early life stages are more sensitive than adults.
- The **exposure route** is the way the organism is exposed to the substance, including ingestion (directly or in food), absorption through the gills or contact with the skin.

Observed biological effects are a function of both the **duration of exposure** to the chemical and the **concentration** of the chemical. In the aquatic environment, the length of exposure varies with tides and currents and the mobility of the potentially affected organism. The concentration of a chemical is heavily influenced by (i) the physical, chemical and biological properties of the ecosystem, (ii) sources and rate of input of the chemical into the environment, and (iii) the physical and chemical properties of the chemical.

- **Acute** toxicity involves harmful effects in an organism through a single or short-term exposure.
- **Chronic** toxicity is the ability of a substance or mixture of substances to cause harmful effects over an extended period, usually upon repeated or continuous exposure, sometimes lasting for the entire life of the exposed organism.

Toxicity testing is undertaken for a variety of reasons and different methods are used.

- LC_{50} (lethal concentration to 50% of test organism population) involves exposing the test organisms to a series of increasing concentrations (for example 1, 10, 100, 1,000 ppm in water) for a standard time period (typically 48 or 96 hours). The dose or concentration that kills 50% of the test organism population is calculated. This is a good method for assessing the relative toxicity of different substances, but the results are not relevant to the actual exposure of organisms in real-world situations.
- In order to determine the potential for toxic effects that may be caused by substances in real-world situations it is essential that the exposure conditions (concentration of substance and duration of exposure) are replicated in testing.
- Data can be used in oil spill trajectory modelling, with the model modified for more appropriate exposures.

Regulations regarding dispersant use

Why do national governments have dispersant regulations?

Development of dispersant regulations by competent national authorities or appropriate government regulators forms a critical part of national oil spill contingency planning processes. National governments have a right and responsibility to protect their citizens and the natural resources within their national waters from the effects of oil pollution. The purpose of dispersant use in oil spill response is to reduce the total amount of damage that could be caused by the spilled oil. Some coastal state governments have laws that control or prohibit the addition of chemicals into the sea within their national boundaries. Exceptions have to be made for some circumstances, such as the use of dispersants. In addition, there is a need to regulate dispersant use to prevent the use of overly toxic products to disperse the oil, or to limit uncontrolled use of dispersant in situations that could cause significant harm to marine life.

The legal basis of regulations about dispersants varies between countries because such regulations are often subsidiary to the existing primary environmental protection legislation. The differences in primary environmental legislation mean that the regulations about dispersants have to be developed or formulated in different ways in different countries. Many countries have two sets of regulations about dispersants, as described below.

Dispersant product approval regulations

These describe which dispersants are approved for use and how dispersants can be added to an approved dispersant list by meeting the requirements of specified testing. Dispersant product approval regulations most often require:

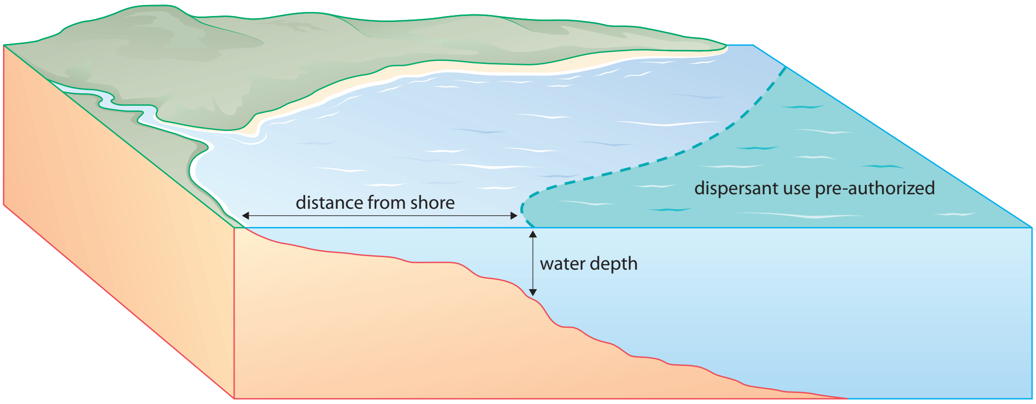
a) effectiveness testing to ensure that any dispersant will be reasonably effective; and
b) toxicity testing to ensure that a dispersant will not be overly toxic (e.g. more toxic than oil).
c) Some countries may also require additional information about the biodegradability of the dispersant, permitted and prohibited ingredients, physical properties and required labelling.

Dispersant use authorization regulations

These define which national organization can authorize dispersant use, and where and when approved dispersants could be used on spilled oil in national waters. Pre-authorization of dispersant use in specified areas can be essential in enabling rapid dispersant use as soon as possible after the oil has been spilled. Dispersant use authorization regulations should take into account the net environmental benefit that dispersed oil can provide.

i. Generalized restrictions based on water depth (for example 10 or 20 metres) and distance from shore (for example 1 or 2 km or nautical miles) can be used. This ensures that there is a sufficient volume of water to allow the dispersed oil to be diluted to concentrations in the water that are below those which could have significant negative effects on marine organisms.
ii. In the case of dispersant use on floating oil in shallower water, or where particularly sensitive resources are present, there might be the need for more specific geographic and seasonal restrictions, justified by NEBA.

Figure 10 *Dispersant use authorization regulations define where and when approved dispersants can be used*



Testing for dispersant product approval purposes

Countries that currently do not have a list of approved dispersants or dispersant product approval regulations, and whose relevant regulatory authority wishes to develop such an approved dispersant list, have the following options:

i. Adapt one or another of the existing internationally recognized test methods to improve its relevancy to the locally prevailing conditions. It is unnecessary to consider developing unique effectiveness and toxicity testing regimes for dispersant product approval, as a wide variety of standard and proven methods already exist.

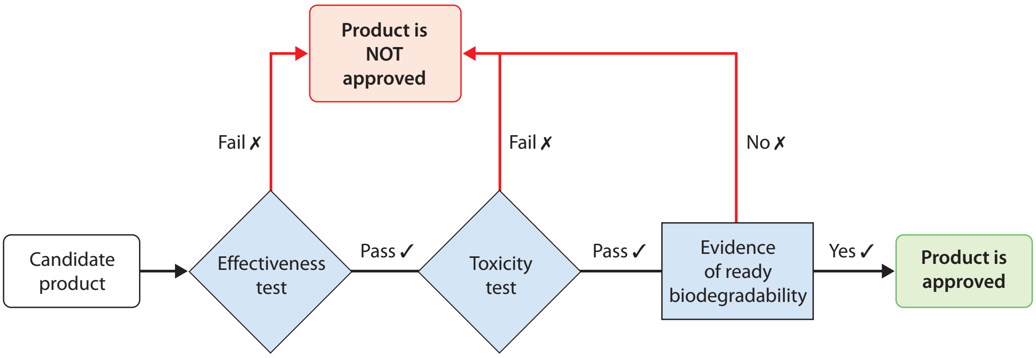
ii. Accept the dispersants approved in another country (or selected countries) utilizing published testing protocols, for inclusion on their own approved dispersant list. This approach avoids the need to conduct any further testing and greatly simplifies the approval process.

It is important to appreciate that these tests are designed to discriminate between candidate dispersants and not necessarily represent realistic conditions. In both cases (effectiveness and toxicity testing), the tests are not accurate simulations of 'real world' dispersant use on spilled oil at sea because the scale of these laboratory tests cannot mimic what is happening in the open sea.

The threshold or pass mark for approval using these effectiveness and toxicity tests is set at a level that a regulator can be comfortable with in terms of its suitability for approving dispersants that are reasonably effective and much lower in toxicity than the oil they will be used to treat.

A flow chart describing recommendations for a dispersant product approval process is illustrated in Figure 11 on page 30.

Figure 11 *Example dispersant product approval process*



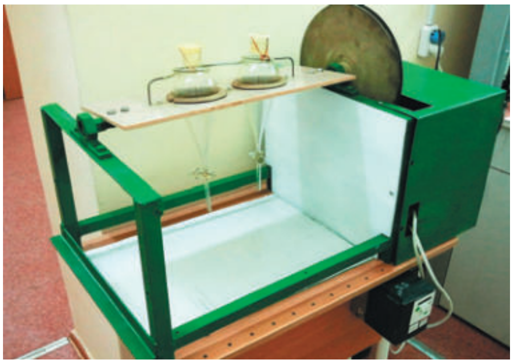
Effectiveness testing for dispersant product approval purposes

The objective of dispersant effectiveness testing for product approval purposes is to identify those products which have, as a minimum, appropriate effectiveness at dispersing oil, thereby avoiding the approval of poorly performing products.

Different effectiveness (or 'efficacy') test methods have been developed (Rewick *et al.,* 1981; Becker *et al.,* 1993) and used by different national authorities. All the effectiveness tests use laboratory apparatus to apply a degree of mixing energy to sample quantities of a reference oil, dispersant and water within an enclosed vessel, aiming for repeatability (Clayton *et al.,* 1993).

None of the laboratory test methods can simulate all the complex mixing scenarios and energies encountered in the marine environment (Mukherjee and Wrenn, 2009). Prevailing wave conditions at sea can vary over a wide range from flat calm to very rough. One laboratory test method may superficially resemble a particular sea state more than another, but an accurate simulation of oceanic conditions is not possible for reasons of scale (Kaku *et al.,* 2006).

Effectiveness testing for dispersant product approval purposes uses a specified test oil, dispersant treatment rate and conditions of temperature and salinity. The results, typically expressed as a 'percentage effectiveness', should only be used to compare the relative effectiveness of different dispersants tested under the same conditions and using the same protocol. A relevant pass mark indicating the acceptable minimum level of effectiveness in the test then needs to be defined. Most combinations of test methodology and reference oil, able to discriminate poor products from good ones, will lead to a pass mark being set around the middle-range (i.e. around 50%). However, a relevant pass-mark may be higher or lower than this.


Karaganda State University

An example of effectiveness testing apparatus—the WSL method.

This arbitrary pass mark should not be interpreted as being an indicator of dispersant performance in the field. The UK pass mark of 60% in the WSL test method (WSL, 2007) with a medium fuel oil does not indicate that only 60% of oil would be dispersed and 40% would remain. The proportion of oil dispersed at sea could be 100% or less, depending on prevailing conditions.

Toxicity testing for dispersant product approval

Approval of dispersant products by the regulating agency usually requires that the dispersant should not exceed a given acute aquatic toxicity threshold. The testing should ensure that approved dispersants are substantially less toxic than the oils they are designed to treat.

Toxicity testing of 'dispersant alone'

The original intention of toxicity testing of dispersants was to ensure that the use of toxic industrial detergents, such as those used in massive quantities at the *Torrey Canyon* oil spill in the UK in 1967, would not be repeated. To be approved, dispersants had to exhibit a toxicity less than a level deemed acceptable. A 96-hour or 48-hour LC_{50} (lethal concentration to 50% of test population) toxicity test with a variety of test species was used to determine the toxicity of the dispersants. The purpose of the 48- or 96-hour LC_{50} toxicity test is to determine the concentration of dispersant in water that kills half the creatures exposed for the specified time. The test can therefore rank one dispersant as being more or less toxic than another dispersant. The exposure regime (concentration of dispersant in the water and exposure duration) in an LC_{50} test does not simulate the exposure to dispersant that a marine organism would experience if the dispersant was used on spilled oil at sea.

Toxicity test species vary and can include fish, shrimps, plankton, bivalves and others.

Some countries currently use LC_{50} tests of dispersant alone for toxicity testing in the dispersant product approval process. The pass mark is often set as being less toxic than a reference toxicant; in France, a dispersant must be ten times less toxic than a named quaternary amine.

Toxicity testing of 'dispersant plus oil'

The first true oil spill dispersants were developed in the 1970s. These were of far lower toxicity than the detergents used at the *Torrey Canyon* incident. The concentrations of dispersant in water required to cause 50% mortality of shrimp were very high, up to 10,000 ppm (1% by volume), and this made it difficult to obtain accurate results in these tests.

It became recognized that concern about the toxicity of the dispersant was misplaced and that the real concern should be about the potential toxic effects on marine organisms being caused by exposure to dispersed oil. It might seem reasonable that toxicity testing with 'dispersant plus oil' is more relevant than testing with 'dispersant alone', because:

- dispersant would not be used if no spilled oil was present; and
- the potential for toxic effects when modern dispersants are used on spilled oil at sea is caused by the dispersed oil, not by the dispersant.

However, this is to misunderstand the purpose of toxicity testing for dispersant product approval purposes, which is to select dispersants that do not exceed a given acute aquatic toxicity threshold.

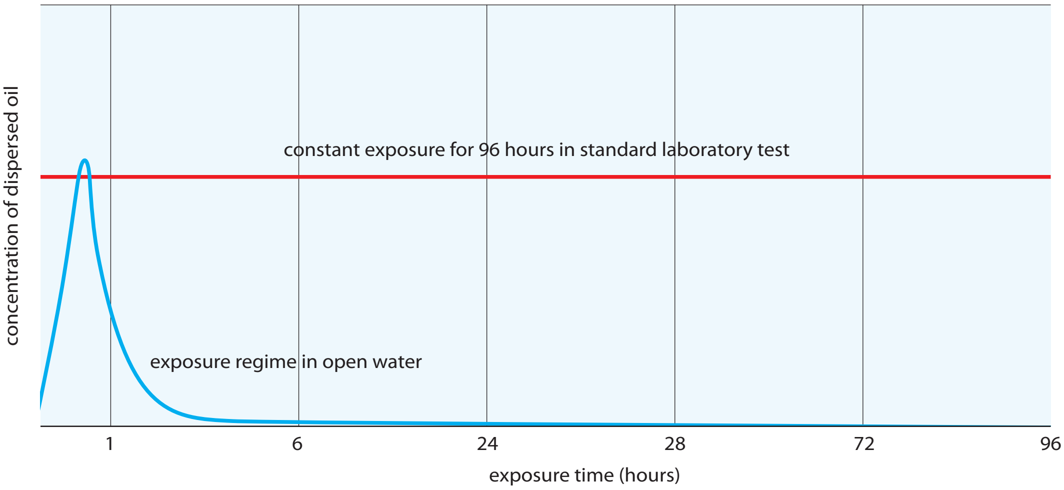
Some countries currently conduct 'dispersant plus oil' testing for dispersant product approval purposes (Blackman *et al.,* 1978; Kirby *et al.,* 1996). However, the use of this testing approach has several issues:

- These tests do not simulate actual dispersant use on spilled oil in the marine environment. The exposure regimes used in 'dispersant plus oil' toxicity tests are far greater than would be experienced by marine organisms if the dispersant was used on spilled oil at sea (Figure 12). This is a necessary aspect of any toxicity test that is designed to discriminate between the effects of different dispersants.
- Analyses of chemical components in the water are rarely conducted, and it is only nominal oil concentrations that are reported.
- As the toxicity is largely derived from the oil components, tests with more toxic oils will produce higher toxicity results.
- 'Dispersant plus oil' toxicity testing inevitably discriminates against highly effective dispersants and towards less effective dispersants.

Results from 'dispersant plus oil' (i.e. dispersed oil) toxicity tests conducted for dispersant product approval purposes are frequently misinterpreted as indicating likely effects at sea when dispersants are used on spilled oil. The concern over the potential for toxic effects to be caused by dispersed oil is legitimate and needs to be addressed, but not during toxicity testing for dispersant product approval regulations. Instead, the concern should be addressed by the use of data from scientific studies on the potential for dispersed oils to have toxic effects on various marine organisms under realistic exposure conditions (Clark *et al.,* 2001). These data supply the scientific justification required for a NEBA process when considering dispersant use authorization regulations.

Figure 12 *Comparison of toxicity effects on marine organisms due to prolonged exposure to dispersed oil—standard laboratory tests versus transient exposure at sea*

Exposure to a constant dispersed oil concentration for a prolonged period in most standard laboratory toxicity tests is much more severe than the transient exposure experienced by marine organisms at sea.



Toxicity testing of oil, 'dispersant alone' and 'dispersant plus oil'

In the USA, the current toxicity tests required by the US Environmental Protection Agency (EPA) for dispersants to be included on the NCP (National Oil and Hazardous Substances Pollution Contingency Plan) Product Schedule involves testing with two US EPA standard species: inland silverside fish (*Menidia beryllina*) and mysid shrimp (*Americamysis bahia*). These species are exposed to: (i) No. 2 fuel oil alone; (ii) dispersant alone; (iii) a 1:10 mixture of dispersant to No. 2 fuel oil; and (iv) a reference toxicant. The test procedures used are a 96-hour LC$_{50}$ for *Menidia* and 48-hour LC$_{50}$ for *Americamysis*. There is no pass/fail criterion and the results are simply reported.

As noted above, the exposure regime of the LC$_{50}$ toxicity testing procedure does not simulate dispersant use on spilled oil at sea because the concentrations used in the test are much higher, and the duration of exposure is much longer, than would occur at sea. However, LC$_{50}$ toxicity testing provides a way of assessing the relative magnitude of toxic effects that could be caused by dispersants or dispersed oil under the test's exposure conditions.

The same toxicity testing methodology used for listing on the NCP Product Schedule was used by the EPA (US EPA, 2010) to determine the relative magnitude of the toxic effects that could be caused by:

i. mechanically dispersed Louisiana Sweet Crude (LSC) oil;
ii. the dispersant used during the response to the 2010 Macondo incident—COREXIT® EC9500A; and
iii. LSC crude oil dispersed by using a mixture of 1:10 of COREXIT® EC9500A and LSC.

The measured levels of toxicity in the LC$_{50}$ tests were ranked on a five-level scale from 'very highly toxic' to 'practically non-toxic' as used by the US EPA for interpreting the results of LC$_{50}$ tests (US EPA, 2012).

The results summarized in Table 4 show that the dispersant alone causes less toxic effects than the crude oil alone. The dispersant alone is considered to be 'practically non-toxic' to the fish species and only 'slightly toxic' to the shrimp, while the mechanically dispersed crude oil is rated as being 'moderately toxic' to both. The crude oil dispersed with the dispersant has the same rating as the mechanically dispersed crude oil of 'moderately toxic' to both species. In this case the measured toxic effects are caused by the oil, not the dispersant.

Table 4 *US EPA's aquatic toxicity testing summary results for the spilled oil, dispersant and dispersed oil from the response to the 2010 Macondo incident*

	Louisiana Sweet Crude (LSC) oil		**Dispersant (Corexit® EC9500A)**		**Dispersed oil (LSC + Corexit® EC9500A)**	
EPA ecotoxicity categories (ppm = parts per million)	Mysid shrimp	Silverside fish	Mysid shrimp	Silverside fish	Mysid shrimp	Silverside fish
Very highly toxic: <0.1 ppm						
Highly toxic: 0.1–1 ppm						
Moderately toxic: >1–10 ppm	2.7 ppm	3.5 ppm			5.4 ppm	7.6 ppm
Slightly toxic: >10–100 ppm			42 ppm			
Practically non-toxic: >100 ppm				130 ppm		

US EPA, 2010

Issues regarding toxicity testing and dispersant regulations are discussed in more detail in the IPIECA-IOGP publication on the regulatory approval of dispersant products and authorization of their use (IPIECA-IOGP, 2014).

Dispersant use authorization regulations

The purpose of dispersant use regulations is to ensure that dispersants are only authorized for use in situations where and when they will prevent or minimize damage that would be caused by spilled oil.

Successful dispersant use will cause more oil to be transferred into the water column. Marine organisms will therefore be exposed to elevated concentrations of dispersed oil, and of water-soluble compounds from the oil, compared to the situation if dispersants were not used. This raises concerns about the potential for dispersant use to increase the toxic effects of dispersed oil on some marine organisms. To address these concerns, the potential toxic effects caused by exposure to dispersed oil needs to be considered as part of the NEBA process (see pages 36–42 and refer to IPIECA-IOGP, 2015e).

The simplest general-case application of the NEBA process is to consider using a defined minimum water depth and a defined distance from the shore to ensure that the dispersed oil concentrations in the water and exposure duration will be sufficiently low. This reduces to a low level the risk of significant toxic effects on the marine organisms that may be present. The validity of this approach has been underpinned by past studies of dispersed oil toxicity. This principle is incorporated into the dispersant use authorization regulations in many countries, including France and the UK, and in different regions in the USA. For example, the UK dispersant use regulation requires the permission of the licensing authority for dispersant use on oil in shallow water, where shallow waters are defined as areas of the sea where the water depth is less than 20 metres or within 1 nautical mile of any such area. In deeper waters, dispersant use is pre-authorized. The 'pre-authorized' sea areas or zones where dispersant use on spilled oil is permitted are therefore often based on general restrictions, such as:

i. a minimum water depth (for example, 10 or 20 metres);

ii. a minimum distance from the shore (for example 1 kilometre or 1 nautical mile); and

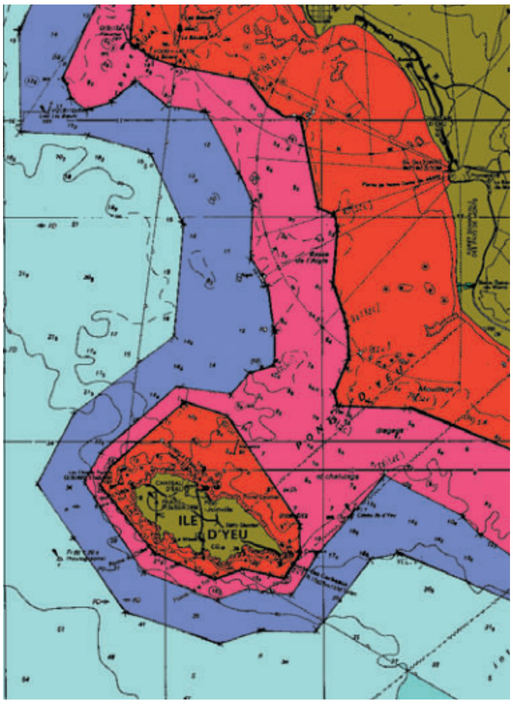
iii. avoiding ecological or socio-economic features, such as industrial seawater intakes and fish farms, that are identified as being particularly vulnerable to dispersed oil.

In many cases, the dispersant use regulations also stipulate other conditions, such as:

- oil pollution must be present before dispersant is applied;
- an exemption can be granted to permit the use of dispersant under the regulation, i.e. preventing prosecution or fines under existing environmental law(s) for use of dispersants;
- applying dispersant in non-conformity to the regulation may lead to prosecution, with stipulated penalties;
- observation/monitoring should be established during application to verify that the dispersant is working, and requiring that application must cease if the dispersant is not working—the use of observation/monitoring beyond visual should occur as the equipment becomes available and its unavailability should not delay the response;

- dispersant is applied using suitable application equipment and conforming to manufacturer's instruction; and
- operational guidance for dispersant application is followed (e.g. published IMO guidelines).

The use of dispersant may be a justifiable technique in waters shallower than a pre-authorized minimum depth or closer to shore than the minimum distance stipulated, provided it can be demonstrated that this will result in less environmental damage overall and that alternative response techniques cannot achieve the same result. The process and authority by which special-case approvals are issued should be identified in the regulation. In this case, the onus falls on the organization that is applying for special-case dispersant use to undertake the associated specific NEBA and present the justification to the relevant authority for their consideration, following which the authority may, or may not, authorize the use of dispersant.



CEDRE

In France, zones of allowable volumes of oil which may be treated with dispersant are defined for inshore areas based on depth and distance from shore; there is no limit in waters deeper than 15 m.

USDA

Suitable equipment should be used; here, nozzles are tested with water to ensure that a suitable dispersant droplet size is created.

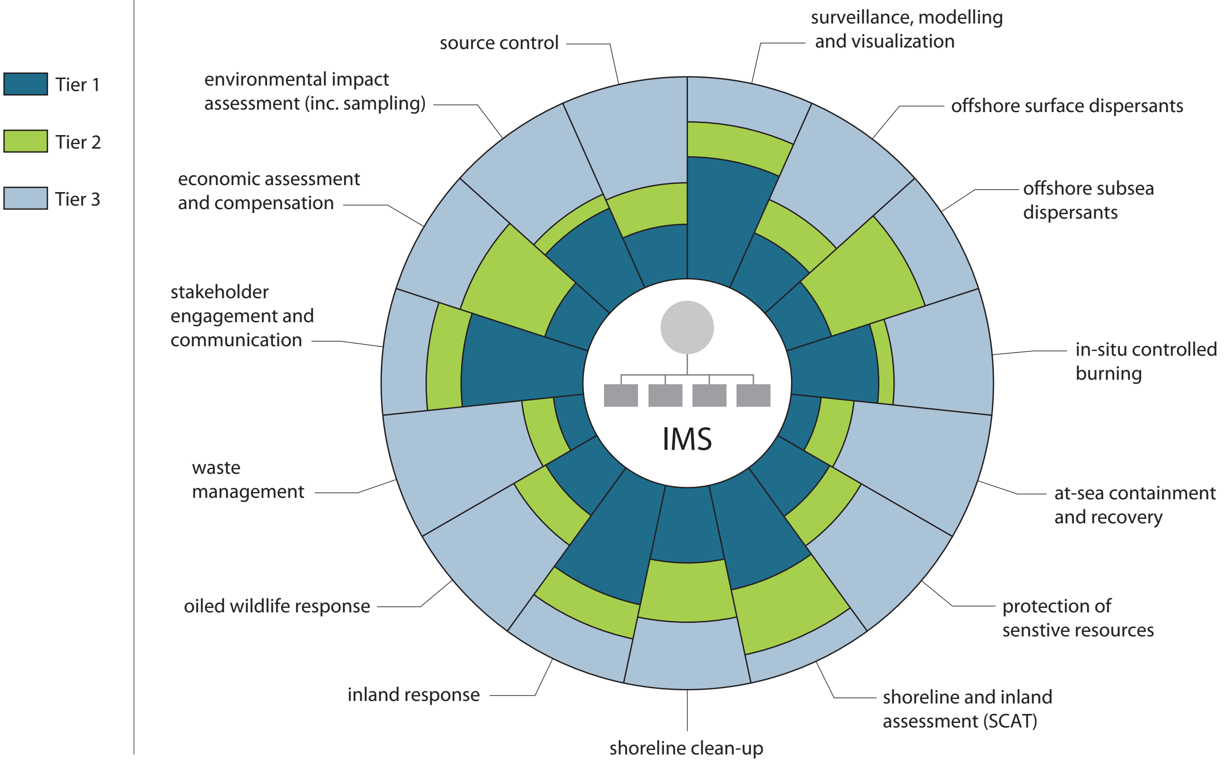
Dispersants and contingency planning

Oil spill contingency planning is an essential process for effectively dealing with potential oil spills. Oil spill incidents are far easier to resolve and potential damages can be significantly reduced using a well prepared and tested oil spill contingency plan. Contingency plans provide the structure for the management and implementation of response operations. The scope of a contingency plan should be based on what is known as a 'tiered response' framework. This helps ensure that the planned response reflects the scale of the particular spill risk.

Spills that are relatively small can often be dealt with locally (Tier 1). Should an incident prove to be beyond the local capability or affect a larger area, an enhanced but compatible response using shared, national or regional resources will be required (Tier 2). The foundation of this tiered response is the local response plan for a specific facility such as a port or oil terminal, or for a specific length of coastline at risk from a spill. These local plans may form part of a larger district or national response plan that can leverage further national or international support (Tier 3). The planning process is described in more detail in the IPIECA-IOGP Good Practice Guides on contingency planning (IPIECA-IOGP, 2015c) and tiered preparedness and response (IPIECA-IOGP, 2015d). In the tiered preparedness and response model (see Figure 13), dispersant use planning is incorporated into preparedness activities alongside other preparedness criteria.

Note that each wedge in Figure 13 represents a type of response preparedness, and the thickness of each tier represents the level of resources required to respond to the spill for a specific facility or region.

Figure 13 *The tiered preparedness and response model—each tier represents the resource capacity required to respond to a specific spill*



Planning for dispersant use

For dispersants to be a viable option in the response toolkit, they need to be available without delay. Dispersants are most effective if they are sprayed onto spilled oil as soon as possible after it has been spilled, although this ‘window of opportunity’ can vary with oil type and prevailing conditions. The window ‘opens’ when the oil hits the water and starts to ‘close’ as the oil weathers. If the product approval and dispersant use authorizations are already in the oil spill contingency plans, it is much more likely that they will be successfully applied in the short time frame available. In essence, if you don’t plan to use dispersants, you may be planning NOT to use dispersants.

The following steps in the oil spill contingency planning process have importance for the choice of response options, particularly with respect to dispersant use.

Regulations

The policy and procedures for dispersant product approval and pre-authorization of their use by relevant authorities should be established in regulations.

Scenarios

The oil spill risk assessment should include the consideration of potential oil spill scenarios. This will include the location, types and volumes of a potential spill, prevailing environmental conditions and the ecological and socio-economic resources that may be threatened. It is usual to include spilled oil fate and trajectory modelling to support this step. The level to which these scenarios can be developed depends on the nature of the operation. For fixed locations such as offshore installations, ports and harbours, or known shipping choke points, the level of detail may be high. However, for general shipping lanes and areas where many oils are traded, the approach may necessarily be more generic. The scenarios should be chosen to address all response tiers.

NEBA

The available and viable response techniques should be considered in relation to the chosen scenarios. The best option(s) for minimizing overall environmental damage (net environmental benefit) should be analysed. This will inform the determination of the type, amount and locations for response capability for all the response tiers.

Capability

Appropriate equipment should be either identified or established to meet the identified needs. In the case of dispersants, this will include dispersant stockpile locations, suitable application systems and logistical support. Trained personnel will be needed to ensure safe and controlled application of dispersants. Further details are available in the IPIECA-IOGP report on dispersant logistics and supply planning (IPIECA-IOGP, 2013).

Monitoring

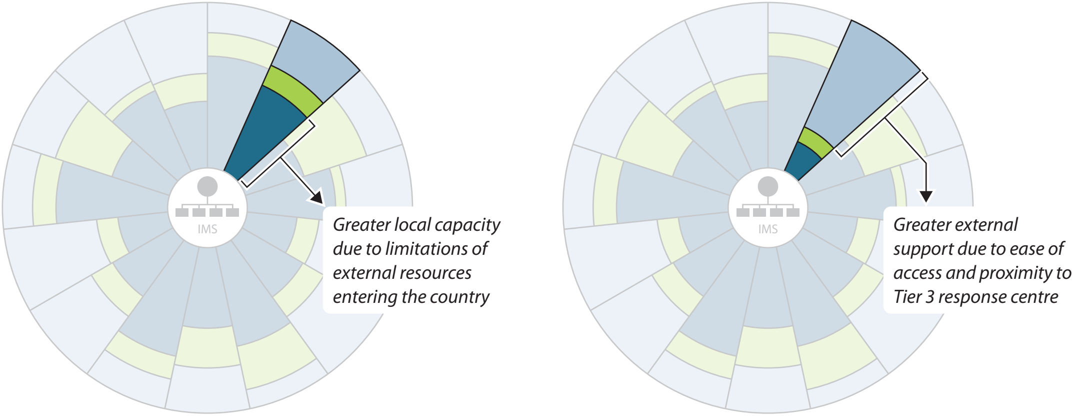
Procedures for monitoring the initial and ongoing effectiveness of dispersant use during an incident should be developed.

At each location, factors may exist which influence the ability to cascade resources, and which will therefore determine the need for tailored capacities.

Figure 14 *Location-specific factors will determine the nature of a response*

a) Remote location in a country with access challenges and/or severe weather

b) Coastal location adjacent to a Tier 3 response centre



Greater local capacity due to limitations of external resources entering the country

Greater external support due to ease of access and proximity to Tier 3 response centre

🟦 Tier 1

🟩 Tier 2

🟦 Tier 3

Net environmental benefit analysis

NEBA is a process used by the response community for making the best choices to minimize the impacts of oil spills on people and the environment—see the IPIECA-IOGP Good Practice Guide on NEBA (IPIECA-IOGP, 2015e). Consideration and judgment are required when comparing the likely outcomes of using different response techniques and recommendations as to the preferred tactics from experienced response/NEBA practitioners. NEBA typically involves the steps shown in Table 5, and should be carried out prior to an oil spill as an integral part of oil spill contingency planning.

Table 5 *The steps involved in the NEBA process*

NEBA step	Description
Evaluate data	The first stage is to consider where the spilled oil is and to where it will drift under the influence of currents and wind—various oil spill trajectory models exist to support this. It is also useful to know how an oil will 'weather' as it drifts. This is part of evaluating the available data.
Predict outcomes	The second stage is to assess what is likely to be affected by the spilled oil if no response is undertaken. This may include ecological resources offshore, nearshore and on shorelines, alongside socio-economic resources. The efficiency and feasibility of the response toolkit should also be reviewed. This covers the response techniques, the practicalities of their utilization and how much oil they can recover or treat. If areas under threat include oil-sensitive coastal habitats, the role of oil spill response at sea is to either prevent or limit the spilled oil from reaching these habitats. Previous experience can help assess which oil spill response techniques are likely to be effective. Pragmatic, operational considerations should form a very important part of the NEBA process applied to all feasible response techniques.
Balance trade-offs	The advantages and disadvantages of the potential response options are considered and weighed against the ecological and socio-economic impacts of each to understand and balance the trade-offs.
Select best options	The process concludes with the adoption of response technique(s) within oil spill contingency plans that minimize potential spills' impacts on the environment and promote the most rapid recovery and restoration of the affected area.

Selecting options

Table 6 presents a simplified decision matrix to help determine the suitability of the available response techniques.

Table 6 *Simplified decision matrix to guide the choice of response options*

Response technique	Will the response be effective in the prevailing conditions?	Is the response capability sufficient to significantly affect the outcome in the time available?	Can sufficient equipment and personnel be made available?
At-sea containment and recovery	Yes / No	Yes / No	Yes / No
Protective booming	Yes / No	Yes / No	Yes / No
Controlled in-situ burning	Yes / No	Yes / No	Yes / No
Dispersant use	Yes / No	Yes / No	Yes / No

The apparent 'luxury of choice' between different response techniques can cause confusion and unnecessary debate, but often a realistic choice does not exist because the type of oil spilled or the prevailing conditions will dictate the combination of response techniques that should be used. For example:

- If the sea is cold and a very high viscosity oil such as Mazut M-100 (a heavy fuel oil for power station use) has been spilled, such as happened at the *Prestige* spill off the Spanish coast in November 2002, the use of dispersants is not likely to be effective and all efforts should be devoted to recovery at sea and to protection of the shoreline.
- If the spill is of a crude oil and the sea is too rough for the effective use of booms and skimmers, then dispersant use—and the possible consequences—should be considered. Protective booming of especially oil-sensitive areas should also be considered as a 'back-up', because no at-sea oil spill response technique is likely to be 100% effective.

All feasible response options should be compared, and their advantages and disadvantages weighed against each other and compared with the option of no intervention and allowing natural recovery.


USCG

Protective booming of key coastal areas should be considered as a backup to dispersant use.

NEBA and dispersant use

As described above, the first two steps of a NEBA process are common for all oil spill response techniques, including dispersant use. They involve evaluating data and predicting outcomes, with a focus on:

- estimating possible spill scenarios and where the spilled oil would drift under the influence of currents and wind; and
- assessing the ecological and socio-economic resources that may be affected.

The third step addresses trade-offs, and assesses whether the response techniques in the toolkit are:

- likely to be effective on the spilled oil in the prevailing conditions;
- capable of preventing a significant amount of oil from coming ashore within the time available; and
- feasible with the available resources.

When considering dispersant use, the first task of this step is to assess whether dispersant use would be effective on the spilled oil under the prevailing conditions.

Most oils that could be spilled at sea will be amenable to dispersant use soon after they have been spilled. Dispersant use is feasible in a wide range of prevailing sea conditions. When dispersants are sprayed from large aircraft, large areas (and therefore volumes) of spilled oil can be treated more rapidly than by other response techniques. Therefore, in many cases, dispersant use would be effective and feasible. The controlling factor might be the availability of dispersant equipment and trained personnel; this should have been addressed in oil spill contingency plans. If it is clear that dispersant use is unlikely to be successful due to oil type, prevailing conditions or lack of available time, alternative at-sea response techniques should be considered, but most will also be constrained by the same factors.

The operational analysis could therefore have concluded at this stage that dispersant use is a justifiable response. The next task is to consider the consequences, the benefits and the potential risks, of dispersant use.

The benefits and potential risks of dispersant use can be summarized as follows:

- The benefit of dispersant use is to minimize ecological and socio-economic damage by removing oil from the sea's surface, preventing it from reaching sensitive coastal and shoreline habitats and enhancing the natural biodegradation processes.
- The potential disadvantage of dispersant use is that marine organisms inhabiting the upper water column will be briefly exposed to diffuse clouds of dispersed oil droplets and water-soluble oil compounds in the water column, compared to the situation if dispersants were not used. This exposure to dispersed oil can potentially have toxic effects on the marine organisms.

The decision to use, or not to use, dispersants is sometimes described as balancing a 'trade-off'; that is, to accept damage to the coastal resources if dispersant is not used, versus damage to marine organisms if dispersant is used. The implication of a 'trade-off' is that it is a choice between a certain amount of damage being caused on the coast by drifting oil, versus the same amount of damage being caused by dispersed oil in the water column. However, this is not the case and is one of the most-often misunderstood aspects of dispersant use. When spilled oil is transferred from the sea surface and into the water column by dispersant use, the potential for damage in the two ecological compartments is not equivalent. The damage in the offshore water column from dispersed oil can be much less than the damage that undispersed oil may cause to shorelines and coastal areas.

The benefit of dispersant use

Floating oil that drifts close to shore over seagrasses or comes ashore in particularly sensitive coastal habitats such as mudflats or wetlands can cause severe and long-lasting damage to these habitats and to the populations and shoreline communities of birds, mammals and other species. It can take years to decades for some of these shoreline communities to recover from oiling. Dispersant use can prevent this damage from happening. Further information on the much slower recovery potential for sensitive shorelines versus open waters is provided in the IPIECA-IOGP Good Practice Guide on the impacts of spills on marine ecology (IPIECA-IOGP, 2015) and on shorelines (IPIECA-IOGP, 2015a).

Dreamstime.com

Wetlands such as mangroves are particularly sensitive to long-term damage from floating oil.

Additionally, removing floating oil will reduce the threat to surface-dwelling animals. Industrial seawater intakes, tourism beaches and other coastal and shoreline industrial and amenity features are also protected if oil is dispersed offshore.

The potential risks of dispersant use

Past experience during several major oil spill incidents has shown that negative effects on marine organisms caused by the elevated concentrations of dispersed oil in water of 10 metres depth or more due to dispersant use were localized and of short duration (Baker *et al.,* 1984). A considerable amount of evidence from past toxicity studies indicates that any effects of realistic exposures to oil dispersed into reasonable water depths will be relatively slight and localized. Ecological studies and monitoring following major oil spills have repeatedly shown that the populations and communities of water column organisms (e.g. algae and zooplankton) recover much more quickly from brief exposure to dispersed oil in the water than the populations and communities of birds, mammals, seagrasses, saltmarshes or mangroves that may be exposed to oil that stays afloat as a slick or comes ashore.

Wellcome Images

Plankton populations recover quickly from the effects of brief exposure to dispersed oil.

Any 'trade-off' consideration of dispersant use therefore has to consider the amount of severe and long-lasting damage to oil-sensitive coastal habitats and socio-economic resources that can likely be *prevented by dispersant use* and compare that with highly localized and short-lived effects that might be *caused to the marine environment by dispersant use*.

Table 7 *The benefits and drawbacks of dispersant use*

Benefits	Drawbacks
● Reaches and treats significantly more oil than other response techniques. ● Can be applied over a broad range of weather conditions. ● Speeds up oil removal from the water column by enhancing biodegradation. ● Prevents oil from drifting to the shoreline, reducing the threat to ecological and socio-economic features. ● Reduces the potential for harmful vapours in the vicinity of a spill, and hence provides a safety benefit. ● Removes the need for potentially large-scale and prolonged shoreline clean-up operations. ● Avoids the creation of large volumes of waste material often associated with shoreline clean-up operations.	● Does not collect oil directly from the environment but rather transfers it from the surface to the water column. ● Potential effects of dispersed oil on marine life in the water column (anticipates short-lived and localized exposures). ● May not be effective on high viscosity oils in cold seas. ● Has a limited time 'window of opportunity' for use following a spill. ● Potential impact on the market confidence in fisheries due to misunderstandings of the effects of dispersant on seafood.

The NEBA case justifying the use of dispersant on spilled oil in waters of depths greater than 10 or 20 metres is generally clear: the potential benefits are large and the potential risks are very small (Kucklick *et al.*, 1997). A retrospective NEBA has been conducted for dispersant use at the *Sea Empress* oil spill, confirming that dispersant use achieved overall environmental benefit (Lunel *et al.*, 1997). In the USA, the Coast Guard have undertaken a number of Ecological Risk Assessment Workshops in conjunction with various Federal and State agencies. These workshops have considered the impacts and ecosystem recovery rates from various oil spill response options at hypothetical open water spills in the Gulf of Mexico and beyond. Similar workshops have been held in New Zealand and the UK. These events use NEBA and have favoured the use of surface dispersant application during larger spills in offshore waters.

Where oil is spilled on waters less than 10–20 metres deep, or close to the shore or bays, one should examine the suitability of dispersant use more closely. This would most likely be the case where the adjacent shoreline is of very high sensitivity to long-term damage from undispersed stranding oil, such as biologically productive wetlands or mangroves (Baca *et al.*, 2005). Here, the general-case approach may be rendered insufficient, due to the reduced dilution potential. More specific information on dispersed oil toxicity may therefore be required as part of the NEBA considerations.

How dispersants are applied

Principles of surface dispersant application

Dispersant can be sprayed onto floating oil from a number of platforms, including vessels, helicopters and fixed-wing aircraft of various sizes. The aim of any dispersant spraying operation is to accurately deposit the dispersant on the spilled oil as evenly as possible and achieve the recommended dispersant dosage rate.

Dispersant droplet size

The spray system used should deposit dispersant droplets onto the spilled oil with diameters of approximately 0.4 to 0.7 mm, resembling light rain (Lindblom and Cashion, 1983). Smaller dispersant droplets are likely to be blown off target by the wind, and dispersant droplets larger than approximately 1 mm in diameter may pass through thinner oil layers and be lost into the water.

Recommended treatment rate

The recommended rate of application for surface dispersant is usually 1 part dispersant to 20 or 25 parts of spilled oil. This can be difficult to achieve in practice as it is not possible to accurately assess the thickness of the floating oil. An average oil layer thickness of 0.1 mm is often assumed, although the actual thickness can vary over a wide range (from less than 0.0001 mm to more than 1 mm) over short distances. Some degree of localized over-dosage and under-dosage is inevitable when dispersant is sprayed.

Capabilities of different dispersant spraying systems

The successful use of dispersant requires planning and training. Accurately spraying dispersant onto spilled oil from aircraft (helicopters or fixed-wing) at low altitude is a specialized task that requires training and experience. Crews of vessels of opportunity (VOOs) will need to be trained in the safe and effective use of dispersant. A successful dispersant spraying operation requires good organization and communication between several groups of people.

Cedre

USCG

USCG

Dispersant spraying from vessels

A suitable vessel dispersant spraying system must be used (ASTM International have produced a number of Standards relating to dispersant application equipment—see www.astm.org). Some dispersants can be sprayed diluted with water and other dispersants should not be used in this way. Spray systems often consist of long spray arms fitted with multiple nozzles, and can be mounted at various locations on the vessel (bow, amidships or stern). Single-nozzle systems are also available.

The speed of the vessel will have a direct impact on the concentration of dispersant being applied to the oil; the faster the vessel speed the lower the concentration of dispersant and vice versa (Merlin *et al.,* 1989). The optimum speed will depend on a number of factors, but will generally lie within the range of 1–10 knots. A typical rate of application should be 5–20 m^3/km^2 (approximately 5–20 US gallons/acre). Some areas may require repeated passes to ensure the dispersion of thicker patches of oil.

Any dispersant operation must be directed at the thickest portion of the slick (the leading edge) and not the thinner iridescent silvery sheen areas. When the thickest part of the slick has been located, most often with the help of aerial surveillance, a 'ladder' or zigzag approach should be adopted when spraying the thicker oil.

Dispersant spraying from fixed-wing aircraft

Dispersant spraying from aircraft was investigated in the late 1970s and 1980s (Lindblom and Barker, 1978; Parker, 1979; Cormack, 1983; Lindblom and Cashion 1983). Several systems for spraying dispersant from fixed-wing aircraft exist. These include the NIMBUS package, the Modular Aerial Spray System (MASS) package and the Aerial Dispersant Delivery System (ADDS) package. The ADDS package has the biggest payload of the three systems. It consists of a removable tank and spray system that can be fitted to a Hercules aircraft. It is rolled into the airplane's cargo bay and quickly set up to carry and spray up to 5,000 US gallons (19,000 litres) of dispersant. Dispersant spraying systems using Boeing 727 and 737 aircraft are being developed.

US Air Force

Restocking a large-scale aerial system with dispersant between sorties.

To ensure accurate deposition of dispersant on the spilled oil, dispersant spraying needs to be conducted at low altitude. The spraying speed should be as low as is consistent with safe operation of the aircraft. During dispersant spraying, it is not possible for the crew in the spraying aircraft to identify exactly where the thicker patches of oil are located. A second, smaller aircraft flying at 400 or 500 feet is needed to direct the spraying aircraft onto the oil to be sprayed, and to give instructions, i.e. 'spray on' and 'spray off', at the appropriate times.

Table 8 *The benefits and limitations of different types of dispersant spraying systems*

	Fixed-wing aircraft	Helicopter	Vessel
System	● Dispersant application systems have been developed for large aircraft platforms such as the Boeing 727 / 737 and the Hercules. ● Smaller 'crop sprayer' type aircraft can also be used to apply dispersant.	● Helicopters can be used to carry specialist 'Helibucket' spray systems.	● Vessels of opportunity (VOOs) can be fitted with a dispersant spray system.
Benefits	● Aircraft can get to the oil spill site quickly. ● Large aircraft systems can hold a large volume of dispersant and treat a large area of oil in a relatively short period of time.	● Helicopter application can be more targeted than aircraft application and can therefore be used to treat smaller 'break away' spills.	● Can stay 'on station' for long periods and carry a large volume of dispersant. ● Dispersant application vessels are easier to obtain than aircraft as VOOs can be fitted with boat spray sets. ● Convenient for monitoring effectiveness.
Limitations	● Limited numbers of systems are available. ● Aircraft have to return regularly to base to be resupplied with dispersant. ● Crew hours have to be taken into consideration when calculating the amount of spray runs that are possible.	● Helicopters have a shorter range than aircraft. ● Helibuckets generally have a smaller capacity than aircraft spray systems.	● If deck space is used by other equipment, additional capacity to hold dispersant may be limited. ● Are able to cover a smaller area than an aerial system.

Health and safety aspects of dispersant use

A primary human health concern is exposure to crude oil or products that can potentially present hazards, including hydrogen sulphide and volatile organic compounds (VOCs) such as hexane, and light aromatics. As oil weathers on the sea surface, the lighter constituents (VOCs) rapidly evaporate or dissipate. Typically, the heavier components, if not dispersed into the water column, eventually form tar balls or mousse and deposit on land or in sediment. Such 'weathered' oil is considered less acutely toxic to humans and animals compared to fresh oil. These heavier weathered fractions can still have significant environmental and amenity effects through smothering.

The safety of the general public and responders is assigned the highest priority during spill response operations. An incident management system, with safety and health as its core, starts from the top and penetrates to all levels within the organizations participating in response activities. The management team will appoint an individual with a supporting team that has the skills to undertake responsibility for safety and health management of all oil spill response operations. The responsible individual will consider issues such as monitoring and maintaining awareness of active and developing situations, assessing hazardous and unsafe situations and developing measures to assure personnel and public safety. These measures include:

- An initial site assessment with documented processes for: hazard identification; risk assessment; and selection and protection of responders, including local labour, provision of control zones, and specialized equipment and PPE required in those zones, exclusion of shipping, fishing and recreational vessels from the spill response area, assessment of training needs, and identification of decontamination areas. Competent personnel, i.e. those appropriately trained and experienced in the issues surrounding spill safety, will manage and supervise the response.
- Developing and implementing a Site Safety and Health Plan (SSHP): information to develop the plan can be obtained from competent health and safety professionals, the risk assessment process and environmental monitoring. The Plan should be reviewed regularly with regard to the safety and health implications of the activities proposed or in progress.

When assessing the risk for dispersant operations two questions must be taken into consideration:

1. Is there any potential exposure?
2. If there is a potential exposure, what protective measures should be put into place to eliminate that exposure?

The solvents in modern dispersants are selected for performance and low toxicity, and are primarily used as a carrier to deliver the surfactant to the oil. As previously mentioned, many of the surfactants found in dispersants are also found in household cleaners, shampoos, detergents, soaps and foodstuffs. Each dispersant will have a Safety Data Sheet (SDS) identifying potential hazards, including human health hazards, and exposure controls and required personal protection. The SDS should be consulted, and appropriate measures put in place to minimize any risk to human health.

The key to managing the potential health risks associated with dispersants is to ensure that possible exposure routes are assessed and then either removed or minimized. For dispersant operations, this is achieved by suitable controls during storage, handling and spraying operations, and by wearing appropriate PPE to prevent any skin or eye contact. Recommended PPE for operators on a vessel includes: impervious suit; personal flotation device (PFD) or lifejacket; chemical resistant goggles and gloves; ear defenders (whilst machinery is running); steel toe cap boots; and a respirator. Vessel decks should be washed with sea water if dispersant is blown aboard, as dispersant makes the decks extremely slippery.

When spraying from vessels or aircraft, exclusion zones must be established around other response vessels and around vessels involved with transportation, fishing or recreation. These zones ensure that low-flying aircraft remain safe when spraying but in both cases the exclusion zones will also take into account the potential wind drift of the droplets and any aerosols produced when spraying. This will eliminate the potential exposure of other responders as well as the general public. In general, the public is unlikely to be exposed to dispersed oil since the dispersed oil will be mixed into the water column and be diluted far from shore and away from the public. In the unlikely event that exposure was to occur, short-term exposures to dispersed oils would be expected to have effects similar to those of being exposed to the oil itself.

If observers are close to the dispersant spraying operation, they should also wear the appropriate PPE; the exposure of observers can usually be minimized by avoiding close proximity to the spraying. Dispersant is normally sprayed onto spilled oil some distance from the shore, hence the general public will not be exposed to dispersant spray.

Judging dispersant effectiveness at sea

The effectiveness of the dispersant spraying operation should be monitored to ensure that the spilled oil is being dispersed.

Field test kits are available to give an indication of whether dispersant use is likely to be successful (AMSA, 2012). A test spray of dispersant on the spilled oil should be carried out prior to commencement of full operations.

Visual estimation of dispersant effectiveness

Visual observation requires good viewing conditions. Successful use of dispersant will cause the spilled oil to be transferred into the water column as a light-brown ('café au lait') coloured cloud, or plume, which slowly fades from sight as the dispersed oil is diluted into the water. The plume of dispersed oil may not be formed immediately as wave action is required to disperse the dispersant-treated oil. The absence of an immediate cloud does not therefore mean that the dispersant is not effective. The plume of dispersed oil may drift under oil remaining on the sea surface and be obscured from view. A milky white plume will be present if the dispersant has missed the oil or has run off very viscous or highly emulsified oil.


Dr Tim Lunel

A white plume indicates that the dispersant is not effective on this highly viscous oil.

SMART protocol

The SMART (Special Monitoring of Applied Response Technologies) protocol was developed by the US Coast Guard and others (Henry *et al.*, 1999; Henry and Roberts, 2001). The purpose of this monitoring is to judge the operational effectiveness of the dispersant application and decide whether it is working or not. It does not aim to monitor the impact of the dispersed oil. The SMART protocol has three tiers of monitoring as described below (note that these are not related to the response tiers used in oil spill contingency planning):

Tier 1: Visual monitoring (as described in the previous sub-section).

Tier 2: Combines visual monitoring with on-water teams conducting real-time water column monitoring (using a fluorometer) at a single depth with water sample collection for later analysis.

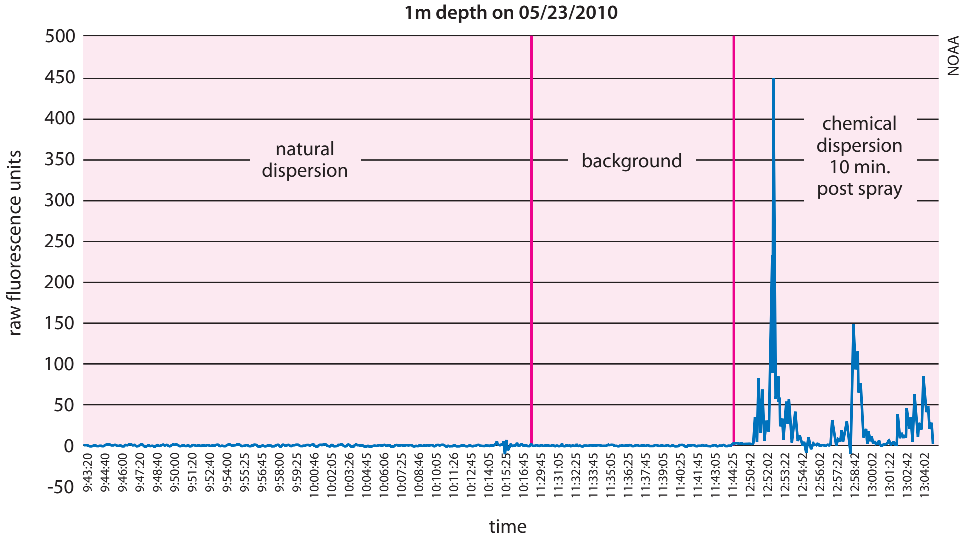
Tier 3: Expands on the Tier 2 water monitoring to meet the information needs of the incident. This may include monitoring at multiple depths (using the fluorometer) and also taking water quality measurements or more extensive water samples.

USCG

Above: preparation of a fluorometer to monitor dispersant effectiveness.

A fluorometer is used to measure the ultra-violet fluorescence (UVF) of oil in the water (Hurford *et al.*, 1989). Under the SMART protocol, UVF is used as a comparative technique. The UVF signal at various water depths is measured at locations where: (i) no oil is present on the sea surface (background); (ii) oil is present on the sea surface (natural dispersion); and (iii) where oil has recently been sprayed with dispersant (chemically dispersed). Significantly higher UVF signals from locations under dispersant-treated oil compared to either background or under untreated oil indicate that oil has been dispersed into the water. Samples of the water containing dispersed oil should be taken to calibrate the UVF signal, but UVF in these circumstances cannot be quantitative because measurements are only made in a small fraction of the water that could contain dispersed oil.

Figure 15 *Example result from fluorometer monitoring of a vessel dispersant application test to evaluate effectiveness*



NOAA

Left: Example of the results from the use of fluorometry testing to evaluate dispersant effectiveness.

During a spill response, flexibility and adaptability are essential for success (OSRL, 2011). The sampling plan is dictated by many factors such as the availability of equipment and personnel, on-scene conditions, and the window of opportunity for dispersant application. The need for flexibility in sampling design, effort and rapid deployment (possibly using a vessel of opportunity), may dictate the nature and extent of the monitoring. It can be challenging to mobilize a vessel into a zone that has been sprayed from the air, as the dispersed cloud may become separated from any remaining floating oil and be difficult to locate. This monitoring is most effective when spraying from a vessel, but there are still challenges. In cases where the primary application is by aerial systems, on-water monitoring of continued operational effectiveness on weathering oil may be carried out from a dedicated monitoring vessel. Further information is provided in the IPIECA-IOGP report on dispersant effectiveness monitoring (IPIECA-IOGP, 2015f).

Examples of dispersant use

Incident reports indicate that dispersants were used during approximately 210 oil spill response operations over almost four decades, from 1968 through 2007 (Steen, 2008). Many of these applications were on a relatively limited scale with small amounts of dispersant being used. A review of the ITOPF (International Tanker Owners Pollution Federation) database of past oil spills has found that, of the 258 marine incidents that ITOPF were involved with between 1995 and 2005, 46 (18%) involved the use of dispersants (Chapman *et al.*, 2007).

A large dispersant spraying operation using aircraft was undertaken in response to the *Sea Empress* oil spill in February 1996 off Milford Haven in Wales, UK (Harris, 1997; Edwards and White, 1999). Approximately 72,000 tonnes of Forties crude oil leaked into the sea from the grounded vessel over a period of seven days. A total of 446 tonnes of dispersant were sprayed from aircraft onto the oil on the sea surface. It was estimated (SEEEC, 1996) that 40% (±5%) of the oil evaporated, 2.5–5.5% was recovered at sea and from the shore, and 2–6% became stranded on the shore and in sediments. An estimated 52% (±7%) of the oil dispersed at sea and, by comparison to data obtained from carefully controlled sea trials, it was further estimated that 14% (±7%) was naturally dispersed and 38% (±14%) was dispersed by dispersant use (Lunel *et al.,* 1997). Dispersant use therefore dispersed at least 18,000 tonnes, and possibly 38,000 tonnes, of oil into the sea. Effects on marine life were monitored (SEEEC, 1996; Law *et al.*, 1997; Dyrynda *et al.,* 1997; Law *et al.*, 1998; Law and Kelly, 2004). The high concentrations of dispersed oil in the water resulted in notable impacts on seabed life, but recovery was rapid and there was no persistent contamination of sub-tidal sediments.

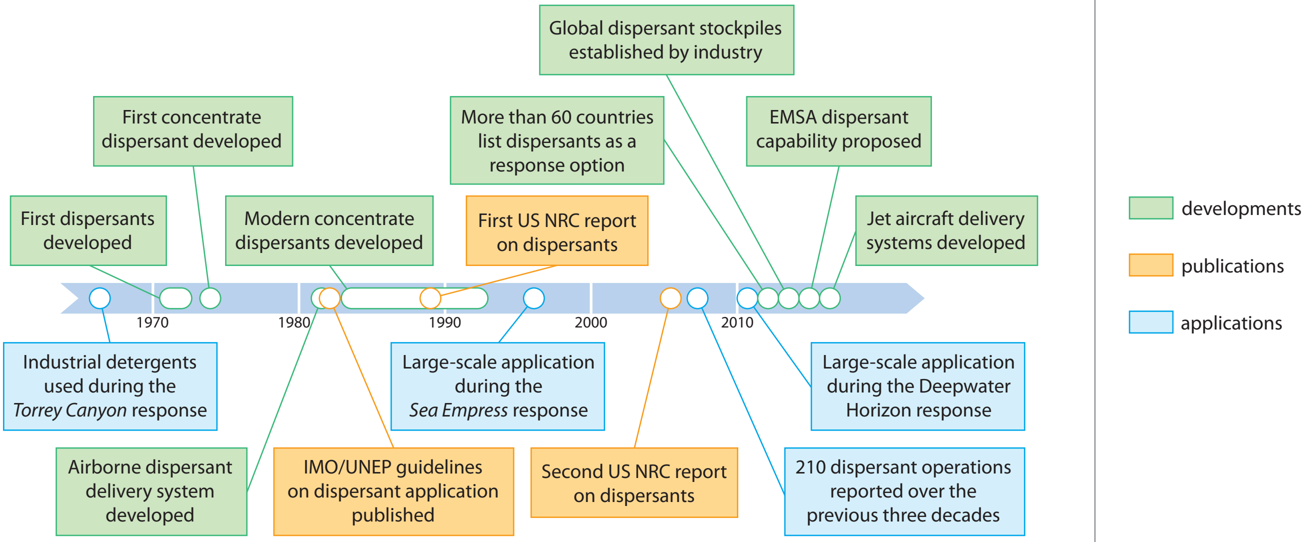
USCG

More than 3,500 tonnes of dispersant were applied by air in the Gulf of Mexico during the response to the Macondo incident in 2010.

During the response to the release of oil resulting from the Macondo incident in the Gulf of Mexico in 2010, a total of 3,857 tonnes of dispersant were sprayed, 3,511 tonnes from aircraft (Gass *et al.*, 2011 and Joeckel *et al.*, 2011) and 346 tonnes from ships, onto floating oil (National Commission, 2011). Water sampling and the use of SMART protocols indicated that dispersant use was effective (BenKinney *et al.,* 2011; Levine *et al.*, 2011). The amount of oil from the subsea release that reached the sea surface has not been estimated with any degree of certainty, and estimating the amount of oil that was dispersed has therefore not been possible.

Dispersant use is an established and proven part of the response toolkit in many countries, used to reduce the overall ecological and socio-economic damage that potential oil spills may threaten. Figure 16 illustrates the key dispersant developments, applications and publications over a selected timeline.

Figure 16 *Selected timeline showing key dispersant developments (green), applications (blue) and publications (orange)*



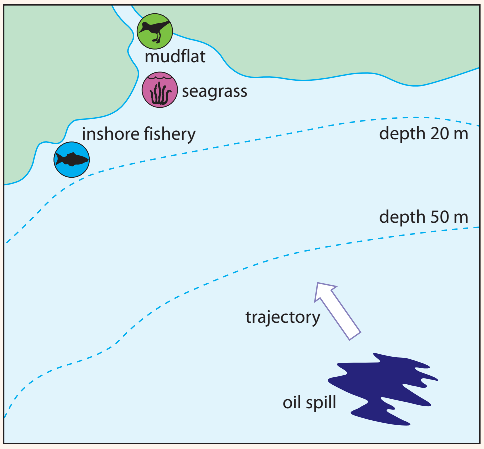
EMSA = European Maritime Safety Agency IMO = International Maritime Organization
UNEP = United Nations Environment Programme US NRC = United States National Research Council

Illustrative scenarios of potential dispersant use

The scenarios on the following pages illustrate the factors that would need to be taken into account when considering the use of dispersants as one of the oil spill response options. In each case it is assumed that it is logistically feasible to apply dispersants.

Scenario 1

A crude oil tanker has been in collision with a general cargo vessel 15 nautical miles from land in water that is 70 metres deep. Several thousand tonnes of a light crude oil have been released onto the sea surface.



- The oil slick is drifting toward the shore under the influence of the prevailing 15-knot wind.
- Wave height is around 1 to 1.5 metres.
- The sea temperature is 15°C.
- There are fishing grounds closer to the coast and seagrass beds in shallow water.
- Coastal resources that could be impacted by the oil include an estuarine mudflat that supports a large population of wading birds.

Should dispersant use be considered?

Under prevailing conditions, the spilled oil would reach the shore approximately 30 to 40 hours after the release. During this time the spilled oil would become 'weathered' and emulsified. The spilled oil volume would initially decrease due to evaporative loss, but then increase due to emulsification. If 3,000 tonnes of oil had been spilled, this could form more than 10,000 tonnes of emulsified oil.

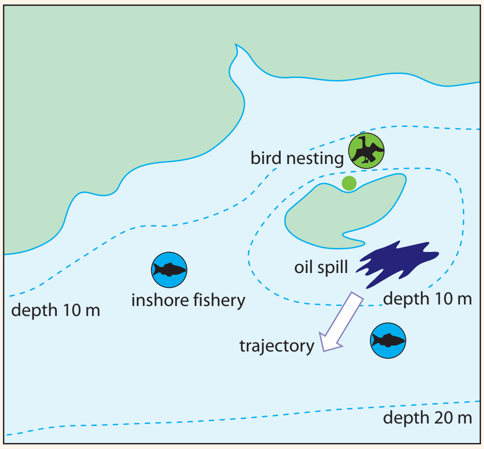
The near-shore and coastal sensitivities are high and their protection from oil would result in high environmental benefit. The estuarine mud-flat is biologically productive and difficult to either protect with booms or clean up if oiled.

It is most unlikely that either at-sea containment and recovery or controlled in-situ burning alone could deal with the amount of spilled oil in the time available. Most light crude oils are amenable to dispersant use soon after they have been spilled. It would be important to obtain information about the pour point of the crude oil to ensure that it is well below 15°C. The viscosity and pour point of the oil will rise during 'weathering'. The prevailing conditions of 1 to 1.5 metres wave height and 15 knot wind are good for dispersant use. The effectiveness of dispersant use would need to be monitored.

Dispersant use on the spilled oil as far as possible from shore would be an effective part of the response and is supported by NEBA.

Scenario 2

A large ferry has run aground on a rocky island. A fuel tank has been ruptured and several thousand litres of MDO (marine diesel oil) have been released onto the sea surface in water that is 2 to 3 metres deep next to the ferry.



- The ferry has high-speed diesel engines with MDO as fuel.
- The sea temperature is 15°C.
- The oil is being blown out to sea and into deeper water by a 15-knot offshore wind.
- Wave height is around 1 to 1.5 metres.
- There is an important bird nesting area on the cliffs of the island.
- The island is in the middle of an important fishery.

Should dispersant use be considered?

The spilled MDO would drift offshore and be naturally dispersed and dissipated within a day or two in the prevailing conditions. It is therefore inevitable that the water-soluble oil compounds and naturally dispersed oil would enter the water, although a lot of the oil would eventually evaporate.

The fishery could be the subject of a temporary closure due to the naturally dispersed oil in the water. Birds from the nesting colony diving through oil on the sea surface could be affected.

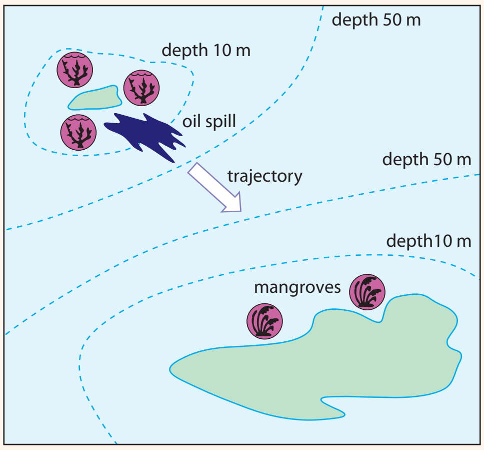
At-sea containment and recovery and controlled in-situ burning are unlikely to be effective; the spilled MDO will rapidly spread out to a very thin layer. It would not be feasible to concentrate this in booms for recovery with skimmers or burning. Although the prevailing conditions are good for dispersant use, this is not an appropriate response to spills of MDO. Dispersing MDO into the water column would add to the already elevated concentrations of oil in the water from natural dispersion without any benefit as the oil is drifting offshore and coastal resources are not threatened.

Dispersant use should not be undertaken as it would not produce a net environmental benefit. The situation should be monitored, but no active at-sea responses such as at-sea containment and recovery or controlled in-situ burning are likely to succeed.

… Illustrative scenarios of potential dispersant use (continued)

Scenario 3

A large general cargo vessel has run aground on a coral reef in a group of islands. The coral reef surrounds a very small island that is 5 nautical miles from a larger tropical island. A fuel tank has been ruptured and 50 tonnes of IFO-180 heavy fuel oil have been released onto the sea surface.



- The oil slick is drifting away from the small island and toward the larger island under the influence of the prevailing wind at 5 knots wind speed.
- The water depth at the site of grounding is only 3 metres. There is deeper water (70 metres) between the two islands.
- Wave height is around 0.2 to 0.3 metres.
- The sea temperature is 25°C.
- There are extensive areas of mangroves on the coast of the larger island that are threatened by the oil.

Should dispersant use be considered?

Depending on the prevailing currents, the spilled oil will take approximately 35 hours to drift ashore on the larger island. Water-in-oil emulsification will be slow in the calm conditions.

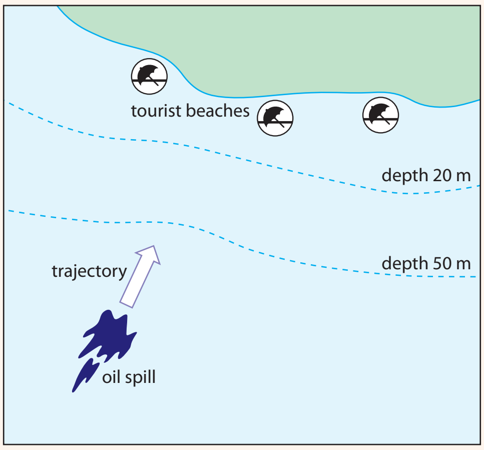
The vessel is grounded on the coral reef surrounding the small island and oil will be floating above the reef. Mangroves have high biodiversity and may suffer long-term damage from oil smothering. The strategic priority should be to prevent the oil from drifting onto the shore of the larger island and into the mangroves.

At-sea containment and recovery with booms and skimmers would be feasible in the prevailing conditions. Controlled in-situ burning is not effective with this grade of heavy fuel oil. Dispersant use would be effective on this grade of heavy fuel oil at the sea temperature of 25°C.

This spill scenario would require the coordinated use of response techniques. Dispersant use should be concentrated on oil drifting on water more than 10 or 20 metres deep, where a clear net environmental benefit can be achieved by reducing the volume of oil threatening the mangroves. Dispersing the oil in shallower waters near the smaller island could cause some additional damage to the submerged coral, hence this does not have NEBA justification. At-sea containment and recovery equipment should be deployed in the shallow water off the coast of the larger island to recover oil that has not been treated with dispersant. Where feasible, protective booms should be deployed to deflect oil away from mangroves on the larger island.

Scenario 4

A subsea crude oil export pipeline from an offshore installation has been ruptured by a seismic event. An estimated total of 300 tonnes of the heavy crude oil reached the sea surface from a release depth of 100 metres before the pipeline was isolated, and a slow release of oil continues as the ruptured pipeline fills with seawater.



- The oil slick is drifting toward the shore that is 30 nautical miles away under the influence of the prevailing wind at 25 knots wind speed.
- Wave height is around 3 to 4 metres.
- The sea temperature is 15°C.
- Coastal resources include a number of adjacent tourist resorts with sandy beaches.

Should dispersant use be considered?

The oil is likely to start coming ashore after approximately 40 to 48 hours at sea. In the rough seas, the heavy crude oil is predicted to 'weather' rapidly and become emulsified, creating approximately 600 tonnes of emulsion.

The main identified threat is to the socio-economic value of the tourist resorts. The sandy beaches could be cleaned using a relatively straightforward operation if no at-sea response is undertaken, but allowing the oil to strand would cause immediate major disruption to the resorts and potentially lead to longer-term issues of reputational damage to the area's tourism.

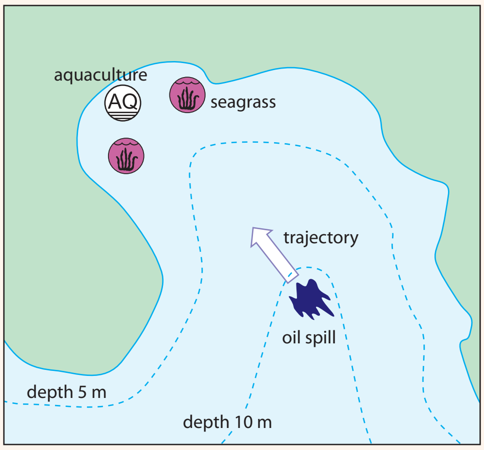
At-sea containment and recovery with booms and skimmers or controlled in-situ burning would not be feasible in the prevailing sea conditions. Dispersant use would be feasible with dispersant sprayed from aircraft, and would be effective until the oil had become too emulsified, perhaps after 24 or 36 hours.

Dispersant use on the oil, plus monitoring for effectiveness, would have a NEBA justification, as it would protect the tourism industry by minimizing the shoreline threat.

… Illustrative scenarios of potential dispersant use (continued)

Scenario 5

A double-hulled 35,000-dwt oil tanker with a cargo of light crude oil has lost power and run aground on a rocky reef in a large shallow bay. The rocky seabed has torn a hole in two tanks and oil is leaking into the sea. Approximately 4,000 tonnes of oil is likely to be lost from the vessel before it can be salvaged.



- The oil is drifting toward the rocky shore that is 15 nautical miles away under the influence of the prevailing wind at 20 knots wind speed.
- Wave height is 2 to 2.5 metres.
- The water near to the shore is shallow, with depths ranging from 5–10 metres.
- There are extensive seagrass beds in the shallow water.
- There are extensive oyster beds and other aquaculture activities closer to the shore.

Should dispersant use be considered?

The spilled oil will drift across the shallow water before coming ashore in approximately 24 hours.

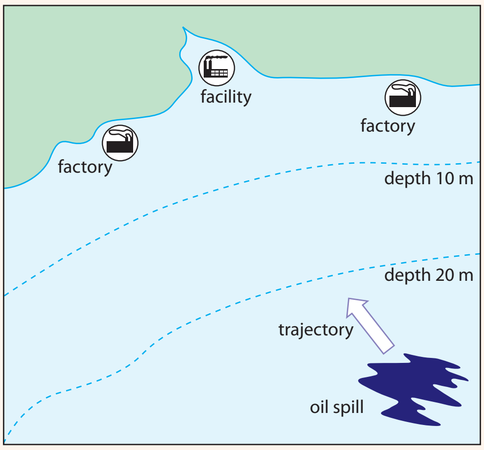
The threatened resources, i.e. the seagrass beds, oyster beds and other aquaculture activities, could be affected by oil that is naturally dispersed into the water by the prevailing conditions. Some of the oil that eventually drifts onto the rocky shore will subsequently be re-mobilized by tides and cause prolonged exposure to spilled oil, although oil weathering will reduce the potential effects with time.

At-sea containment and recovery and controlled in-situ burning are unlikely to be effective response techniques in the prevailing conditions. Dispersing the oil into the relatively shallow water will expose the threatened resources to more highly elevated concentrations of oil, although tidal flushing would likely remove the dispersed oil quite rapidly.

On balance, and because the prevailing conditions make other response options ineffective, dispersant use could be justified by NEBA compared to the alternative of no active at-sea response. The benefit would be preventing prolonged exposure of the threatened resources to the oil, but at the cost of temporarily increasing the effects caused by the spilled oil.

Scenario 6

An oil tanker with a cargo of waxy crude oil (pour point of +27°C and heated to 35°C for transport) has been in collision with a general cargo vessel in dense fog while approaching an oil terminal and harbour. A wing tank on the tanker has been damaged above the waterline. Approximately 1,000 tonnes of the crude has been released onto the sea surface



- The wind speed is 1 to 2 knots and the dense fog is lifting.
- Wave height is approximately 0.1 metres.
- The sea temperature is 5°C and the air temperature is 0°C.
- The water depth is 30 metres.
- The nearby shore is heavily industrialized.

Should dispersant use be considered?

The crude oil will rapidly solidify into waxy lumps shortly after it comes into contact with the cold sea. Oil weathering will then be minimal with little evaporative loss and no emulsification in the very calm sea conditions. The patches of solidified oil will drift very slowly under the influence of the wind and currents.

The oil presents little hazard to ecological resources in its solid state. The risk of smothering of small coastal creatures is low and the potential for toxic effects on marine organisms is low because of the physical state of the spilled oil. However, oil that does reach the shoreline would be persistent and could eventually become incorporated into the shoreline substrate.

Controlled in-situ burning would not be an appropriate or effective response. The oil could be corralled with booms and recovered using some types of skimmers, such as brush skimmers.

Dispersant use should not be undertaken as it would not be effective. At-sea containment and recovery would be the most effective response.

Conclusion

The use of oil spill dispersants is one of several possible at-sea oil spill response techniques that remove floating spilled oil. Dispersant use can be an effective way of minimizing the overall ecological and socio-economic damage, by preventing oil from reaching shorelines and enhancing the natural biodegradation processes that break down oil.

Modern dispersants are blends of surfactants in solvents. The surfactants in the major dispersants in use around the world today are also used in many other products, including consumer products. These surfactants are biodegradable. Dispersant use greatly enhances the rate and extent of natural dispersion of oil caused by wave action. The surfactants allow the mixing energy of the waves to convert a greater proportion of the oil into small oil droplets. These droplets are pushed into the upper water column by wave action and maintained there by turbulence. The dispersed oil droplets are readily available to naturally-occurring hydrocarbon-degrading microorganisms in the water. Dispersion increases the oil/water surface area, facilitating biodegradation whereby the majority of the oil is broken down primarily to carbon dioxide and water.

Like all other techniques in the oil spill response toolkit, dispersant use has some limitations, but it also has capabilities that make it particularly useful in responding to larger oil spills at sea. Most crude oils will be amenable to dispersant use, but the effectiveness of the dispersant will decrease with increased oil viscosity caused by oil 'weathering'. Dispersants may not be effective on high viscosity residual fuel oils in cold seas or on crude oils with pour points above the sea temperature.

In comparison with the other spill response tools, dispersant use can often be the most rapid and effective technique to remove floating oil:

- Spraying dispersants from aircraft enables large areas of floating oil to be dispersed into the sea within a relatively short time.
- Aerial application capability can respond to remote locations relatively quickly.
- There is reduced exposure and safety risk to response personnel and the public.
- Dispersants can be used in sea conditions that are too rough for the effective use of at-sea containment and recovery or controlled in-situ burning.

However, there is a potential risk that marine organisms inhabiting the upper water column will be briefly exposed to diffuse clouds of dispersed oil droplets and water-soluble oil compounds, to a greater extent than if dispersants were not used. This exposure to dispersed oil has the potential to cause toxic effects on the marine organisms.

Oil contains low levels of water-soluble compounds that can cause toxic effects on some marine organisms. The severity of toxic effects is related to the concentration of these compounds in water and the length of time that the organisms are exposed to them. The exposure of marine organisms will be to a brief 'spike' of elevated concentration of these compounds and dispersed oil droplets shortly after dispersant use on spilled oil. These exposure conditions are far less severe than used in standard laboratory toxicity testing procedures. Evidence from toxicity studies on dispersed oil indicates that effects from realistic exposures to dispersed oil in reasonable water depths will be relatively slight and localized.

Planning is an essential process for effectively dealing with potential oil spills. In order that the use of dispersants can be a viable response option, they need to be available without delay. It is therefore important to consider the various aspects of dispersant use in oil spill contingency planning. Net environmental benefit analysis (NEBA) is part of the planning process and is used by the response community for making the best choices to minimize impacts of oil spills on people and the environment. It considers potential spill scenarios, likely damages and the efficiency and feasibility of the response options.

When considering the use of dispersant, the first task is to assess whether dispersant use would be effective on the spilled oil under the prevailing conditions. If dispersant use would be effective, the next task is to consider the consequences, the benefits and the potential risks, of dispersant use:

- The benefit of dispersant use is to minimize ecological and socio-economic damage by removing oil from the sea's surface, preventing it from reaching sensitive coastal and shoreline habitats and enhancing the natural biodegradation processes.
- The potential disadvantage of dispersant use is that marine organisms inhabiting the upper water column will be briefly exposed to diffuse clouds of dispersed oil droplets and water-soluble oil compounds in the water column, compared to the situation if dispersants were not used. Past experience at several major oil spill incidents has shown that negative effects on marine organisms caused by the elevated concentrations of dispersed oil in water greater than 10 metres depth due to dispersant use were localized and of short duration.

The NEBA case for dispersant use on spilled oil in waters of depths greater than 10 or 20 metres is generally clear; the potential benefits are large and the potential for damage is very small. Where spilled oil is in waters less than 10 or 20 metres deep, or close to the shore or bays, one should examine the suitability of dispersant use more closely.

It is appropriate for countries to develop regulations regarding dispersant use. These normally consist of two parts:

1. Dispersant product approval regulations: these describe which dispersants would be approved for use in national waters, and ensure that these products are both effective and of relatively low toxicity compared to oil.
2. Dispersant use authorization regulations: these define where and when approved dispersant products may be authorized, including pre-authorization, for use on spilled oil in national waters.

If dispersants are to be used they must be applied effectively, i.e. sprayed onto the thicker patches of oil at the recommended dispersant treatment rate of 1 part dispersant to 20 or 25 parts of oil. Dispersant spraying can be done from aircraft or ships. The effectiveness of dispersant application needs to be monitored by methods such as the SMART (Special Monitoring of Applied Response Technologies) protocol. The need for flexibility in sampling design, effort and rapid deployment (possibly using a vessel of opportunity), may dictate the nature and extent of the monitoring.

Dispersant use is an established and proven part of the response toolkit and can make a major contribution to minimizing the ecological and socio-economic impacts of marine oil spills.

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