A Review of Literature Related to Oil Spill Dispersants Especially Relevant to Alaska

for

Prince William Sound Regional Citizens' Advisory Council (PWSRCAC)
Anchorage, Alaska

by

Merv Fingas
Environmental Technology Centre
Environment Canada

March, 2002

Abstract

This paper is a review of the literature on oil spill dispersants published from 1997 to January, 2002. As in the literature before this time period, it was found that results are often contradictory from one study to another. The paper also identifies and summarizes recent advances in dispersant effectiveness, toxicity, and application technology.

The results of the review indicate that dispersant effectiveness continues to be a major issue and is unresolved for Alaska North Slope (ANS) crude oil. Results of one recent dispersant effectiveness study for moderate-energy apparatus demonstrate dispersant effectiveness values ranging from 5 to 15% for ANS crude oil. This study was conducted at water salinities and temperatures known to occur in Alaskan waters, specifically Prince William Sound. High-energy tests such as the MNS, IFP, and EXDET demonstrate higher dispersant effectiveness results, however, the temperatures and salinities used are outside the range of those known for Prince William Sound. New studies question the high values of such tests. Large-scale testing and field tests show effectiveness values that are fractions even of the moderate-energy tests.

Since 1997, there have been numerous studies on the toxicity of oil and dispersed oil. Many of these indicated that the acute toxicity of chemically dispersed oil and physically (naturally) dispersed oil is different for different marine test species. In most of the cases, the chemically dispersed oil is somewhat more toxic than the physically dispersed oil. Studies of the food chain indicate that dispersed oil is more likely to result in the passing of naphthalene through the food chain. Similarly, body burdens of PAHs vary depending on the marine species and whether the oil is naturally or chemically dispersed.

There is little new in operational matters regarding application of dispersants. The finding that Corexit 9500 is much less effective on thick oil slicks when applied diluted with water than when applied neat is, however, significant.

A review of legislation shows that there are no significant changes in dispersant use policy in North America or Europe. There are only eight documented cases of dispersant use in the literature during this time period. One of these is in Nigerian waters, one in Australia, one in Israel, one in Venezuela, one in Britain, and the other three are in the U.S.

Summary and Issues

Overall

The literature on oil spill dispersants since 1997 is extensive, consisting of over 140 papers. The effectiveness of dispersants continues to be a major issue. Tests results with Alaskan crude oils show wide disparities in the effectiveness of dispersants. New results for moderate-energy apparatus show effectiveness values of 5 to 15% for Alaska North Slope (ANS) crude oil at salinities of about $20^{o}/oo$ and temperatures of about $10^{o}C$. High-energy tests such as the MNS, IFP, and EXDET show much higher values, but at higher temperatures and salinities.

There are a number of new toxicity studies. Many of these show that the acute toxicity of chemically dispersed oil and physically dispersed oil is different for different species. In most of the cases, the chemically dispersed oil is somewhat more toxic than the physically dispersed oil. Studies of the food chain show that dispersed oil is more likely to result in the passing of naphthalene through the food chain. Similarly, body burdens of PAHs vary depending on the marine species and whether the oil is naturally or chemically dispersed.

There is little new in operational matters regarding dispersants. The finding that Corexit 9500 is much less effective on thick oil slicks when applied diluted with water than when applied neat is, however, significant.

Efficacy of Dispersants in Alaskan Waters

The efficacy of dispersants in Alaskan waters remains an issue. Recent literature shows that the effectiveness of Corexit 9527 on Alaska North Slope, as measured in laboratory tests at the same temperatures and salinities as found in Prince William Sound, would range from 5 to 10%. Tests at regular temperatures for range show effectiveness for Corexit 9527 range from 16 to 57% for Prudhoe Bay or Alaska North Slope crude oils. High-energy tests show percentages above this mark. Some new data question the high-energy test results, indicating that in the field, results even lower than the moderate-energy tests are more likely.

Dispersants Stockpiled in Alaska

The primary dispersant stockpiled in Alaska is Corexit 9527. Although much of the current thinking is that Corexit 9500 would yield higher effectiveness results, laboratory tests show that this is not necessarily so. There are about equal numbers of laboratory results that show that Corexit 9527 is more effective on Alaskan crudes and those that show that Corexit 9500 is better. It should be noted that the same surfactant package is included in the formulation of both dispersants.

Operational Descriptions of Dispersant Use

There are no new descriptions in the literature of operations directly relevant to dispersant use in Alaska. There have been three small applications of dispersant in the Gulf of Mexico. It should be noted, however, that oil is highly dispersible and the water temperatures much higher in the Gulf of Mexico. There are no cold water dispersant applications described in the literature. Only one dispersant application other than those in the Gulf was noted in the world, that of the *Sea Empress* in Britain. In this case, dispersants were applied from DC-3 and Hercules aircraft over a part of the slick. Mass balance calculations indicated a loss of oil, although there was extensive coastal oiling.

A significant new finding was that Corexit 9500 was significantly less effective when applied diluted with water than when applied neat.

Dispersants Not Stockpiled in Alaska

Corexit 9500 is the only potentially useful dispersant that is not stockpiled extensively in Alaska. As already noted, there is variable data on the difference in effectiveness of Corexit 9527 and 9500 on Alaskan crude oils.

What Impacts Will Non-dispersed Remnants Have?

Extensive studies on the behaviour and fate of non-dispersed remnants of oil have not been conducted. There is no reason to believe that the effects of these remnants on the environment would be much different than the oil by itself. As reviewed in this report, extensive literature in recent years indicates that dispersed oil and untreated oil generally have similar effects on marine species, with this being somewhat species-dependent. For some species, the added dispersant may present a problem, whereas for others, it may present less of a problem. It is suspected that undispersed oil treated with dispersant is less adhesive, which is beneficial for shorelines, but not for physical recovery. No definitive tests have been conducted on this.

Policies in Other Parts of the World

Policies concerning dispersants in other parts of the world have not changed significantly since the last report. In Europe, only Britain uses dispersants extensively, although they may be used in Norway and France. No documented use of dispersants has been found in any European country except for the *Sea Empress* case noted throughout this report. The Baltic countries do not use dispersants and laws against their use are found nationally and internationally in the HELCOM treaties. In North America, several states in the U.S. have moved to allow dispersant use, but dispersants have only been used three times, all of them in the Gulf of Mexico.

List of Acronyms

ANS - Alaska North Slope - Usually referring to the crude oil mixture at the end of the pipeline

CISPRI - Cook Inlet Spill Prevention and Response Inc. - A co-op in the Cook Inlet Area

Corexit 9527 - Brand name of a dispersant from Exxon

Corexit 9500 - Brand name of a dispersant from Exxon

Enersperse - Brand name of a dispersant

EPA - US Environmental Protection Agency

EXDET - An Exxon laboratory test for dispersants

HELCOM - Helsinki Convention - Conventions passed by the Baltic nations

IFO - Intermediate Fuel Oil - A mixture of Bunker C and diesel used for ship propulsion

IFP - The French Petroleum Institute - Usually used here as a description of their laboratory test

LC50 or LC_{50} - Lethal concentration to 50% of the test population

MNS - Mackay, Nadeau, Steelman - A laboratory effectiveness test

NOEL - No-Effect Level

PAH - Polynuclear Aromatic Hydrocarbons

PWSRCAC - Prince William Sound Regional Citizens' Advisory Council

SERVS - Ship Escort Response Vessel System - A co-op operating in Prince William Sound

WAF - Water-Accommodated Fraction - The sum total of oil in a water sample including physically dispersed and soluble oil

Acknowledgements

The author thanks Lisa Ka'aihue of the Regional Citizens' Advisory Council of Prince William Sound, the contract manager for this project. The author also thanks Jennifer Charles for her editorial work and Lloyd Gamble for collecting the references necessary for this report.

Table of Contents

Abstract iii
Summary and Issues v
List of Acronyms vii
Acknowledgements viii

1. Introduction 1
  1.1 Objectives 1
  1.2 Scope 1
  1.3 Organization 1

2. Review of Dispersants, Their Use, and Issues 2
  2.1 Formulations 2
  2.2 Effectiveness 2
    2.2.1 Field Trials 3
    2.2.2 Laboratory Tests 4
  2.3 Toxicity 5

3. Recent Issues 7
  3.1 Effectiveness 7
  3.2 Toxicity and Environmental Concerns 8
    3.2.1 Acute Toxicity of Dispersant and Oil 8
    3.2.2 Acute Toxicity of Dispersant 8
    3.2.3 Sublethal Toxicity of Dispersant and Oil 9
    3.2.4 Body Burdens 9
    3.2.5 Biodegradation 9
  3.3 Field Application 9
  3.4 Dispersant Use Policies in Other Countries 9
    3.4.1 Canada 9
    3.4.2 Norway 10
    3.4.3 Baltic Countries in General 10
    3.4.4 Sweden 10
    3.4.5 Finland 10
    3.4.6 Latvia 10
    3.4.7 United Kingdom 10
    3.4.8 Germany 10

4. Detailed Literature Review 11
  4.1 Journal Articles and Reports 11
  4.2 Trade Magazines and News Articles 33

5. References 34

List of Tables

1 Comparison of Laboratory and Field Effectiveness Results 5
2 Dispersant Effectiveness Measured by Blondina et al., 1997a.............................13
3 Dispersant Effectiveness Measured by Blondina et al., 1997b.............................13
4 Summary of Alaskan Oils Tested 17
5 Dispersant Effectiveness Measured by Moles et al., 2001 26
6 Toxicity Data from Rhoton et al., 2001 28
7 Acute Toxicity Data from Singer et al., 1998...30

List of Figures

1 Correlation of Effectiveness with Temperature and Salinity (Data from Moles et al., 2001) 8

1. Introduction

1.1 Objectives

The objectives of this review are to summarize the literature from the last report (1997) to the current date (2002) and to synthesize the literature to answer key questions relevant to the Prince William Sound Regional Citizens' Advisory Council (PWSRCAC).

1.2 Scope

This review covers the literature from the last study sponsored by PWSRCAC and printed in 1997. As such it covers all known dispersant-related literature from that time period to January of 2002.

While the study provides a summary of all the literature found, it focuses primarily on that related to Prince William Sound. Several questions were focussed on, as described in the Summary of this report.

1.3 Organization

The report begins with a summary and then addresses the questions posed by PWSRCAC. A review of the overall dispersant situation is presented in Section 2. In Section 3, recent issues, particularly those relevant to PWSRCAC, are summarized as drawn from the literature review. Section 4 is a detailed review of the new literature, reference by reference. Section 5 is the reference section.

2. Review of Dispersants, Their Use, and Issues

There has been much controversy about the use of dispersants over the past three decades. This controversy has often been based on outdated and unsubstantiated information or poorly documented and contradictory reports from the actual use of dispersants in the field. The difficulty arose largely in the late 1960s and early 1970s when dispersants were used that were either ineffective and resulted in wasted effort or were highly toxic and severely damaged the marine environment (Fingas, 2000). Thus, the two major issues associated with the use of dispersants are their effectiveness and the toxicity of the oil that is dispersed into the water column as a result of their use. Both these topics will be discussed extensively in this section.

There is still much discussion about dispersants and strong polarization between dispersant proponents and opponents. Many studies have been conducted since the birth of the oil spill industry after the *Torrey Canyon* incident in 1968. Documentation on actual field use of dispersants is poor. Interviews with operators who have used dispersants often result in contradictory opinions on whether the dispersant worked in a particular situation. Large-scale biological experiments have failed to convince environmentalists that the use of dispersants is safe in all conditions. It is becoming increasingly clear, however, that in many situations, dispersants cause little, if any, ecological damage more than that caused by untreated oil. This is particularly true in offshore regions.

The use of dispersants remains a controversial issue in some quarters. This is generally reflected by the fact that in most jurisdictions, special permission is required to use dispersants, while in other jurisdictions, the use of dispersants is not allowed at all.

2.1 Formulations

Dispersants are oil spill treating agents formulated to disperse oil into water in the form of fine droplets. Typically, the hydrophilic-lipophilic balance (HLB) of dispersants ranges from 9 to 11. A typical dispersant formulation consists of a pair of non-ionic surfactants in proportions to yield an average HLB of 10 and some proportion of ionic surfactants. Some dispersants contain small proportions of ionic surfactants and yield a total HLB closer to 15 than 10. Studies have not been done on the specific effect of this on the effectiveness or mode of action.
Ionic surfactants are rated using an expanded scale and have HLBs ranging from 25 to 40.

Ionic surfactants are strong water-in-oil emulsifiers, very soluble in water and relatively insoluble in oil, that generally work from the water on any oil present. Such products disappear rapidly in the water column and are not effective on oil. Because they are readily available at a reasonable price, however, many ionic surfactants are proposed for use as dispersants. These agents are better classified as surface-washing agents.

2.2 Effectiveness

Dispersant effectiveness is defined as the amount of oil that the dispersant puts into the water column compared to the amount of oil that remains on the surface. Effectiveness is indicated by the presence of a coffee-coloured plume of dispersed oil in the water column, which is visible from ships and aircraft. If there is no such plume, it indicates very little or no effectiveness.

Many factors influence dispersant effectiveness, including oil composition, sea energy, state of oil weathering, the type of dispersant used and the amount applied, temperature, and salinity of the water. The most important of these is the composition of the oil, followed closely by sea energy and the amount of dispersant applied.

Certain components of oil, such as resins, asphaltenes, and larger aromatics or waxes, are barely dispersible, if at all (Fingas, 2000). Oils that are made up primarily of these components will disperse poorly even when dispersants are applied. On the other hand, oils that contain mostly saturates, such as diesel fuel, will disperse both naturally and when dispersants are added. The additional amount of diesel dispersed when dispersants are used compared to the amount that would disperse naturally depends primarily on the amount of sea energy present. Laboratory studies have found a trade-off between the amount of dispersant applied, or the dose, and the sea energy (Fingas, 2000). In general, less sea energy implies that a higher dose of dispersant is needed to yield the same degree of dispersion as when the sea energy is high. There is also a trade-off between other factors, such as salinity and temperature.

While it is easier to measure the effectiveness of dispersants in the laboratory than in the field, laboratory tests may not be representative of actual conditions. Important factors that influence effectiveness, such as sea energy and salinity, may not be accurately reflected in laboratory tests. Results obtained from laboratory testing should therefore be viewed as representative only and not necessarily reflecting what would take place in actual conditions.

When testing dispersant effectiveness in the field, it is very difficult to measure the concentration of oil in the water column over large areas and at frequent enough time periods. It is also difficult to determine how much oil is left on the water surface as there are no methods available for measuring the thickness of an oil slick and the oil at the subsurface often moves differently than an oil slick on the surface. Any field measurement at this time is best viewed as an estimate.

Field effectiveness trials, laboratory effectiveness tests, and factors influencing the effectiveness of a dispersant will be discussed in this section.

2.2.1 Field Trials

Many field trials have been conducted to assess the effectiveness of dispersants. In the past few years, offshore trials have been conducted in the North Sea primarily by Great Britain and Norway (Fingas, 2000). Similar trials were also conducted in the 1980s in France and North America. Several papers have assessed the techniques used to measure effectiveness in these tests. There is no general consensus that effectiveness and other parameters can actually be measured in the field using some of the current methodologies.

The effectiveness determined during these trials varies significantly. Recent results, which may be more reliable, claim that dispersants removed about 10 to 40% of the oil to the sub-surface. This is based on questionable analytical methodology. Ideal methodology may result in larger or smaller values; the results are not predictable at this time. The validity of older test results is even more questionable because of both the analytical methodology, which is now known to be incorrect, and data treatment methods (Fingas, 2000). It is interesting that the percentage values assigned average 16%, both in the older and more recent field trials.

All tests relied heavily on developing a mass balance between oil in the water column and that left on the surface. In early tests, samples from under the oil plume were analyzed in a laboratory using colorimetric methods, which are not accurate for this type of analysis and are no longer used. Firstly, the concentrations to be measured were near or well below the threshold of the technique and secondly, a significant amount of hydrocarbons was lost between the sampling and the laboratory that could not be accounted for. Fluorometry has recently been used, but this method is also unreliable as it measures only a small and varying portion of the oil (middle aromatics) and does not discriminate between dissolved components and oil that actually dispersed. It is difficult to calibrate fluorometers for whole oil dispersions in the laboratory without using accurate techniques such as extraction and gas-chromatographic analysis. It is uncertain whether the aromatic ratio of the oil changes as a result of the dispersion process.

In early tests, it was not recognized that the plume of dispersed oil forms near the heavy oil in the tail of the slick and that this plume often moves away from the slick in a separate trajectory. Many researchers 'measured' the hydrocarbon concentrations beneath the slick and then integrated this over the whole slick area. As the area of the plume is always far less than this area, the amount of hydrocarbons in the water column was greatly exaggerated. Since the colorimetric techniques used at the time always yielded some value of hydrocarbons, the effectiveness values were significantly increased. When effectiveness values from past tests were recalculated using only the area where the plume was known to be, those values decreased by factors as much as 2 to 5 (Fingas, 2000).

Although no applications of dispersants on freshwater spills have been documented in the literature, one field test was (Fingas, 2000). While effectiveness was not measured specifically, it was found that the dispersants appeared to reduce the long-term impact of the spill. The ASTM standards on the use of dispersants in freshwater such as lakes and rivers suggest that they not be used in freshwater primarily because most lakes and rivers are used as sources of drinking water.

In summary, testing in the field is difficult because effectiveness values depend on establishing a mass balance between oil in the water column and on the surface. Because this mass balance is difficult to achieve, results are questionable.

2.2.2 Laboratory Tests

Many different types of procedures and apparatus for testing dispersants are described in the literature. Fifty different tests or procedures are described in one paper (Fingas, 2000). Only a handful of these are commonly used, however, including the Labofina or rotating flask test, the Mackay or MNS test, the swirling flask test (now in several variations including a standard ASTM version), and the IFP (French Institute for Petroleum) test method.

Several investigators have reported results of apparatus comparison tests conducted in early years. In the 11 papers reviewed, all authors concluded that the results of the different tests do not correlate well, but some conclude that some of the rankings are preserved in different tests. Generally, the more different types of oil tested, the less the results correlate. It has been shown that laboratory tests can be designed to give a comparable value of oil dispersion if the parameters of turbulent energy, oil-to-water ratio, and settling time are set at similar values (Fingas, 2000).

In the literature, different protocols are sometimes described for the same apparatus. The protocol used can sometimes change the data more than the actual physical test.

Work has been done recently on determining the reason for the poor correlation between test results (Fingas, 2000). It was concluded that the differences in energy levels and the way the energy was applied to the oil/water mixture result in effectiveness values that are unique. In the past, investigators followed the specified test procedure when using an apparatus and did not vary any of the conditions. Fingas and coworkers found that, by adjusting the oil-to-water ratio and settling time, equivalent effectiveness values could be achieved using five different apparatuses. It was found that energy was important but appeared to simply give higher values along the same line, that is, the relative ranking of dispersant/oil combinations was preserved. The only test developed recently is an internal Exxon effectiveness test known as EXDET. This is a high-energy test and yields much higher results than most other tests.

In an inter-laboratory evaluation of dispersant effectiveness tests, there was some agreement between test results on fresh oils, but very poor agreement between results of tests on oils that were more weathered or had any amount of water content. Some of these laboratory data were compared to the field data by Lunel and coworkers and the results are shown in Table 1 (Lunel et al., 1995). While the data correlate somewhat to the field data, with the wide spread in effectiveness numbers and the few data points, this correlation should not be overstated. Another interesting point is that the effectiveness values obtained in the field are lower than the data obtained in the laboratory, indicating that the energy levels may be much higher in laboratory tests than those in the field conditions described here. This is contrary to what was thought in previous years.

Table 1 Comparison of Laboratory and Field Effectiveness Results

			Effectiveness Results in Percent					
Oil type	**Dispersant**	**Field Test**	**SF GC**	**SF CA**	**IFP**	**WSL Lab 1**	**WSL Lab 2**	**Exdet**
Medium fuel oil	Corexit 9527	26	54	50	91	42	42	67
Medium fuel oil	Slickgone NS	17	49	46	94	29	23	50
Medium fuel oil	LA 1834/Sur	4	2	2	50	16	11	38
Forties crude	Slickgone NS	16	47	65	95	28	25	60
Forties crude	LA 1834/Sur	5	2	2	61	15	12	53
Correlation with field test (R^2)			0.89	0.7	0.54	0.87	0.94	0.41
Ratio Lab test/field test			0.4	0.35	0.19	0.56	0.62	0.27

Legend SF = Swirling Flask, GC= analysis by Gas Chromatography, CA= Colorimetric Analysis, IFP = French Institute for Petroleum test, WSL = Warren Springs Laboratory Test

2.3 Toxicity

The second important issue when discussing dispersants is toxicity, both of the dispersant itself and of the dispersed oil droplets. Toxicity became an important issue in the late 1960s and early 1970s when application of toxic products resulted in substantial loss of sea life. For example, the use of dispersants during the *Torrey Canyon* episode in Great Britain in 1968 caused massive damage to intertidal and sub-tidal life (Fingas, 2000). Since that time, dispersants have been formulated with lesser aquatic toxicity. Dispersants available today are much less toxic (often one hundredth as toxic) than earlier products. There is increasing evidence that in many situations dispersants cause little ecological damage or at least no more than would occur if the oil were left untreated. This is particularly true in offshore regions.

A standard toxicity test is to measure the acute toxicity to a standard species such as the rainbow trout. The LC50 of a substance is the ‘Lethal Concentration to 50% of a test population’, usually given in mg/L, which is approximately equivalent to parts per million. The specification is also given with a time period, which is often 96 hours for larger test organisms such as fish. The smaller the LC50 number, the more toxic the product. The toxicity of dispersants used in the early 1970s ranged from about 5 to 50 mg/L measured as an LC50 to the rainbow trout over 96 hours. Dispersants available today vary from 200 to 500 mg/L in toxicity and contain a mixture of surfactants and a less toxic solvent.

Today, the oil itself is more toxic to most species than the dispersants, with the LC50 of diesel and light crude oil typically ranging from 20 to 50 mg/L for either chemically or naturally dispersed oil. Generally, no increase in toxicity of dispersed oil has been observed as a result of the addition of dispersants. However, the natural or chemical dispersion of oil in shallow waters can result in a mixture that is toxic to sea life. For example, a spill in 1996 from the *North Cape* in a shallow bay on the Atlantic coast caused massive loss of benthic life without the use of dispersants. Another significant factor in terms of the impact of this spill was the closeness to shore which caused a high concentration of hydrocarbons in the water. Similarly, if dispersants are not mixed in the correct ratio, the resulting dispersed oil could be toxic to sea life.

Dispersants have been reviewed extensively in terms of toxicity, particularly in a major review by the National Academy of Sciences published in 1989. The major issues have changed since this review was published. First, the concern over the exposure regimes has subsided. In the last decade, there was concern that the time-dose applied to test organisms was not relevant to the regime that the same organisms would be exposed to in an actual application of dispersant. New methods for testing aquatic toxicity have enabled more realistic dosing. Toxicity testing is more accurate today due to new analytical techniques.

3. Recent Issues

3.1 Effectiveness

Effectiveness still remains a major issue with dispersants, with test results indicating wide disparities in effectiveness for Alaskan crudes. These disparities can be attributed to the different energy levels in tests. These tests can be categorized into moderate-energy tests as represented by the swirling flask test variants and high-energy tests such as the EXDET, IFP (Institute Francais Petroleum or French tests), and MNS (MacKay-Nadeau-Steelman). The Labofina or Warren Springs test falls between these two. It is important to note from the discussion above, that the only comparison that tried to relate field tests to the laboratory tests, showed that all were too high in energy and even the swirling flask test correlated at a level 2.5 times the value obtained in the field. The effect of temperature is typical, that is, effectiveness goes up with temperature. Figure 1 shows the change in temperature from the Moles et al., 2001 data.

The effectiveness of dispersion at different temperatures and salinity has been measured using various tests. Blondina et al. (1997a,b) measured the effectiveness of dispersing Prudhoe Bay crude at 20°C and 20°/oo as 38% for Corexit 9500 and 57% for Corexit 9527, using the EPA swirling flask method and 16% for Corexit 9500 and 22% for Corexit 9527 using the California method. Moles et al. (2001) conducted a series of measurements on Alaska North Slope (ANS) oil at lower temperatures and lower salinity. Detailed results are given in the literature review (Section 4). For Corexit 9500 at a temperature of 10°C and 22°/oo, the effectiveness was 8% for fresh ANS and 2% for weathered ANS. Under the same conditions, Corexit 9527 showed an effectiveness of 10% for the fresh ANS and 5% for the weathered ANS.

Others have tested Alaskan oils at standard temperatures and salinities. Fingas et al. (2001) tested ANS from various pipeline feeds and found 33 to 46% effectiveness for Corexit 9500 and about 6% for weathered samples. Prudhoe Bay showed 18% for fresh to 0% for a fully weathered sample.

Fiocco et al. (1999) reviewed recent lab and field tests for ANS. The threshold for ANS dispersibility was given as 1,000 cP for Corexit 9527 and 4,000 cP for Corexit 9500. Dispersant testing with the MNS apparatus and water-in-oil mixtures (state unknown) showed effectiveness values ranging from 3 to 100% depending on conditions. Typical values were 70%. Testing some of the same oils with the Labofina test showed effectiveness from 1 to 67%, with no typical values. Weathered samples from the field test were tested in the IFP test with the result of 27 to 35% effectiveness and 80 to 91% in the MNS apparatus. Lewis et al. (1998a,b) noted that the Alaska North Slope oil was left to weather for 55 hours and then sprayed with Corexit 9500. The Alaskan North Slope oil was repeatedly treated with dispersant. While the report does not indicate the effectiveness achieved, it does indicate that the concentration of dispersed oil at the sub-surface reached about the same as the Forties Blend on the first pass, but was lower than that on the second and subsequent treatments.

George-Ares et al. (2001) conducted an effectiveness test in freshwater with the EXDET test and found an effectiveness of 22% for ANS in freshwater and 63% when salts were added along with the dispersant.

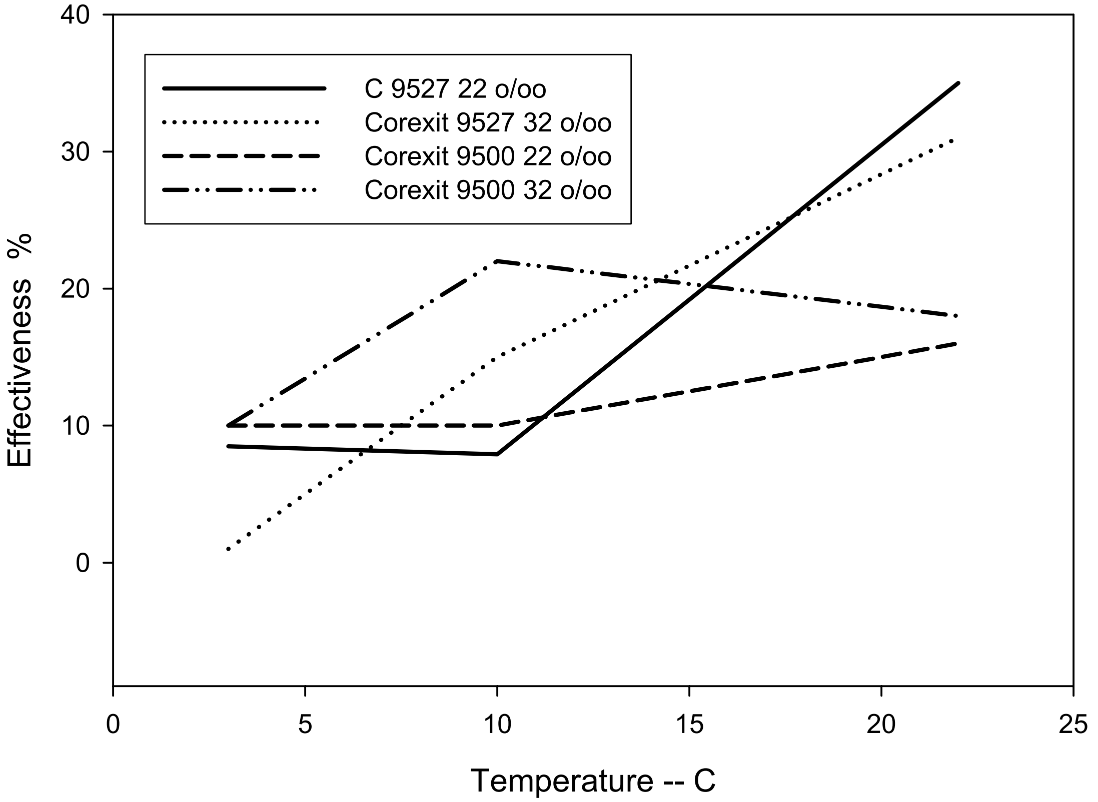

Figure 1 Correlation of Effectiveness with Temperature and Salinity
(Data from Moles et al., 2001)

Guyomarch et al. (1999a,b) compared dispersant results in the Labofina (Warren Springs) test, the IFP test, and a large flume. It was concluded that the dispersant results from the laboratory tests are far too high and are not representative of results that would be achieved in the field under less energetic sea conditions.

3.2 Toxicity and Environmental Concerns

3.2.1 Acute Toxicity of Dispersant and Oil

Older studies have generally shown that the acute toxicity to most species is the same for oil and dispersed oil at the same concentrations. Exceptions to this, where the dispersed oil has shown more toxicity, are reported in the literature (Adams et al., 1999; Epstein et al., 2000; Fuller and Bonner, 2001, Guleg et al., 1997, Singer et al., 1998).

Rhoton et al. (2001) reported on the testing of a number of species with ANS crude oil. They found that the toxicity was generally about the same for oil and dispersed oils, however, the exceptions appeared to be species-dependent. A spiked exposure yielded a lower toxicity, e.g., less toxic, in every case, compared to a continuous exposure. Dispersed and water-accommodated fraction from weathered ANS crude were more toxic to the species measured than a fresh crude oil.

3.2.2 Acute Toxicity of Dispersant

Several authors report acute dispersant toxicity results that are similar to those in previous literature. There is a review published with many values (George-Ares and Clark, 2000).

3.2.3 Sublethal Toxicity of Dispersant and Oil

Wolfe et al. (1997, 1998a,b, 2001) studied the passage of naphthalene through the food chain by a primary producer and a primary consumer. It was found that naphthalene passed through the food chain at much higher rates when the oil was dispersed chemically.

3.2.4 Body Burdens

Coelho et al. (1999) found that hydrocarbon body burdens for the polycheate worm were up to 5.7 times more in the dispersed oil situations compared to the oil-only tests. The body burdens for oyster and minnow were somewhat lower in the dispersant-treated tanks.

3.2.5 Biodegradation

Bruheim et al. (1999) found that overall Corexit 9527 suppressed oil degradation (oxidation) while some of its components enhanced degradation and others suppressed degradation.

3.3 Field Application

Belore and Ross (2000) studied the effect of dispersants applied neat versus applied with water using a test tank. They found that effectiveness decreases if applied dilute, especially with Corexit 9500. For thick slicks, Corexit 9500 decreased in effectiveness from 97 to 16%, while the effectiveness of Corexit 9527 remained about the same.

Plans and facilities for using dispersants have not changed since 1997. Hillman (1998) provides an overview of the facilities and plans for dispersant use. Contact with the Ship Escort Response Vessel System (SERVS) co-op indicates that little has changed since 1997 (Hillman, 2002). Two new dispersant application systems were placed on the tractor tugs. The co-op still has 60,000 gallons of Corexit 9527 and a very small amount of Corexit 9500. Most of the dispersants are stored in IMO containers which are generally kept on trailers for fast deployment.

Alaska Clean Seas does not have dispersants or spraying equipment. Cook Inlet Response Co-op (CISPRI) has primarily Corexit 9527 (20,000 gallons) in stock and some Corexit 9550 (Eldridge, 2002). No new dispersant or equipment have been purchased since 1997.

3.4 Dispersant Use Policies in Other Countries

3.4.1 Canada

In Canada, the use of dispersants is governed under the Fisheries Act, the relevant section of which is administered by Environment Canada. Only approved products are considered for use and these must pass minimum specifications for both toxicity and effectiveness. At this time, only Corexit 9500 and Corexit 9527 are active products on the acceptability list.

Each dispersant use must be authorized by the regional environmental emergency team.

The request is sent to the regional environmental emergency coordinator of Environment Canada. After consultation with his/her colleagues in government agencies, an answer is generally given within 6 hours. Environment Canada has not received a request for specific dispersant application in the past 6 years. The industry and the Canadian Coast Guard have largely sold or disposed of their dispersant stockpiles and their spray equipment in the past 10 years and there is now little equipment or capability for applying dispersants.

3.4.2 Norway

The policy in Norway remains that dispersants can be used if requested under certain circumstances. While preparations and equipment are in place to use them, dispersants have not been used in recent years (Brandvik, 1997, 2002).

3.4.3 Baltic Countries in General

The Baltic Countries are signatories to HELCOM and this agreement has a stipulation that dispersants are not to be used in the Baltic except under certain circumstances. HELCOM Recommendation 22/2 states that "chemical agents may only be used in exceptional cases" (HELCOM, 2002). Most Baltic countries have added their own restrictions to this, resulting in a virtual ban on the use of dispersants.

3.4.4 Sweden

Sweden has added its own rules to that of HELCOM, which makes it almost impossible to use dispersants (Loostrom, 2002). There are no stockpiles of equipment or dispersants.

3.4.5 Finland

Finland is a signatory to HELCOM and does not allow the use of dispersants (Jolma, 2002). In addition, it is noted that the Baltic Sea has poor circulation (complete turnover occurs only every 20 to 30 years), is brackish, and often has ice cover. There are no stockpiles of equipment or dispersants.

3.4.6 Latvia

Latvia is a signatory to HELCOM and does not allow the use of dispersants (Smite, 2002). There are no stockpiles of equipment or dispersants.

3.4.7 United Kingdom

The United Kingdom is the only country in Europe that allows the frequent use of dispersants. The United Kingdom also permits use on smaller spills. It should be noted that dispersants have not been used much in the past 5 years.

3.4.8 Germany

Germany is a signatory to HELCOM and does not allow the use of dispersants in the Baltic or in the North Sea (Wunderlich, 2002). There are no stockpiles of equipment or dispersants.

4. Detailed Literature Review

4.1 Journal Articles and Reports

Adams, G.G., P.L. Klerks, S.E. Belanger and D. Dantin, "The Effect of the Oil Dispersant Omni-Clean on the Toxicity of Fuel Oil No. 2 in Two Bioassays with the Sheepshead Minnow *Cypriodon variegatus*", *Chemosphere*, Vol. 39, pp 2141-2157, 1999.

LC50 - 96-hour and 7-day bioassays using the dispersant Omni-Clean and fuel oil No. 2 were conducted using sheepshead minnows. The LC50 of the dispersant alone was found to be 190 mg/L. The toxicity of the oil and dispersant was found to be lower than that of the oil or dispersant separately. It was noted that the findings were similar for other dispersants. Seven-day tests were found to be very sensitive.

AMSA, "National Plan Oil Spill Dispersant Effectiveness Test - Field Kit (Nat-DET)", Australian Marine Safety Agency, Melbourne, Australia, 4 p., 1998.

This is a detailed description of a method to measure dispersant effectiveness at sea. This method is similar to the Labofina test and uses simple comparison to standards.

Armato, P., "Oil Fate and Effects: An Overview of Issues in Prince William Sound", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 149-158, 1998.

This is an overview of dispersant issues from a local point of view.

Aurand, D., "Observations on the Integration of Laboratory, Mesocosm and Field Research on the Ecological Consequences of Dispersant Use for Marine Oil Spills Into Response Planning", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 215-247, 1998.

This paper is an author's review of how toxicity and effectiveness testing should proceed. Future testing is proposed to include basin and at-sea testing.

Aurand, D. and G. Coelho, "Using Laboratory, Mesocosm and Field Data in Ecological Risk Assessments for Near-Shore Dispersant Use", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1023-1026, 1999.

This paper is a discussion of the use of dispersants nearshore, based on toxicity values from the literature.

Aurand, D., G. Coelho, J. Clark and G. Bragin, "Goals, Objectives and Design of a Mesocosm Experiment on the Environmental Consequences of Nearshore Dispersant Use", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 629-643, 1999.

The experimental setup and methodologies for a mesocosm experiment on nearshore dispersant use are described. The facility, COSS, near Corpus Christi, Texas, was used to conduct experiments in which typical species were placed in a tank and pre-mixed oils and dispersants were added.

Baron, M. and L. Ka'aihue, "Potential for Photoenhanced Toxicity of Spilled Oil in Prince William Sound and Gulf of Alaska Waters", *Marine Pollution Bulletin*, Vol. 43, No. 1-6, pp. 86-92, 2001.

The potential of photoenhancement of toxicity is reviewed. The components that may have the greatest potential for photoenhancement are the 3- to 5-ring PAHs. Photoenhanced toxicity may be greatest for embryo and larval stages of aquatic organisms that are relatively translucent to UV.

Baron, M. et al., “Photoenhanced Toxicity of Aqueous Phase and Chemically-Dispersed Weathered Alaska North Slope Crude Oil to Pacific Herring Eggs and Larvae”, Prince William Sound Regional Citizens’ Advisory Council, 2002.

The photoenhancement of toxicity was studied on eggs and larvae of the Pacific herring. It was found that UV exposure increased the toxicity of oil by 18 to 450 times that of unexposed oil. There was no difference between dispersed and undispersed oil. Because of the increased toxicity from UV, it was found that parts-per-billion concentrations of Alaska North Slope crude oil can damage or kill herring embryos and larvae.

Baussant, T., S. Sanni, G. Jonsson, A. Skadsheim and J.F. Borseth, “Bioaccumulation of Polycyclic Aromatic Compounds: 1. Bioconcentration in Two Marine Species and in Semipermeable Membrane Devices during Chronic Exposure to Dispersed Crude Oil”, *Environmental Toxicology and Chemistry*, Vol. 20, pp 1175-1184, 2001.

A continuous-flow experiment was used to evaluate bioaccumulation of PAHs in the blue mussel and juvenile turbot. The system was dosed with dispersed oil as a source of PAHs. A Semipermeable Membrane Device (SPMD) was also used to evaluate its usefulness in measuring the PAHs. For both SPMD and mussels, the distribution of accumulated PAHs was similar to that of the water. The PAHs in the juvenile turbot displayed a different distribution, showing that bioconcentration was affected by metabolism.

Baussant, T., S. Sanni, A. Skadsheim, G. Jonsson and J.F. Borseth, “Bioaccumulation of Polycyclic Aromatic Compounds: 2. Modelling Bioaccumulation in Marine Organisms Chronically Exposed to Dispersed Oil”, *Environmental Toxicology and Chemistry*, Vol. 20, pp 1185-1195, 2001.

This study is a description of the application of mathematical kinetic models to the above data.

Belore, R. and S. Ross, “Laboratory Study to Compare the Effectiveness of Chemical Dispersants When Applied Dilute Versus Neat”, in *Proceedings of the Twenty-third Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 733-748, 2000.

Laboratory tests were conducted to measure the difference in effectiveness of the dispersants, Corexit 9527 and Corexit 9550, on Alaska North Slope oil when applied neat versus diluted with water. The effectiveness of Corexit 9527 was not significantly affected by water dilution, however, the effectiveness of Corexit 9500 was severely reduced when applied diluted with water at ratios of both 1:10 and 3:10. The thick oil results changed the effectiveness of Corexit 9500 on Alaska North Slope oil from 97 to about 16% and there was no change for the Corexit 9527, with effectiveness of about 98%. For thin oil slicks, the effectiveness went from 41 to 22% for Corexit 9500 and stayed about the same for Corexit 9527 at about 30%.

Blondina, G.J., M.L. Sowby, M.A. Ouano, M.M. Singer and R.S. Tjeerdema, “Comparative Efficacy of Two Corexit Dispersants as Measured Using California’s Modified Swirling Flask Test”, in *Proceedings of the Twentieth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 561-573, 1997a.

A new swirling flask method was developed to improve the standard deviation of dispersant effectiveness tests. Dispersants were also added one drop at a time. The flask unit was modified by enclosing it and adding a stopcock at the bottom. Analysis was by GC-FID. A comparison study was conducted of results of testing Prudhoe Bay crude by the EPA and new test methods. The standard deviation achieved was about half of the EPA-specified test of about 5 for four test runs and about the same as 12 test runs (new SD is about 2.5). These results are summarized in

Table 2.

Table 2 **Dispersant Effectiveness Measured by Blondina et al., 1997**

all values are effectiveness averages directly from paper

Oil Type	**EPA Premixed Method**		**California one drop**
Prudhoe Bay	**n=4**	**n-12**	
Corexit 9500	41	38	16
Corexit 9527	57	57	22

In addition, the effectiveness of Corexit 9527 and Corexit 9500 was measured with several oils. The results for the testing with Prudhoe Bay crude are given in Table 3.

Table 3 **Dispersant Effectiveness Measured by Blondina et al., 1997**

all values are effectiveness averages directly from paper

Oil Type	**Salinity (^{0}/oo)**					
Prudhoe Bay	**35**	**30**	**25**	**20**	**15**	**10**
Corexit 9500	23	21	22	23	15	12
Corexit 9527	34	29	13	13	9	5

Blondina, G.J., M.L. Sowby, M.T. Ouano, M.M. Singer and R.S. Tjeerdema, "A Modified Swirling Flask Efficacy Test for Oil Spill Dispersants", *Spill Science and Technology Bulletin*, Vol. 4, pp 177-185, 1997.

The development of a modified swirling flask test, as described above, is summarized.

Boyd, J.N., D. Scholz and A.H. Walker, "Effects of Oil and Chemically Dispersed Oil in the Environment", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1213-1216, 2001.

The dispersant projects of the American Petroleum Institute are summarized.

Brandvik, P.J., *Optimisation of Oil Spill Dispersants on Weathered Oils: A New Approach Using Experimental Design and Multivariate Data Analysis*, PhD Thesis, University of Science and Technology, Department of Chemistry, Trondheim, Norway, 83 p, 1997.

This thesis is a summary of work on the dispersant program at SINTEF. New material is reported elsewhere in this review. The work summarized includes laboratory testing, a field test, the optimization of dispersant formulation and a review of contingency plans for dispersant use in Norway.

Brandvik, P.J. and P.S. Daling, "Optimisation of Oil Spill Dispersant Composition by Mixture Design and Response Surface Methods", *Chemometrics and Intelligent Laboratory Systems*, Vol. 42, pp 63-72, 1998.

Brandvik, P.J. and P.S. Daling, "Optimisation of Oil Spill Dispersant as a Function of Oil Type and Weathering Degree: A Multivariate Approach Using Partial Least Squares (PLS)", *Chemometrics and Intelligent Laboratory Systems*, Vol. 42, pp 73-91, 1998.

These papers describe the optimization of dispersant composition for various oils. The composition of a dispersant consisting of three surfactants was varied. These variations were tested using laboratory procedures on Statfjord and Oseberg crude oils. The results were then treated mathematically to analyze them. The surfactant mixtures (dispersants) were then optimized for the oil and weathering state.

Bruheim, P., H. Bredholt and K. Eimhjellen, “Effects of Surfactant Mixtures, Including Corexit 9527, on Bacterial Oxidation of Acetate and Alkanes in Crude Oil”, *Applied and Environmental Microbiology*, Vol. 65, pp 1658-1661, 1999.

Biodegradation tests were conducted on oil along with mixtures of surfactants and Corexit 9527. Corexit 9527 was found to inhibit the oxidation of alkanes by *Acinetobacter calcoacetiucs*, but Span 80, an ingredient in Corexit 9527, was found to increase the oil oxidation rate. Another ingredient, dioctyl sulfosuccinate (AOT), strongly reduced the oxidation rate. The combination of Span and AOT increased the rate of oxidation to some degree. The study also revealed that nonionic surfactants interacted with the acetate uptake system while the anionic surfactant interacted with the bacterial oxidation system. The overall effect of the surfactant mixtures in Corexit 9527 appears to be a sum of the effects of the individual surfactant. In another experiment with *Rodococcus sp.*, alkane oxidation was nearly zero with Tergitoal 15-S-7 and AOT.

Canevari, G.P., P. Calcavecchio, R.R. Lessard, K.W. Becker and R.J. Fiocco, “Key Parameters Affecting the Dispersion of Viscous Oil”, in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 479-483, 2001.

Fourteen viscous oil products were analyzed for composition and the dispersant effectiveness tested in the EXDET apparatus. Viscosity correlated to effectiveness somewhat, showing a cutoff at a viscosity of about 20,000 cSt. There was little or no dispersion past this value. Effectiveness correlated best with saturate content. There was little or no apparent correlation between dispersant effectiveness and sulphur, aromatic, resin, and metal content.

Clark, J.R., G.E. Bragin, E.J. Febbo and D.J. Letinski, “Toxicity of Physically and Chemically Dispersed Oils Under Continuous and Environmentally Realistic Exposure Conditions: Applicability to Dispersant Use Decisions in Spill Response Planning”, in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1249-1255, 2001.

Toxicity tests were performed on embryo larval stages of the Pacific oyster, two marine mysids, turbot, and inland silversides. The oils used were fresh and weathered Kuwait crude, fresh Forties crude, and a medium fuel oil mix. The oils were administered either physically or chemically dispersed with Corexit 9527 or 9500 and doses were either a continuous exposure for 48 or 96 hours depending on the species, or a spiked exposure. The spiked exposure was administered so that the half life of concentration was about 100 minutes, as might be seen under a dispersed slick. The resulting aquatic toxicities showed no statistical differences between those oils dispersed chemically and those dispersed naturally. The oyster LC50 ranged from 0.5 to >1.1 mg/L for oils and dispersed oils, while the toxicity of Corexit 9527, neat, was found to be 3 mg/L. The spiked exposures ranged from 1.9 to 4 mg/L and that of the dispersant was 14 mg/L. The least sensitive species, turbot, displayed a range of LC50s of 0.4 to 4 mg/L for the dispersed oils under continuous exposure and >1.3 to 49 mg/L for spiked exposure. The toxicity of Corexit 9500 to the turbot was 75 for continuous exposure and >1,055 mg/L for spiked exposure.

Coelho, G.M., D.V. Aurand and D.A. Wright, “Biological Uptake Analysis of Organisms Exposed to Oil and Chemically Dispersed Oil”, in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 685-694, 1999.

As part of the study of organism exposure in a mesocosm, the body burden of PAHs was measured. The total PAH body burden of the sheepshead minnow exposed to chemically dispersed oil for 24 hours was about 18 µg/g, about twice that of the physically dispersed oil. The body burden for the oyster samples exposed to chemically dispersed oil was about half that of the physically dispersed oil. The body burdens for the polychaete worm exposed to chemically dispersed oil were 1.5 times that of those exposed to physically dispersed oil for a 24-hour exposure and 5.7 times higher for a 10-day exposure. These exposures did not cause lethality and sub-lethal effects were not measured. The TPH concentrations in the polycaetes in the dispersed oil treatment were about 5 times that of the oil-only treatment, however, the TPH in the sediments was significantly higher for the oil-only treatment.

Cohen, A., D. Nugegoda and M. Gagnon, "Metabolic Response of Fish following Exposure to Two Different Oil Spill Remediation Techniques", *Ecotoxicology and Environmental Safety*, Vol. 48, pp 306-310, 2001.

Changes in the enzyme, C oxidase (CCO) and lactate dehydrogense (LDH), activities were monitored following exposure to chemically dispersed oil and physically dispersed oil. LDH was significantly stimulated by the dispersed crude oil. Fish exposed to the dispersed oil had significantly higher oxygen consumption than those exposed to the oil only.

Cohen, A.M., D. Nugegoda and M.M. Gagnon, "The Effect of Different Oil Spill Remediation Techniques on Petroleum Hydrocarbon Elimination in Australian Bass (*Macquaria novemaculeata*)", *Archives of Environmental Contamination and Toxicology*, Vol. 40, pp 264-270, 2001.

Juvenile Australian bass were used as a test species to evaluate oil remediation techniques. The treatments, chemically dispersed oil and burnt crude oil, were administered for 16 hours through the water column or as part of diet. For both exposures, chemically dispersed oil yields the highest PAH-type biliary metabolite concentrations. It was concluded that chemical dispersion had the greatest influence on the bioavailability of oil.

Cotou, E., I. Castritsi-Catharios and M. Moraitou-Apostolopoulou, "Surfactant-Based Oil Dispersant Toxicity to Developing Nauplii of *Artemia*: Effects on ATPase Enzymatic System", *Chemosphere*, Vol. 42, pp 959-964, 2001.

The dispersant Finasol OSR-5 was evaluated for toxicity to developing *Artemia nauplii* (shrimp). The LC50s were 415 and 51 ppm after 6 and 24 hours respectively. The no-effect level was found to be 10 ppm.

Daling, P., P.J. Brandvik and M. Reed, "Dispersant Experience in Norway: Dispersant Effectiveness, Monitoring and Fate of Dispersed Oil", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 111-147, 1998.

The testing of dispersants in Norway is reviewed. The methodology used to weather and test oils is described. The field dispersant trials in 1994, 1995, and 1996 are reviewed, as well as the use of modelling to review proposed dispersant application.

Duke, N.C., K.A. Burns, J.C. Ellison, R.J. Rupp and O. Dalhaus, "Effects of Oil and Dispersed-Oil on Mature Mangroves in Field Trials at Gladstone", *Australian Petroleum Production and Exploration Association (APPEA) Journal*, Vol. 38, pp 637-645, 1998.

A field oil experiment is described. Oil and dispersants were released into several mangrove plots. Most of the crustaceans in all of the plots died and mangroves began dying 2 to 3 months later in some of the plots. Mangrove death did not correlate to sediment hydrocarbon concentration, but was a function of dispersant use, sediment porosity, and the number of burrowing crabs and mud lobsters.

Duke, N.C., K.A. Burns, R.P.J. Swannell, O. Dalhaus and R.J. Rupp, "Dispersant Use and a Bioremediation Strategy as Alternate Means of Reducing Impacts of Large Oil Spills on Mangroves: The Gladstone Field Trials", *Marine Pollution Bulletin*, Vol. 41, pp 403-412, 2000.

This paper provides details on the later results of the above study. It was found that dispersant use may have reduced mangrove mortality in some plots, although the resulting tree density was not as great as in other plots.

Epstein, N., R.P.M. Bak and B. Rinkevich, "Toxicity of Third Generation Dispersants and Dispersed Egyptian Crude Oil on Red Sea Coral Larvae", *Marine Pollution Bulletin*, Vol. 40, pp 497-503, 2000.

Five dispersants (Inipol IP-90, Petrotech PTI-25, Bioreico R-93, Biosolve, and Emulgal C-100) were evaluated for their toxicity to larvae of two types of coral in 2- to 96-hour bioassays. In all cases, the oil-only was much less toxic than with the dispersant. Several sub-lethal effects were also noted with the oil and dispersants treatment.

Fingas, M.F., E. Huang, B. Fieldhouse, L. Wang and J.V. Mullin, "The Effect of Energy, Settling Time and Shaking Time on the Swirling Flask Dispersant Apparatus", in *Proceedings of the Twentieth Arctic Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 541-550, 1997.

Fingas, M.F., E. Huang, B. Fieldhouse, L. Wang and J.V. Mullin, "The Effect of Energy, Settling Time and Shaking Time on the Swirling Flask Dispersant Apparatus", in *Spill Science and Technology*, Vol 3, No. 4, pp. 193-194, 1997.

The results of testing the effect of basic operational variables associated with the laboratory effectiveness test known as the 'swirling flask' are reported. It was found that most settings for the swirling flask test were in stable regions, although some changes, such as increasing settling time, could reduce the standard deviation. The effect of changing energy levels by changing the rotational speed from 50 to 250 rpm in steps of 50 rpm was measured. This results in an increase in apparent effectiveness as would be expected. It was found that dispersion onsets rapidly between 100 and 150 rpm. This is consistent with previous findings that dispersion has an onset threshold of energy.

The effect of changing the settling time of 10 minutes from 5 to 80 minutes was measured. It was noted that the change in apparent effectiveness decreases slowly after 10 minutes of settling time. This indicates that mostly large, unstable droplets resurface during the initial period of time.

The amount of shaking time was measured. Only a small increase in effectiveness is observed with increased times ranging from 10 to 160 minutes. This indicates that dispersion is largely a threshold rather than a continuous process.

Fingas, M.F., B. Fieldhouse, L. Sigouin, Z. Wang and J.V. Mullin, "Dispersant Effectiveness Testing: Laboratory Studies of Fresh and Weathered Oils", in *Proceedings of the Twenty-fourth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 551-566, 2001.

Recent results of dispersant testing are reviewed, including the testing of several new and weathered oils for effectiveness. The swirling flask test was used to measure the effectiveness of these oils in the laboratory. The dispersant used was Corexit 9500. The results show the typical trends of decrease in effectiveness with weathering. The weathering trend is shown to be characteristic of that oil and cannot be predicted by correlation with simple physical properties of the starting oil. Results for Alaskan oils are summarized in Table 4.

Table 4 Summary of Alaskan Oils Tested

Oil	Dispersant	Effectiveness
Alaska North Slope (Middle Pipeline)	Corexit 9500	46.1
Alaska North Slope (Middle Pipeline) 30.5% Weathered	Corexit 9500	5.1
Alaska North Slope (Northern Pipeline)	Corexit 9500	32.6
Alaska North Slope (Northern Pipeline) 31.1% Weathered	Corexit 9500	6.4
Alaska North Slope (Southern Pipeline)	Corexit 9500	44.9
Alaska North Slope (Southern Pipeline) 30.5% Weathered	Corexit 9500	5.7
Bunker C (Anchorage)	Corexit 9500	13.8
Bunker C (Anchorage) 8.41% Weathered	Corexit 9500	6.4
Bunker C Fuel Oil (1987)	Corexit 9500	6.6
Diesel (Anchorage)	Corexit 9500	69.7
Diesel (Anchorage) 37.44% Weathered	Corexit 9500	39.4
Prudhoe Bay	Corexit 9500	17.9
Prudhoe Bay 18% Weathered	Corexit 9500	2.5
Prudhoe Bay 27% Weathered	Corexit 9500	0.0
Trading Bay	Corexit 9500	47.0
Trading Bay	Corexit 9527	39.3
Trading Bay	Dasic LTS	5.2
Trading Bay	Enersperse 700	17.9
Trading Bay 33.3% Weathered	Corexit 9500	9.1

Fingas, M.F., B. Fieldhouse, Z. Wang, L. Sigouin and J.V. Mullin, "The Development and Application of a Modified Analytical Procedure for Laboratory Dispersant Testing", in *Proceedings of the Twenty-first Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 271-280, 1998.

This paper reports on studies of the analytical procedures for measuring dispersant effectiveness in the laboratory. Older work on the development of a gas chromatographic method for measuring dispersant effectiveness is also reviewed. This method was shown to have far greater accuracy than the old colorimetric methods. A new gas chromatographic method has been developed that shows improvements in the data quality and time required for analysis. New features of the method include correction for very low oil-in-water values and use of fewer calibration points directly around the expected or actual value. These new features improve accuracy and decrease the amount of sample taking. Only about 1/3 of the calibration points are used compared to the previous test. As calibration points are taken at specific intervals around the actual or predicted value, however, an improved accuracy results. The increased accuracy is particularly evident at low values of dispersant effectiveness.

Fingas, M., B. Fieldhouse, Z. Wang, L. Sigouin, M. Landriault and J.V. Mullin, "Analytical Procedures for Dispersant Effectiveness Testing", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 231-241, 1999.

This paper reports on studies of the analytical procedures for measuring dispersant effectiveness in the laboratory. A new gas chromatographic method has been developed and tested that shows improvements in the data quality and time required for analysis. New characteristics of the method include correction for very low oil-in-water values, use of fewer calibration points directly around the expected value, and a different method for heavier oils with fewer resolvable chromatographic peaks. The new method is demonstrated by comparing results with older methods.

Fiocco, R.J., P.S. Daling, G. DeMarco and R.R. Lessard, "Advancing Laboratory/Field Dispersant Effectiveness Testing", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 177-185, 1999.

This is a review of laboratory and field testing, some data of which is already reported in other papers. The North Sea trial also involved testing Alaska North Slope (ANS) crude after it had weathered. No quantitative results are given, but the dispersibility was good until 32.5 hours of weathering at sea, after which the dispersibility was reduced. The viscosity of the oil was 5,300 cP at this time. Laboratory trials were conducted. The threshold for ANS dispersibility was given as 1,000 cP for Corexit 9527 and 4,000 cP for Corexit 9500. Dispersant testing with the MNS apparatus and water-in-oil mixtures (state unknown) showed effectiveness values ranging from 3 to 100%, depending on conditions. Typical values were 70%. Testing some of the same oils with the Labofina test showed effectiveness from 1 to 67%, with no typical values. Weathered samples from the field test were tested in the IFP test with the result of 27 to 35% effectiveness and 80 to 91% effectiveness in the MNS apparatus. The latter tests were conducted using Corexit 9500.

Fiocco, R.J. and R.R. Lessard, "Demulsifying Dispersant for an Extended Window of Use", in *Proceedings of the 1997 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1015-1016, 1997.

The use of Corexit 9500 on emulsified oil in a test was shown to result in emulsion breaking and dispersion.

Fiocco, R.J. and A. Lewis, "Oil Spill Dispersants", *Pure and Applied Chemistry*, Vol. 71, pp 27-42, 1999.

This is a review of dispersants, including the chemistry and physics of dispersants, planning to use dispersants, decision-making, and their operational use.

Fiocco, R.J., P.S. Daling, G. DeMarco, R.R. Lessard and G.P. Canevari, "Chemical Dispersibility Study of Heavy Bunker Fuel Oil", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 173-186, 1999.

This reports on a series of studies conducted in the laboratory and using a small flume to assess the dispersibility of a heavy oil, IFO-180. In a series of laboratory tests, including the IFP, MNS, WSL, and EXDET tests, it was found that products were qualified to be dispersible up to about 13,000 cP. The flume tests showed similar results.

French-McCay, D.P. and J.R. Payne, "Model of Oil Fate and Water Concentrations With and Without Application of Dispersants", in *Proceedings of the Twenty-fourth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 611-645, 2001.

A three-dimensional water model was used to predict the fate, behaviour, and effects of dispersed and non-dispersed oil. It was found that the treatment by dispersants was severely lethal only if the dispersants were applied within a few hours of the spill. This was attributed to the presence of acutely toxic compounds (BTEX for example) which rapidly evaporate as a spill resides on the sea. If dispersed in the first few hours, it is predicted that these compounds will be dispersed along with the oil into the water column and cause massive lethality.

French-McCay, D.P. “Modelling Evaluation of Water Concentrations and Impacts Resulting from Oil Spills With and Without the Application of Dispersants”, in *Proceedings of the Fifth International Marine Environmental Modelling Seminar*, SINTEF Applied Chemistry, Trondheim, Norway, pp 53-84, 2001.

A three-dimensional model was used to compare the fate, behaviour, and effects of dispersed and non-dispersed oil. It was found that the dispersants were severely lethal only if applied within a few hours of the spill. This was attributed to the presence of acutely toxic compounds (monoaromatic and polyaromatic hydrocarbons) which rapidly evaporate as a spill resides on the sea. If dispersed in the first few hours, it is predicted that these compounds will be dispersed along with the oil into the water column and cause massive lethality.

Fuller, C. and J.S. Bonner, “Comparative Toxicity of Oil, Dispersant and Dispersed Oil to Texas Marine Species”, in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1243-1241, 2001.

Comparative toxicity studies were conducted using luminescent marine bacteria (*Vibrio fischeri*), two marine vertebrae (*Cyprinodon variegatus* and *Menidia beryllina*), and one invertebrate test species (*Mysidopsis bahia*). The exposure was 96 hours except for the bacteria, which followed standard procedure. Testing was conducted under a spiked or short episodic exposure and for dispersant only, water-accommodated fraction, and chemically dispersed oil. The oil was weathered Arabian medium crude. The spiked exposures showed less toxicity in all cases. The dispersant (Corexit 9500) displayed an LC50 of only 73 to 500 mg/L. The water-accommodated fraction showed an LC50 of 0.7 to 83 mg/L and the chemically dispersed oil, an LC50 of 0.6 to 60 mg/L. The chemically dispersed oil was more toxic except in the case of the bacteria.

Fuller, C., J. Bonner, T. McDonald, G. Bragin, J. Clark, D. Aurand, A. Hernandez and A. Ernest, “Comparative Toxicity of Simulated Beach Sediments Impacted with Both Whole and Chemical Dispersions of Weathered Arabian Medium Crude Oil”, in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 659-670, 1999.

Simulated beaches in test tanks were exposed to whole oil and chemically dispersed oil. The toxicity of the sediment samples was evaluated using amphipods and Microtox. The sediments in the chemically dispersed oil tank typically yielded 100% mortality, whereas in the oil-only tanks, mortality varied from 30 to 75%. The authors claim that, if the effects and the sub-lethal effects are combined, the tank treatments showed no difference.

George-Ares, A. and J.R. Clark, “Acute Aquatic Toxicity of Three Corexit Products: An Overview”, in *Proceedings of the 1997 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1007-1008, 1997.

This is a review of toxicity values for Corexit 9527 and 9550 in the literature .

George-Ares, A. and J.R. Clark, “Aquatic Toxicity of Two Corexit Dispersants”, *Chemosphere*, Vol. 40, pp 897-906, 2000.

This is a review of toxicity values for Corexit 9527 and 9550 in the literature. Data tables are provided in this version.

George-Ares, A., R.R. Lessard, K.W. Becker, G.P. Canevari and R.J. Fiocco, “Modification of the Dispersant Corexit 9500 for Use in Freshwater”, in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1209-1211, 2001.

The effectiveness of Corexit 9500 in freshwater is low and the addition of a bivalent, inorganic salt, calcium, was found to increase this effectiveness. The effectiveness with Alaska North Slope crude in freshwater was 22% in the EXDET test, but was increased to 63% by the modification to the product. Similar results were found for other oils in local fresh waters.

Goodlad, J., "The Braer Oil Spill in Shetland, 1993 to 1997", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 189-202, 1998.

The damage to seafood from the naturally dispersed oil from the *Braer* spill is reviewed. The spill had a serious impact on the Shetland food industry. While the commercial stocks were contaminated, the effects on the market for the products were even greater. The long-term problems of biological damage continue and oil deposits on the bottom remain a concern.

Gugg, P.M., C.B. Henry, T. Bridgeman, S.P. Glenn, G.W. Buie and M.L. Austin, "Proving Dispersants Work", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1007-1010, 1999.

The monitoring of dispersants using the SMART protocol is reviewed. Examples of two dispersant applications are given. The results of the sub-surface monitoring indicate successful dispersion.

Guleg, I., B. Leonard and D.A. Holdway, "Oil and Dispersed Oil Toxicity to Amphipods and Snails", *Spill Science and Technology Bulletin*, Vol. 4, pp 1-6, 1997.

The acute 96-hour LC50 toxicity of Bass Strait crude oil was measured for an amphipod. The LC50s for the crude oil were 310,000 ppm, for Corexit 9527, 3 ppm, for Corexit 9500, 3.5 ppm, for oil dispersed with Corexit 9527, 16 ppm, and for oil dispersed with Corexit 9500, 15 ppm. The EC50 values for these tests were analogous. Concern was expressed about the high toxicity of the chemically dispersed oil.

Guyomarch, J., O. Kerfourn and F.-X. Merlin, "Dispersants and Demulsifiers: Studies in the Laboratory, Harbor and Polludrome", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 195-202, 1999.

Comparisons between the Warren Springs and IFP tests and a test tank indicated that similar ranking of dispersion is obtained. No numerical results are given.

Guyomarch, J., F.-X. Merlin and S. Colin, "Study of the Feasibility of Chemical Dispersion of Viscous Oils and Water-in-Oil Emulsions", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 219-230, 1999.

Comparisons between the Warren Springs and IFP tests and a test tank indicated that viscous oils showed lower performance in the test tank. It is concluded that the two lab tests do not simulate conditions at sea. Effectiveness in the lab tests was found to be highly overestimated. On the basis of the test tank results, it was concluded that the limit of successful dispersion is 2,000 cSt. Some de-emulsification was seen with the dispersants.

Guyomarch, J., F.-X. Merlin and P. Bernanose, "Oil Interaction with Mineral Fines and Chemical Dispersion: Behaviour of the Dispersed Oil in Coastal or Estuarine Conditions", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 137-149, 1999.

Laboratory tests and a test tank were used to assess the effect of mineral fines on chemical dispersion. It was found in all tests that even a small amount of mineral fines lowered the amount of oil chemically dispersed. Oil from the surface was removed by mineral fines and this was sedimented. At very high water velocities, however, sedimented material was re-suspended.

Henry, C.B., P.O. Roberts and E.B. Overton, “A Primer on In Situ Fluorometry to Monitor Dispersed Oil”, in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 225-228, 1999.

The basics are provided for the use of an in-situ fluorometer to monitor chemical dispersion of oil spills.

Hillman, S., “Dispersant Application Plans for Prince William Sound, Alaska: Rationale, Operational Deployment and Implications of Regulatory Controls”, in *Dispersant Application in Alaska: A Technical Update*, Conference sponsored by ADEC, SERVS, PWSRCAC, PWSOSRI, and USCG, Anchorage, AK, p. 13-34, 1998.

Dispersant use plans by SERVS (Ship Escort Response Vessel System) for Prince William Sound are reviewed. The rationale for using dispersants is given as mitigating environmental impacts of spills in areas where sea states and other factors dictate against conventional countermeasures. The dispersant deployment arrangements are reviewed, noting that application systems include fixed wing, helicopter, and ship systems. Deployment bases and available facilities are also reviewed. Procedures are described for applying dispersant under various circumstances. The areas where dispersants would be used and permitted are detailed.

Hoffman, R.W., R. Belore and A. Mearns, “A Comparison of Effluent Discharge Criteria to Oil Spill Dispersion Criteria”, in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 209-218, 1999.

A comparison was made between effluent discharges and oil dispersion criteria for Alaskan waters. Dispersion values were based on computer modelling. It was concluded that the criteria for oil dispersion are more stringent than those for wastewater discharges.

Kanga, S., J. Bonner, C. Page, M. Mills and R. Authenreith, “Solubilization of Naphthalene and Methyl-substituted Naphthalenes from Crude Oil using Biosurfactants”, *Environmental Science and Technology*, Vol. 31, pp 556-561, 1997.

Studies were conducted on biosurfactants and comparisons made to surfactants sometimes used in oil dispersants. The biosurfactants showed an increased solubilization of two-ring aromatics compared to surfactants. The synthetic surfactants showed an increased toxicity per mass of PAH.

Kaser, R.M., J. Gahn and C. Henry, “Blue Master: Use of Corexit 9500 to Disperse IFO 180 Spill”, in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 815-819, 2001.

An application of Corexit 9500 to 100 barrels of IFO 180 was reported to be successful. This was based on the arrival of only 1.5 barrels on the shoreline (from 30 miles out) and no subsequent reports of oil sighting.

Kucklick, J.H. and D. Aurand, “Historical Dispersant and In-Situ Burning Opportunities in the United States”, in *Proceedings of the 1997 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 805-810, 1997.

Studies on historical spills of over 1,000 barrels and in a 21-month period of time indicated that the 138 spills of refined products and the 68 spills of crude oil showed some potential for dispersant use. It was estimated that 10 to 51% of the crude oil spills and 4 to 18% of the refined product spills could have been dispersed.

La Schiazza, J., J. Rodriguez-Grau and F. Losada, "Effects of a Dispersed Oil Spill on Biofouling Communities", in *Proceedings of the 1997 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1034-1035, 1997.

Laboratory tests were conducted on biofouling organisms on Plexiglas plates. It was found that dispersed oil affected these organisms significantly, but that recovery was swift.

Law, R.J., "The Effects of a Chemically-Dispersed Oil Spill on Fish and Shellfish: Experience from the Sea Empress Spill in Whales in 1996", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 189-202, 1998.

This is a review of the observed effects of the *Sea Empress* oil spill. The paper concludes that the effect on fisheries was less than might have been expected for the size of spill, especially when compared to the *Braer* spill. There were no reports of mortalities of commercially exploited species. Measured concentrations of PAHs in crustaceans and fin fish showed elevated levels, but these were lower than might have been expected. The concentrations in mussels were highest near the contaminated shorelines. Further studies of recruitment after the spill were recommended.

Lessard, R.R. and G. Demarco, "The Significance of Oil Spill Dispersants", *Spill Science and Technology Bulletin*, Vol. 6, pp 59-68, 2000.

The benefits of using dispersants are reviewed and some recent uses summarized.

Levine, E.A., "Development and Implementation of the Dispersant Observation Job Aid", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1015-1018, 1999.

The job aid for dispersants, which is a guide to assist observers of dispersant application, is described.

Lewis, A. and D. Aurand, *Putting Dispersants to Work: Overcoming Obstacles*, Technical Report IOSC-004, American Petroleum Institute, Washington, DC, 78 p, 1997.

This is an issue paper that presents the case for using dispersants. It provides a review of certain dispersant work and makes recommendations for dispersant application.

Lewis, A., A. Crosbie, L. Davies and T. Lunel, "Large Scale Field Experiments Into Oil Weathering at Sea and Aerial Application of Dispersants", in *Proceedings of the Twenty-first Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 319-344, 1998.

This is a description of the 1997 North Sea dispersant test on emulsified and weathered crude oils. Four experimental slicks were laid out, two of 50 m^3 of Forties Blend crude oil, one of 30 m^3 of Alaska North Slope crude oil, and one of 20 m^3 of IFO-180 (a diesel-diluted residual fuel oil). After two days at sea, the Forties Blend crude oil slicks were treated with Corexit 9500 and Dasic Slickgone NS dispersants applied from a DC-3 aircraft. The Alaska North Slope oil was left to weather for 55 hours and then sprayed with Corexit 9500. The IFO-180 slick was sprayed after about 4½ hours on the surface. The Forties Blend oils took up water but were apparently dispersed. The IFO oil was poorly dispersed.

The Alaskan North Slope oil was repeatedly treated with dispersant. This report does not indicate the effectiveness achieved, but does indicate that concentrations of dispersed oil at the sub-surface reached about the same as the Forties Blend on the first pass, but were lower than that on the second and subsequent treatments.

Lewis, A., A. Crosbie, L. Davies and T. Lunel, "The AEA '97 North Sea Field Trials on Oil Weathering and Aerial Application of Dispersants", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 78-109, 1998.

This paper gives a similar description to the one above, however, with slightly different conclusions.

Lindstrom, J.D. White and J. Braddock, "Biodegradation of Dispersed Oil Using Corexit 9500", Report prepared for the Alaska Department of Environmental Conservation, Anchorage, AK, 35 p., 1999.

Biodegradation assays were conducted on chemically and naturally dispersed oils. The results of specific assays of hexadecane, phenanthrene, dodecane, and 2-methyl naphthalene showed that the bacterial consortium used metabolized soluble species selectively. The use of dispersant appears to have resulted in lower mineralization potential for hexadecane and phenanthrene. The relatively soluble substrates were not affected by the addition of dispersant.

Lunel, T., "Sea Empress Spill: Dispersant Operations, Effectiveness and Effectiveness Monitoring", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 59-77, 1998.

The dispersant operation during the *Sea Empress* spill cleanup is described. A final mass balance of oil was estimated to be: evaporated - 35 to 42%; naturally dispersed - 7 to 21%; chemically dispersed - 24 to 52%; and on shoreline - 2 to 6%.

Lunel, T., "Dispersant Pre-Approvals: Best Practice", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 441-444, 2001.

The use of dispersants and pre-approvals are reviewed. The author concludes that pre-approvals are required in order to use dispersants expediently.

Lunel, T. and A. Lewis, "Optimisation of Oil Spill Dispersant Use", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 187-193, 1999.

The recent usage and trials of dispersants are reviewed. The author makes the point that new formulations increase the time window to use dispersants. It is also felt that other developments make the use of dispersants more feasible.

Lunel, T., J. Rusin, N. Bailey, C. Halliwell and L. Davies, "The Net Environmental Benefit of a Successful Dispersant Operation at the Sea Empress Incident", in *Proceedings of the 1997 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 185-194, 1997.

The use of dispersants at the *Sea Empress* incident is reviewed. Dispersant application was monitored and this monitoring information was then able to provide a relatively good picture of how successful the dispersant operation was. The use of dispersants is credited with preventing many tons of oil from impacting the beach.

Martin, C., G. Kanazawa and K. Beasley, "Partnering for a Dispersant Application Capability in Hawaii", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1391-1394, 2001.

Preparations for using dispersants in Hawaii are summarized.

Melbye, A.G., D. Altin and T. Frost, "Determination of Uptake of Dispersed Oil in Copepod *Calanus* *finmarchicus*", in *Proceedings of the Twenty-fourth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 223-235, 2001.

A test of the biological uptake of dispersed oil to a copepod was conducted in a flow-through system. The bioaccumulation of the oil ranged from 200 to 800 over 14 days. A significant portion of the hydrocarbon was absorbed to the surface of the organism.

Merlin, F.-X., "Les dispersants: Sur quels critΠres environnementaux decider de leur emploi", *Bulletin d'Information du Cedre*, Vol. 9, pp 4-6, 1997.

Criteria for using dispersants in French waters are reviewed.

Michel, J. and C.B. Henry, "Oil Uptake and Depuration in Oysters After Use of Dispersants in Shallow Water in El Salvador", *Spill Science and Technology Bulletin*, Vol. 4, pp 57-70, 1997.

This is a report on the monitoring of sub-tidal oysters after a dispersant is used in shallow water (4-6 m) off the coast of Venezuela. At one week, two samples of oysters contained as much as 147 and 164 ppm PAHs compared to less than 1 for a background level. Four weeks later, the PAHs decreased by 94 to 98%.

Mitchell, F.M. and D.A. Holdway, "The Acute and Chronic Toxicity of the Dispersants Corexit 9527 and 9500, Water Accommodated Fraction (WAF) of Crude Oil and Dispersant Enhanced WAF (DEWAF) to *Hydra viridissima* (Green Hydra)", *Water Research*, Vol. 34, pp 343-348, 2000.

The acute toxicity of Corexit 9527 and Corexit 9500 to green hydra was found to be 230 and 160 ppm (LC50, 96 hour). The no-observed effect and the least-observed effect concentrations were found to be <15 and 15 ppm for Corexit 9527 and 13 and 43 ppm for Corexit 9500. The acute toxicity of Bass Strait WAF was found to be 0.7 ppm, for Corexit 9527 dispersed oil, 9 ppm, and for Corexit 9500, 7.2 ppm. The no-observed effect and LOEC values for 7 days were found to be 0.6 and > 0.6 ppm for the WAF, 0.6 and 0.6 for the Corexit 9527 dispersed oil, and 2 and 4 ppm for the Corexit 9500 dispersed oil.

Moles, A., L. Holland and J. Short, *The Effectiveness of Corexit 9527 and 9500 in Dispersing Fresh, Weathered and Emulsion of Alaska North Slope Crude Oil Under Subarctic Conditions*, Prince William Sound Regional Citizens' Advisory Council, Anchorage, AK, 24 p., 2001.

The effectiveness of Corexit 9500 and Corexit 9527 was tested on Alaska North Slope crude oil at various salinities and temperatures representative of conditions found in Southern Alaskan waters. The oil was weathered to different degrees. Tests were conducted in a swirling flask at temperatures of 3, 10, and 22^{o}C with salinities of 22 and 32^{o}/oo. Analysis was by GC. The authors concluded that, at the common temperatures found in the estuaries and marine waters of Alaska, the dispersants were largely ineffective. They also found that there was an interactive effect between temperature and salinity. A high effectiveness for 'emulsion', an uncharacterized mixture of oil and water, was attributed to 'osmotic shock', because of the difference in the salinity of preparation (33 ^{o}/oo) and the test salinity. The results are summarized in Table 5.

Table 5 Dispersant Effectiveness Measured by Moles et al., 2001

all values are effectiveness averages calculated from paper

Oil Type	**Temperature**	**Corexit 9527**		**Corexit 9500**	
		Salinity		**Salinity**	
	°C	**22 ^{0}/oo**	**32 ^{0}/oo**	**22 ^{0}/oo**	**32 ^{0}/oo**
Fresh ANS	*3*	8.5	1	10	10
	10	7.9	15	10	22
	22	35	31	16	18
20% evap. ANS	*3*	6.3	6.5	6.3	6.3
	10	1.7	4.1	4.5	2.6
	22	6.3	6.3	6.3	6.3
emulsified' ANS	*3*	26	20	13	23
	10	73	32	42	29
	22	17	20	24	14

Morris, R., "Regulatory Controls: Nature, Purpose and Legislation", in *Dispersant Application in Alaska: A Technical Update*, Conference sponsored by ADEC, SERVS, PWSCAC, PWSOSRI and USCG, Anchorage, AK, pp 3-11, 1998.

The use of dispersants is reviewed from the point of view of the National Contingency Plan and the Area Contingency Plans. Zones in which authorities have agreed that dispersant use (or non-use) can occur are defined and provided. Specific areas in Prince William Sound are delineated where dispersant use is pre-approved.

Olagbende, O.T., G.O. Ede, L.E.D. Inyang, E.R. Gundlach, E.S. Gilfillan and D.S. Page, "Scientific and Cleanup Response to the *Idoho-Qit* Oil Spill, Nigeria", *Environmental Technology*, Vol. 20, pp 1213-1222, 1999.

An oil spill from an offshore pipeline was dispersed. The oil was driven offshore and little came ashore. The effectiveness of the dispersant was estimated to be high.

Page, C.A., R.L. Autenrieth, J.S. Bonner and T. McDonald, "Behaviour of Chemically Dispersed Oil in a Wetland Environment", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 821-823, 2001.

An experiment was conducted on the behaviour of stranded oil on plots near Houston, Texas. Oil was applied to the plots as oil-only and dispersed oil at ratios of 1:10 (dispersant-to-oil) and 1:20, with 200 parts water. Analysis of the plots was conducted using GCMS and values were normalized to Hopane. There were no significant differences in degradation between any of the treatments. The amount of oil flushed from the plots was much greater for those chemically dispersed.

Page, C.A., J.S. Bonner, P.L. Sumner, T.J. McDonald, R.L. Autenrieth and C.B. Fuller, "Behaviour of a Chemically Dispersed Oil and a Whole Oil on a Near-Shore Environment", *Water Research*, Vol. 34, pp 2507-2516, 2000.

An experiment on the behaviour of stranded oil was conducted in the Coastal OilSpill Simulation System) COSS test tanks. Oil was applied to the plots as oil-only or as dispersed oil. At the end of the 10-day experiment, 49% of the oil remained in the oil-only tanks (mostly in sediments) and <1% in the dispersed oil tanks. It was concluded that application of dispersants to nearshore situations would greatly reduce the oil retained in sediments.

Page, C., P. Sumner, R. Autenrieth, J. Bonner and T. McDonald, "Materials Balance on a Chemically-Dispersed Oil and a Whole Oil Exposed to an Experimental Beach Front", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 645-658, 1999.

A study of the mass balance in the COSS (Coastal OilSpill Simulation System) test tanks showed that about 40 to 70% of the oil could typically be accounted for.

Pearson, L.A., "Alaska's Dispersant Effectiveness and Toxicity Testing Program", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 259-261, 1998.

This paper is a brief review of Alaska's dispersant testing program.

PWSRCAC, "Dispersed Oil Toxicity Issues", Prince William Sound Regional Citizens' Advisory Council, Anchorage, AK, 26 p., 1999.

This report is a review of toxicity issues from the PWSRCAC viewpoint.

Reed, M., P. Daling, A. Lewis, M.K. Ditlevsen, B. Brors, J. Clark and D. Aurand, "Modelling of Dispersant Application to Oil Spills in Shallow Coastal Waters", in *Proceedings of the Fifth International Marine Environmental Modelling Seminar*, SINTEF Applied Chemistry, Trondheim, Norway, pp 379-400, 2001.

Modelling of the application of dispersants in shallow waters shows that about 2 to 7% of the hydrocarbons would be associated with the bottom sediments.

Rhoton, S.L., R.A. Perkins, J.F. Braddock and C. Behr-Andres, "A Cold-Weather Species' Response to Chemically Dispersed Fresh and Weathered Alaska North Slope Crude Oil", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1231-1236, 2001.

Toxicity tests were conducted on a number of species along with ANS or Prudhoe Bay crude oil. Results are shown in Table 6.

Table 6 **Toxicity Data from Rhoton et al., 2001**
Alaska North Slope Crude

all concentrations rounded and in mg/L

Species	**Exposure**	**WAF LC$_{50}$**	**Chem WAF LC$_{50}$**
crab larvae	Spiked	10	11
	Continuous	3	1
mysid	Spiked	8	5
	Continuous	3	1
fish, beryllina	Spiked	26	12
	Continuous	16	12
Microtox		4	2
	Prudhoe Bay Crude		
fish	Spiked	>20	12
	Continuous	15	5
Microtox		4	2
	Weathered ANS Crude		
crab larvae	Spiked	0.4	2
	Continuous	0.3	0.4
fish, beryllina	Spiked	>1	19
	Continuous	0.8	0.7
Microtox		0.4	6

Rhoton, S.L., R.A. Perkins, J.E. Linstrom and J.F. Braddock, "Toxicity of Dispersants and Dispersed Oil to an Alaskan Marine Organism", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1035-1038, 1999.

The authors report toxicity test results to the crab larvae similar to above.

Ross, S.L., "Summary of Major Issues Related to the Effectiveness of Dispersants on Spills of North Slope Crude Oil in Prince William Sound and the Gulf of Alaska", in *Dispersant Application in Alaska: A Technical Update*, Conference sponsored by ADEC, SERVS, PWSRCAC, PWSOSRI and USCG, Anchorage, AK, pp 13-34, 1998.

This paper reviews the report to PWSRCAC prepared by S.L. Ross Environmental Research Limited. The report reviews the effectiveness measures in lab and tank, noting that the results are very diverse. It is concluded that, if used properly, the application of Corexit 9527 is likely to be reasonably effective on North Slope Oil in Prince William Sound. However, it is noted that laboratory tests and tank tests are not accurate predictors of this effectiveness. The second conclusion is that Corexit 9527 is the most effective product available and that Corexit 9500 might be even better. A custom product might be made, especially one that is also de-emulsifying. On the operations side, it is concluded that the industry in Alaska has one of the best dispersant-use plans and preparations in the world and that the governments have the best dispersant approval procedures available. It was suggested that the tactics for spraying and monitoring of field effectiveness required some improvement.

Ross, S.L., I.A. Buist, S.G. Potter and R.C. Belore, "Feasibility of Using Ohmsett for Dispersant Testing and Research", in *Proceedings of the Twenty-third Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 709-731, 2000.

This is a feasibility study on using OHMSETT for conducting dispersant effectiveness tests.

Ross, S.L., I. Buist, S. Potter, R. Belore and A. Lewis, “Dispersant Testing of OHMSETT: Feasibility Study and Preliminary Testing”, in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 461-466, 2001.

A feasibility study is given on the use of OHMSETT for dispersant testing. A preliminary test indicates that the study is correct.

S.L. Ross Environmental Research Limited, *Technology Assessment of the Use of Dispersants on Spills from Drilling and Production Facilities in the Gulf of Mexico Outer Continental Shelf*, United States Minerals Management Service, Herndon, VA, 206 p., 2000.

This study is a comprehensive assessment of the operational and environmental factors associated with the use of chemical dispersants to treat oil spills from OCS facilities in the Gulf of Mexico. The analysis includes a survey of the oils and their dispersibility, application systems and dispersant availability, source of spills, distance to shore, and spill type. Scenarios are established and the fate is predicted of the oil, with and without dispersant use. The net environmental benefit of dispersant use is estimated. For those scenarios where the oil is dispersible and the distance to shore is sufficient to allow treatment, a net environmental benefit would be realized.

S.L. Ross Environmental Research Limited, *Laboratory Study to Compare the Effectiveness of Chemical Dispersants When Applied Dilute Versus Neat*, United States Minerals Management Service, Herndon, VA, 26 p., 2000.

Laboratory tests were conducted to measure the difference in effectiveness of dispersants, Corexit 9527 and Corexit 9550, on Alaska North Slope oil when applied neat versus diluted with water. The effectiveness of Corexit 9527 was not significantly affected by water dilution, but that of Corexit 9500 was severely reduced when applied diluted with water at both 1:10 and 3:10 ratios.

S.L. Ross Environmental Research Ltd., *Reexamination of the Properties, Behaviour and Dispersibility of Hibernia Oil Spills*, Hibernia Management and Development Company Ltd., St. John’s, NF, 93 p., 1999.

Tests of the effectiveness of Hibernia oil dispersion ranged from 6 to 30%. Using a model, it was concluded that this would be sufficient to achieve an effect.

Salt, D., “Aerial Dispersant Spraying: A Daylight-Only Tool”, in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1223-1225, 2001.

Night-time dispersant spraying operations are assessed. The conclusion is that, although not optimal and probably unsafe, night-time operations could possibly be conducted.

Singer, M.M., S. George, S. Jacobson, L.L. Weetman, R.S. Tjeerdema, D. Aurand, G. Blondina and M.L. Sowby, “Acute Aquatic Effects of Chemically Dispersed and Undispersed Crude Oil”, in *Proceedings of the 1997 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1020-1021, 1997.

Toxicity tests were performed on mysids using chemically dispersed Prudhoe Bay crude oil with Corexit 9527. The chemically dispersed oil showed a higher response than did water-accommodated fractions of similar concentration.

Singer, M.M., S. George, I. Lee, S. Jacobson, L.L. Weetman, G. Blondina, R.S. Tjeerdema, D. Aurand and M.L. Sowby, “Effects of Dispersant Treatment on the Acute Aquatic Toxicity of Petroleum Hydrocarbons”, *Archives of Environmental Contamination and Toxicology*, Vol. 34, pp 177-187, 1998.

A series of aquatic toxicity studies was conducted on three different species. The oil used was Prudhoe Bay crude and the dispersant was Corexit 9527. The results, given in Table 7, show that the water-accommodated fraction alone is usually less toxic than the dispersed oil, but that this is somewhat species-dependent.

Table 7 Acute Toxicity Data from Singer et al., 1998

EC or LC_{50} in mg/L

Species/test	WAF	Dispersed
Red abalone larvae Larval abnormality	38	23
Mysid		
96-h mortality	29	11
initial narcosis	13	32
Topsmelt		
96-h mortality	31	45
initial narcosis	36	101

Singer, M.M., S. Jacobson, R.S. Tjeerdema and M. Sowby, "Acute Affects of Fresh Versus Weathered Oil to Marine Organisms: California Findings", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1263-1268, 2001.

A similar toxicity test to that above was conducted using somewhat different species but also with weathered oil. It was found that the weathered oils rendered the water-accommodated fraction and chemically dispersed oil approximately equally toxic.

Sorial, G.A., K.M. Koran, E. Holder, A.D. Venosa and D.W. King, "Development of a Rational Oil Spill Dispersant Effectiveness Protocol", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 471-478, 2001.

This is a preliminary report on a laboratory dispersant test using a baffled flask that is intended to replace the swirling flask test. It is reported that the swirling flask test is too rigorous and causes too much variance among laboratories.

Stevens, L.M., J.T. Roosen and P. Irving, "Guidelines for Dispersant Use in New Zealand", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1185-1194, 2001.

Guidelines for application of dispersants in New Zealand are summarized.

Stephenson, R., "Effects of Oil and Other Surface-Active Organic Pollutants on Aquatic Birds", *Environmental Conservation*, Vol. 24, pp 121-129, 1997.

A review of the effects of oils and surfactants on birds shows that any such material can affect birds.

Stoermer, S., G. Butler and C. Henry, "Application of Dispersants to Mitigate Oil Spills in the Gulf of Mexico: The Poseidon Pipeline Spill Case Study", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1227-1229, 2001.

This is a review of a dispersant application, primarily from the decision-making point of view.

Swannell, R.P.J. and F. Daniel, “Effect of Dispersants on Oil Biodegradation Under Simulated Marine Conditions”, in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 169-176, 1999.

Laboratory tests were conducted on the degradation of oil that was chemically treated with Corexit 9500, Enersperse 1583, Finasol OSR-51, and Dasic Slickgone. Three tests were conducted with each dispersant/oil combination: with low level nutrients, with high level nutrients, and with a sterilized control. An oil-only test was not conducted. The authors concluded that the dispersants do assist in degradation and that this varies with dispersant type.

Tjeerdema, R., M. Singer, M. Wolfe, G. Blondina and M. Sowby, “Deriving Fate and Effects Information to Assess Petroleum Risk”, in *Dispersant Application in Alaska: A Technical Update*, Conference sponsored by ADEC, SERVS, PWSRCAC, PWSOSRI and USCG, Anchorage, AK, p. 249-257, 1998.

This paper is a review of recent studies conducted by the group, with emphasis on bioavailability. Recent studies showed that bioavailability was increased up to 50% by the addition of dispersant, at the same total hydrocarbon concentration. Results were similar with a number of species, except for rotifers, in which case the biotransferability was noted.

Trudel, K., “Environmental Risks and Trade-offs in Prince William Sound”, in *Dispersant Application in Alaska: A Technical Update*, Conference sponsored by ADEC, SERVS, PWSRCAC, PWSOSRI and USCG, Anchorage, AK, pp 159-188, 1998.

This paper reviews the risks and trade-offs of dispersant use in Prince William Sound. The concentration of dispersant alone is estimated. For example, at a dilution depth of 1 m and a 5 gal/acre application, the concentration is 5 ppm. Overall, for a single pass, the maximum concentration is between 5 and 15 ppm. The toxicity studies conducted for Corexit 9527 to date are also summarized. Overall, the 96-hour toxicities range from 2 to 175 mg/L for a wide-ranging variety of species. The concentrations of oil beneath treated Prudhoe Bay crude spills range from 2 to 40 ppm at the 1-m depth. The sensitivity of species (LC50) to chemically dispersed oil is given as ranging from 0.17 to 10 ppm in modern tests and up to 138 for older tests. Tainting results are also reviewed. The author concludes that there is little risk for dispersants alone and that the risk for dispersant operations is low because the concentrations are below that of most species’ thresholds. Tainting might be a risk, although data indicate that tainting could be lost in a few days.

Trudel, K., “Monitoring the Effectiveness and Effects of Dispersant Operations”, in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSRI), Cordova, AK, pp 263-278, 1998.

This paper is a review of effectiveness and effects monitoring after dispersant application. Requirements for such monitoring in the United States are described.

Venosa, A.D., G.A. Sorial, F. Uraizee, T.L. Richardson and M.T. Suidan, “Research Leading to Revisions in EPA’s Dispersant Effectiveness Protocol”, in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1019-1022, 1999.

This is a summary of the re-evaluation of the EPA swirling flask protocol for testing oil spill dispersant effectiveness in the laboratory.

White, D., I. Ask and C. Behr-Andres, “Effectiveness Testing for Corexit 9500 on Alaska North Slope Crude Oil in Prince William Sound Seawater at 8°C”, Report prepared for the Alaska Department of Environmental Conservation, Anchorage, AK, 47 p., 1999.

The dispersant effectiveness of Alaska North Slope crude oil with Corexit 9500 in seawater at 8°C was measured in a modified swirling flask and a modified EXDET test apparatus. Analysis was by relevant fluorescence using a Turner Fluorometer. The dispersant-to-oil ratios were 1:10, 1:20, and 1:50. It was found that the effectiveness of the dispersant was directly related to the ratio. The greatest effectiveness was found when the oil was freshest and the dispersant was allowed to contact the oil before mixing.

Wolfe, M.F., J.A. Schlosser, G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, “Influence of Dispersants on the Bioavailability and Trophic Transfer of Petroleum Hydrocarbons to Primary Levels of a Marine Food Chain”, *Aquatic Toxicology*, Vol. 42, pp 211-227, 1998.

A model food chain consisting of a primary producer (a flagellate) and a primary consumer (a rotifer) was studied for naphthalene processing. The oil was Prudhoe Bay crude and the dispersant was Corexit 9527. It was found that the dispersant had little effect on the transfer of naphthalene through this food chain model.

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, “Influence of Dispersants on Trophic Transfer of Petroleum Hydrocarbons in Marine Food Chain”, in *Proceedings of the Twentieth Arctic Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 1215-1226, 1997.

A model food chain consisting of a primary producer (a flagellate) and a primary consumer (a rotifer) was studied for naphthalene processing. The oil was Prudhoe Bay crude and the dispersant was Corexit 9527. It was found that the dispersant significantly affected the transfer of naphthalene through this food chain model.

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, “Effects of Salinity and Temperature on the Bioavailability of Dispersed Petroleum Hydrocarbons to the Golden-Brown Algae, *Isochrysis galbana*”, *Archives of Environmental Contamination and Toxicology*, Vol. 35, pp 268-273, 1998.

A study of the uptake of napthalene by an algae was looked at. The oil was Prudhoe Bay crude and the dispersant was Corexit 9527. It was found that the dispersant significantly affected the uptake of naphthalene (by as much as 50%).

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, “Influence of Dispersants on the Bioavailability of Naphthalene from the Water-Accommodated Fraction Crude Oil to the Golden-Brown Algae, *Isochrysis galbana*”, *Archives of Environmental Contamination and Toxicology*, Vol. 35, pp 274-280, 1998.

A study of the uptake of napthalene by an algae is looked at. The oil used was Prudhoe Bay crude and the dispersant was Corexit 9527. It was found that the dispersant significantly affected the uptake of naphthalene but had no effect on the bioaccumulation of naphthalene.

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, “Influence of Dispersants on the Bioavailability and Trophic Transfer of Petroleum Hydrocarbons to Larval Topsmelt (*Atherinops affinis*)”, *Aquatic Toxicology*, Vol. 52, pp 49-60, 2001.

A model food chain consisting of a primary producer (a flagellate) and a primary consumer (a rotifer) and larval topsmelt was studied for naphthalene processing. The oil was Prudhoe Bay crude and the dispersant was Corexit 9527. The dispersant was found to have a significant effect on the transfer of naphthalene to the rotifer, but not to the topsmelt.

Wu, R.S.S., P.K.S. Lam and B.S. Zhou, “Effects of Two Oil Dispersants on Phototaxis and Swimming Behaviour of

Barnacle Larvae", *Hydrobiologia*, Vol. 352, pp 9-16, 1997.

Aquatic studies on the survivability and behaviour of barnacle nauplii were conducted with diesel fuel and the dispersants Vecom and Norchem. The LC50 values (24- and 48-hour) varied from 48 to 514 mg/L. The EC50 values were similar.

4.2 Trade Magazines and News Articles

EnviroNEWs, Sept 1999, "Soapy Soup from Sri Lanka Spill Kills Fishery", http://ens.lycos.com/ens/sep99/1999L-09-23-01.html.

Hundreds of thousands of fish died as a result of an oil and fertilizer spill off Sri Lanka. Scientists felt that most of the deaths were the result of the use of chemical dispersants.

OSIR, 15 Jan, 1998, "Mobile Pipeline Spills 1.7 Million Gallons of Crude Oil Off Nigeria"*, Oil Spill Intelligence Report*.

This describes a spill of crude oil, on which dispersants were applied from a Twin Otter aircraft, 2 helicopters, and 12 vessels.

OSIR, 29 Jan, 1998, "Texans Praise 'Textbook' Dispersant Use on Pipeline, Tanker Spills", *Oil Spill Intelligence Report*.

Dispersants were used on two separate incidents off Texas - a leak of crude oil from a pipeline and a leak of crude oil from a tanker. Three-thousand gallons of Corexit 9527 were used on the pipeline spill. A DC-3 was used to spray the pipeline spill. The tanker spill was treated from a DC-4.

OSIR, 16 Sept, 1998, "Corexit 9500 Disperses IFO-180 Slick Off Texas", *Oil Spill Intelligence Report*.

Two tons of Corexit were applied by a DC-4 to 45 tons of IFO-180 spilled from a bulk carrier.

OSIR, 8 Oct, 1998, "Corexit 9527 Disperses Crude Oil Spill in Gulf of Mexico", *Oil Spill Intelligence Report*.

This describes the application of Corexit 9527 from DC-3 and DC-4 aircraft. About 2,000 gallons of dispersant were applied in five passes and this application apparently shrunk the size of the slick.

OSIR, 23 Dec, 1998, "UK Chemical Dispersant Stockpile Opened to Worldwide Use", *Oil Spill Intelligence Report.*

This announces that the combined stockpiles of Oil Spill Response Limited and Briggs Marine Environmental Services will now be available worldwide, giving a total quantity of dispersant of 242,000 L.

OSIR, 14 Jan, 1999, "Israel Applies Dispersant", *Oil Spill Intelligence Report*.

The State of Israel applied dispersant on a small slick from a leaking tanker.

OSIR, 1 Jul, 1999, "Airtractors Treat Mobil Crude Oil Spill off Australia", *Oil Spill Intelligence Report*.

This describes the application of dispersant over two days to a 45-ton slick of Oman crude oil.

OSIR, 27 Jan, 2000, "Planes Disperse US Spill in Gulf of Mexico", *Oil Spill Intelligence Report*.

Four passes by DC-3 and DC-4 aircraft applied 6,000 gallons of Corexit 9527 to a spill from a break in a pipeline.

5. References

Adams, G.G., P.L. Klerks, S.E. Belanger and D. Dantin, "The Effect of the Oil Dispersant Omni-Clean on the Toxicity of Fuel Oil No. 2 in Two Bioassays With the Sheepshead Minnow *Cypriodon variegatus*", *Chemosphere*, Vol. 39, pp 2141-2157, 1999.

Belore, R. and S. Ross, "Laboratory Study to Compare the Effectiveness of Chemical Dispersants when Applied Dilute Versus Neat", in *Proceedings of the Twenty-third Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 733-748, 2000.

Blondina, G.J., M.L. Sowby, M.T. Ouano, M.M. Singer and R.S. Tjeerdema, "A Modified Swirling Flask Efficacy Test for Oil Spill Dispersants", *Spill Science and Technology Bulletin*, Vol. 4, pp 177-185, 1997a.

Blondina, G.J., M.L. Sowby, M.T. Ouano, M.M. Singer and R.S. Tjeerdema, "A Modified Swirling Flask Efficacy Test for Oil Spill Dispersants", *Spill Science and Technology Bulletin*, Vol. 4, pp 177-185, 1997b.

Brandvik, P.J., *Optimisation of Oil Spill Dispersants on Weathered Oils: A New Approach Using Experimental Design and Multivariate Data Analysis*, Phd Thesis, University of Science and Technology, Department of Chemistry, Trondheim, Norway, 83 p, 1997.

Brandvik, P., Personal Communication, January, 2002.

Bruheim, P., H. Bredholt and K. Eimhjellen, "Effects of Surfactant Mixtures, Including Corexit 9527, on Bacterial Oxidation of Acetate and Alkanes in Crude Oil", *Applied and Environmental Microbiology*, Vol. 65, pp 1658-1661, 1999.

Coelho, G.M., D.V. Aurand and D.A. Wright, "Biological Uptake Analysis of Organisms Exposed to Oil and Chemically Dispersed Oil", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 685-694, 1999.

Eldridge, B., Personal Communication, January, 2002.

Epstein, N., R.P.M. Bak and B. Rinkevich, "Toxicity of Third Generation Dispersants and Dispersed Egyptian Crude Oil on Red Sea Coral Larvae", *Marine Pollution Bulletin*, Vol. 40, pp 497-503, 2000.

Fingas, M.F., "Use of Surfactants for Environmental Applications", in *Surfactants: Fundamentals and Applications to the Petroleum Industry*, Laurier L. Schramm, (ed.), Chapter 12, Cambridge University Press, pp 461-539, 2000.

Fingas, M.F., B. Fieldhouse, L. Sigouin, Z. Wang and J.V. Mullin, "Dispersant Effectiveness

Testing: Laboratory Studies of Fresh and Weathered Oils", in *Proceedings of the Twenty-fourth Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 551-566, 2001.

Fiocco, R.J., P.S. Daling, G. DeMarco and R.R. Lessard, "Advancing Laboratory/Field Dispersant Effectiveness Testing", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 177-185, 1999.

Fuller, C. and J.S. Bonner, "Comparative Toxicity of Oil, Dispersant and Dispersed Oil to Texas Marine Species", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1243-1241, 2001.

George-Ares, A. and J.R. Clark, "Aquatic Toxicity of Two Corexit Dispersants", *Chemosphere*, Vol. 40, pp 897-906, 2000.

George-Ares, A., R.R. Lessard, K.W. Becker, G.P. Canevari and R.J. Fiocco, "Modification of the Dispersant Corexit 9500 for Use in Freshwater", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1209-1211, 2001.

Guleg, I., B. Leonard and D.A. Holdway, "Oil and Dispersed Oil Toxicity to Amphipods and Snails", *Spill Science and Technology Bulletin*, Vol. 4, pp 1-6, 1997.

Guyomarch, J., O. Kerfourn and F.-X. Merlin, "Dispersants and Demulsifiers: Studies in the Laboratory, Harbor and Polludrome", in *Proceedings of the 1999 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 195-202, 1999a.

Guyomarch, J., F.-X. Merlin and S. Colin, "Study of the Feasibility of Chemical Dispersion of Viscous Oils and Water-in-Oil Emulsions", in *Proceedings of the Twenty-second Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 219-230, 1999b.

HELCOM, http://www.helcom.fi/recommendations/REC-22-2.htm, 2002.

Hillman, S., "Dispersant Application Plans for Prince William Sound, Alaska: Rationale, Operational Deployment and Implications of Regulatory Controls", in *Dispersant Application in Alaska: A Technical Update*, Conference sponsored by ADEC, SERVS, PWSRCAC, PWSOSRI, and USCG, Anchorage, AK, p. 13-34, 1998.

Hillman, S., Personal Communication, January, 2002.

Jolma, K., Personal Communication, January, 2002.

Lewis, A., A. Crosbie, L. Davies and T. Lunel, "Large Scale Field Experiments Into Oil Weathering at Sea and Aerial Application of Dispersants", in *Proceedings of the Twenty-first Arctic Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 319-344, 1998a.

Lewis, A., A. Crosbie, L. Davies and T. Lunel, "The AEA '97 North Sea Fields Trials on Oil Weathering and Aerial Application of Dispersants", in *Dispersant Application in Alaska: A Technical Update*, Prince William Sound Oil Spill Recovery Institute (OSIR), Cordova, AK, pp 78-109, 1998b.

Lindstrom, J. D. White and J. Braddock, "Biodegradation of Dispersed Oil Using Corexit 9500", Report Prepared for The Alaska Department of Environmental Conservation, Anchorage, AK, 35 p., 1999.

Loostrom, B., Personal Communication, January, 2002.

Lunel, T., Baldwin, G., and Merlin, F., "Comparison of Meso-Scale and Laboratory Dispersant Tests with Dispersant Effectiveness Measured at Sea", in *Proceedings of the Eighteenth Arctic and Marine Oilspill Program (AMOP) Technical Seminar*, Environment Canada, Ottawa, ON, pp 629-651, 1995.

Moles, A., L. Holland and J. Short, "The Effectiveness of Corexit 9527 and 9500 in Dispersing Fresh, Weathered and Emulsion of Alaska North Slope Crude Oil Under Subarctic Conditions", *Spill Science and Technology Bulletin*, in press, 2001.

Rhoton, S.L., R.A. Perkins, J.F. Braddock and C. Behr-Andres, "A Cold-Weather Species' Response to Chemically Dispersed Fresh and Weathered Alaska North Slope Crude Oil", in *Proceedings of the 2001 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp 1231-1236, 2001.

Singer, M.M., S. George, I. Lee, S. Jacobson, L.L. Weetman, G. Blondina, R.S. Tjeerdema, D. Aurand and M.L. Sowby, "Effects of Dispersant Treatment on the Acute Aquatic Toxicity of Petroleum Hydrocarbons", *Archives of Environmental Contamination and Toxicology*, Vol. 34, pp 177-187, 1998.

Smite, E., Personal Communication, January, 2002.

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, "Influence of Dispersants on Trophic Transfer of Petroleum Hydrocarbons in Marine Food Chain", in *Proceedings of the Twentieth Arctic Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp 1215-1226, 1997.

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, "Effects of Salinity and Temperature on the Bioavailability of Dispersed Petroleum Hydrocarbons to the Golden-Brown Algae, *Isochrysis galbana*", *Archives of Environmental Contamination and Toxicology*, Vol. 35, pp 268-273, 1998a.

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, "Influence of Dispersants on the Bioavailability of Naphthalene from the Water-Accommodated Fraction Crude Oil to the Golden-Brown Algae, *Isochrysis galbana*", *Archives of Environmental Contamination and Toxicology*, Vol. 35, pp 274-280, 1998b.

Wolfe, M.F., G.J.B. Schwartz, S. Singaram, E.E. Mielbrecht, R.S. Tjeerdema and M.L. Sowby, "Influence of Dispersants on the Bioavailability and Trophic Transfer of Petroleum Hydrocarbons to Larval Topsmelt (*Atherinops affinis*)", *Aquatic Toxicology*, Vol. 52, pp 49-60, 2001.

Wunderlich, M., Personal Communication, January, 2002.