Dispersant Application in Alaska:

A Technical Update

Anchorage, Alaska
March 18 and 19, 1998

Sponsors:

Alaska Department of Environmental Conservation
Alyeska Pipeline Service Company - SERVS
Prince William Sound Oil Spill Recovery Institute
Prince William Sound Regional Citizens' Advisory Council
U.S. Coast Guard Marine Safety Office, Valdez

Proceedings of Conference:

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FOREWORD

Dispersant knowledge, experience and planning have advanced far more quickly in the past five years than in the previous decade. These developments have prompted planners and policy-makers to re-evaluate existing positions on dispersants. Advances and developments include:

- experience with large-scale use and monitoring of dispersant use during the Sea Empress spill (Wales, February 1996);

- U.S. programs to study effects of dispersed oil (e.g., Chemical Response to Oil spills: Ecological Effects Research Forum);

- extensive series of field experiments in North Sea in recent years;

- wide-spread planning for expedited dispersant decision-making and monitoring in U.S.

The purpose of this conference was to describe and explain these developments for the benefit of stakeholders, regulators and responders in Alaska and discuss the application of these developments to the issue of dispersant use in the Prince William Sound area of Alaska.

TECHNICAL PRESENTATIONS

Dispersant Policies in Alaska

Regulatory Controls: Nature, Purpose and Implications

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Morris, R. 1998. Regulatory Controls: Nature, Purpose and Implications In Trudel, B.K. (ed.). Proceedings of the Conference, "Dispersant Use in Alaska: A Technical Update", Anchorage, Alaska, March 18 & 19, 1998, Prince William Sound Oil Spill Recovery Institute, Cordova, Alaska.

Abstract

This presentation will look into dispersants from a perspective of the National Contingency Plan down to the Area Contingency Plans, highlighting the regulatory language within them that authorizes the use of dispersants as a response tool. The authorities vested within the plans to the Federal On-Scene Coordinator will be reviewed, along with Regional Response Team coordination when a request to use dispersants is made. Criteria for dispersant use within Alaska's Unified Plan will be presented, with the specific details for Cook Inlet and Prince William Sound. The Dispersant Decision Matrix and zone descriptions for pre-approval of dispersant use in both Cook Inlet and Prince William Sound will be shown. Alaska decision makers have agreed through pre-approvals that dispersants are a viable response tool. The dispersant guidelines for Alaska aid the FOSC during a response, allowing for use or don't use choices in a timely fashion.

Introduction

While preparing for this presentation one of the references I used was a report to Congress that studied the Nation's oil spill clean-up capabilities and assessed the technologies for responding to catastrophic spills. Their assessment was that cleaning up a discharge of millions of gallons of oil at sea under even moderate environmental conditions is an extraordinary problem. One comment from the forward of the report struck home to me. We need to understand, that even the best national response system will have inherent practical limitations that will hinder spill response efforts for catastrophic events, sometimes to a major extent. For that reason it is important to pay at least equal attention to preventive measures as to response systems. In this area, the proverbial ounce of prevention is worth many, many pounds of cure.

Dispersants are one of several alternative response technologies that a Coast Guard Federal On-Scene Coordinator (FOSC) may consider for use on an oil spill. Historically in the U.S. we have emphasized the use of mechanical equipment to mitigate spilled oil. Mechanical means, however are not overly effective or efficient in many cases, typically experiencing a 20% rate of recovery, and therefore may not provide the best response strategy.

Around the country, Regional Response Teams (RRTs) and Area Committees (ACs) have gotten together and developed Memorandums Of Understandings (MOUs) that describe areas pre-approved for use of dispersants. Some of these agreements are for a case-by-case basis only, some are for quick or expedited decision making, and some give the FOSC the sole discretion to decide to use dispersants in certain amounts and areas. I will briefly run through the pyramid of regulations, plans and authorities used to develop these agreements.

Federal Regulations

The National Contingency Plan (NCP) lists several processes that OSCs can use to obtain authorization for dispersant use during a response. The OSC with the concurrence of the Environmental Protection Agency (EPA) representative to the RRT and as appropriate, the concurrence of the RRT representatives from the states with jurisdiction over the navigable waters threatened by the discharge, and in consultation with the Department Of Commerce (DOC) and Department Of Interior (DOI) natural resource trustees, when practicable, may authorize the use of dispersants provided the dispersant is listed on the NCP Product Schedule.

The OSC may authorize the use of any dispersant, including products not listed on the NCP Product Schedule, without obtaining the concurrence of the EPA representative to the RRT and as appropriate the concurrence of the RRT representatives from the states with jurisdiction over the navigable waters threatened by the discharge when in the judgment of the OSC, the use of the product is necessary to prevent or substantially reduce a hazard to human life. The OSC is to inform the EPA RRT representative and as appropriate, the RRT representatives from the affected states and, when practicable the DOC/DOI natural resource trustees of the use of a product not on the schedule as soon as possible, obtain their concurrence or their comments on its continued use once the threat to human life has subsided.

RRTs shall as appropriate consider, as part of their planning activities, the appropriateness of using the dispersants listed on the NCP Product Schedule. Regional Contingency Plans shall as appropriate, address the use of such products in specific contexts. If the RRT representatives from the states with jurisdiction over the waters of the area to which an Regional Contingency Plan (RCP) applies and the DOC and DOI natural resource trustees approve in advance the use of certain products under specified circumstances as described in the RCP, the OSC may authorize the use of the products without obtaining the specific concurrences noted earlier.

Regulations in Alaska

The Alaska RRT response to the NCP has been the development of Oil Dispersant Guidelines for Alaska, with specific guidelines for Cook Inlet and Prince William Sound. Dispersant use in Alaska will be considered only when an effective conventional response is not feasible or not totally adequate in containing or controlling the spill. A Dispersant Decision Matrix (Figure 1) has been developed to outline the logic used by the OSC to determine the feasibility of chemically dispersing oil spills in environmentally sensitive areas. Dispersant use criteria developed for Alaska classify coastal waters into three dispersant use zones. In all cases, the use of dispersants will be based on the determination that the impact of dispersants, or dispersed oil will be less harmful than that of non-dispersed oil. The three zones are defined by: 1) physical parameters such as bathymetry and currents; 2) biological parameters such as sensitive habitats or fish and wildlife concentration areas; 3) nearshore human use activities; and 4) time required to respond. The use of dispersants in Zone 1 is acceptable and should be evaluated after consideration of mechanical means as a response tool

Figure 1. Dispersant Decision Matrix

to mitigate oil-spill impacts. The FOSC is not required to acquire approval from EPA or the State of Alaska prior to use of dispersants in this zone, however the FOSC will notify the EPA and the State of the decision as soon as practicable. Zone 1 is defined as an area in which dispersant use should be considered as a means to prevent or reduce the amount of oil reaching the shoreline or other sensitive resources. Zone 1 areas are characterized by water conditions (depth, distance, and currents) that will allow dispersed oil to be rapidly diluted to low concentrations, and are far enough away from sensitive resources that dispersant operations would not cause disturbances. In this zone, there is a significant likelihood that spilled oil will impact sensitive resources, and an immediate response is required in order to mitigate environmental consequences.

The use of dispersants is conditional in Zone 2 in order to protect sensitive wildlife and other resources. The FOSC is required to consult with the RRT and obtain approval of the EPA and the State of Alaska prior to the use of dispersants in Zone 2. A spill in Zone 2 must be continuously monitored and the need for dispersant-response actions reappraised accordingly. Zone 2 areas are characterized by water conditions (depth, distance, and currents) that will allow rapid dilution of dispersed oil to low concentrations, a sufficient distance from sensitive resources that an immediate response is not necessary and dispersant operations would not cause disturbances.

The use of dispersants is not recommended in Zone 3. Dispersants may be used in Zone 3 if, on a case- by-case basis, it is determined that the disturbance of the organisms and/or direct exposure to dispersants or dispersed oil would be less deleterious than the impact of spilled oil. As in Zone 2, the OSC is required to consult with the RRT and obtain approval of the EPA and the State of Alaska prior to the use of dispersants in Zone 3. Zone 3 is defined as the area immediately in or around the resources requiring protecting, including the resources themselves. Dispersant use in this area may disturb resources, may not have adequate time for effectiveness, may directly expose the resources to dispersants, or may expose other resources to unacceptably high levels of dispersed oil.

For Cook Inlet, because of the presence of large numbers of commercially valuable adult salmon, that section of Cook Inlet north of a line drawn along the latitude at Anchor Point north of Kachemak Bay is considered to be Zone 3 during the period from July 1 to August 15. Guidance for use in the Upper Cook Inlet (Figure 2) is unique because the extreme upper portion contains two Zone 3 designations which are based upon tidal stages. A dual Zone 3 designation is needed because dispersant use during a flood tide could result in relatively high concentrations of dispersed oil impacting shallow waters or intertidal habitats. Restricting dispersant use in this area to the ebb tide period eliminates these concerns while still allowing dispersant use in the northern portion of Upper Cook Inlet.

Middle Cook Inlet's Zone 3 occurs inshore of the five-fathom isobath due to a lack of fish and wildlife resources and the presence of strong currents that runs parallel to the shoreline. The remaining waters within this Inlet section are designated Zone 1.

Lower Cook Inlet (Figure 3) includes the use of all three zones. The variety of five and ten fathom isobaths are used along with one-mile buffer zones to delimit the three areas. Zone 1 areas are

Figure 2. Cook Inlet Dispersant Use Zones, Northern Sector

Figure 3. Cook Inlet Dispersant Use Zones, Southern Sector

identified as approximately five-mile wide buffer areas extending outside of zone 3. The remaining waters within Cook Inlet are designated as Zone 2. The dispersant use guidelines for Prince William Sound focus on the tanker traffic lanes and reflect the remoteness and fjord geomorphology of the Sound. Designation of the tanker lanes primarily as Zone 1 was deemed desirable due to the large volume of oil transported through the sound via these lanes, the difficulty in mechanically containing and removing spilled oil; and the likelihood that dispersant use would assist in minimizing the environmental effects of a spill, particularly oil contamination of sensitive coastal resources and habitats. Most of the area outside the tanker lanes has been designated as Zone 3 due to the variety and abundance of biological resources in Prince William Sound. There are some areas with Seasonal Designation changes designed to protect sensitive fisheries resources, such as migrating adult salmon and commercial fishing activities. Prince William Sound is divided into five different areas for dispersant use consideration: the Port of Valdez and Valdez Arm (Figure 4); the main body of Prince William Sound, Hinchinbrook Entrance and Montague Island (Figure 5); and lastly the Copper River Delta (Figure 6).

The guidance from the Unified Plan for Alaska (our equivalent of RCP) is also found in the subarea plans. Along with the zone designations is the oil spill response checklist for dispersant use. Two different checklists have been developed. Those for zone 1 and another for Zone 2 and 3 use. In the case of zone 1 use, the Responsible Party (RP) will prepare the checklist and submit it to the FOSC. The checklist includes spill data, such as location with reference to nearest land, time of spill, type of oil and quantity and whether the oil has emulsified. The Dispersant use plan that is also completed by the RP names the dispersant, application dosage and estimated percentage of the spill area to be treated. The FOSC may deny the RP's request, may approve under certain conditions limited or selected areas or may approve their plan as requested.

In Zone 2 and 3 the RP will complete the spill data, weather and water conditions (real time) and the dispersant use plan portions of the checklist. The National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator (SSC) will complete the predicted weather and water and oil behavior portions of the checklist. The Resource agencies are responsible for completing the resources at risk, Habitats, biological resources and human resources. The FOSC provides an evaluation of the response options concerning mechanical cleanup, in-situ burning and dispersant use to the RRT. The RRT CO -chairman then consults with the members of the RRT and returns the application with an answer. The RRT may deny the request, approve the request under certain conditions limited or selected areas or may approve the plan as requested. If the RRT has approved the request the FOSC still has final approval on the use of dispersants.

The dispersant guidelines for Alaska and the specific guidelines for Cook Inlet were approved in April 1986, and the Prince William Sound policy was later approved on March 6, 1989. Improvements could be made to the application process. On the application itself, there is no place for the State of Alaska to sign off on the application. Even though the State is consulted there is no clear indication on the application by way of a signature block. When looking at the resources at risk, guidance is not clear as to which agency will complete each section of the application, and finally there is no trade off of these risks offered in the application evaluation by the resource agencies.

Figure 4. Dispersant Us Zones in Prince William Sound, Valdez Port and Arm

Figure 5. Dispersant Us Zones in Prince William Sound, Main Body

Figure 6. Dispersant Us Zones in Prince William Sound, Copper River Delta

Conclusion

Decisions makers have agreed, through pre-approvals that dispersants are a viable response tool. To successfully use dispersants, the proper equipment and trained personnel are needed. This includes an adequate amount of the necessary dispersant, a delivery system to apply the dispersant, and personnel trained in carrying out this function and monitoring the results. The primary benefit of effective pre-spill decision making is that the OSC is not faced with sifting through reams of scientific and technical data during the response. Having the responsible government agencies do that in advance allows the OSC to make a use or don't use choice, in a timely fashion. With that incentive, in those areas where pre-spill decisions made by the responsible government agencies is to authorize use, the industry can stockpile the approved countermeasures so they will be ready to use when the OSC determines the conditions warrant it. Likewise, in those areas where the pre-spill decision is not to use, the OSC does not waste any time even speculating about the issue and focuses all energies on mechanical measures.

In the final analysis, oil spill response planning should look to minimize ecological impacts and facilitate ecosystem recovery, keeping in mind that no single countermeasure is totally effective in an oil spill response. Therefore a variety of techniques are needed to respond during an incident.

Biographical Sketch of the Author. Commander Ronald J. Morris is the Commanding Officer of the U.S. Coast Guard Marine Safety Office Valdez, Alaska. He assumed command on July 8th 1996.Commander Morris began his career when he enlisted in 1972. He served on board the Coast Guard Icebreaker NORTHWIND and at the Coast Guard Air Station Port Angeles, Washington before being commissioned in 1975. Since his commissioning he has served at the Fifth Coast Guard District, Portsmouth, Virginia, working in Boating Safety and Coast Guard Auxiliary Assistant Director; the Marine Safety Office Buffalo, New York conducting commercial vessel inspections and investigations and pollution response in port operations; the Marine Inspection Office New Orleans, Louisiana working in vessel inspections and investigations; the Marine Safety School in Yorktown, Virginia where he was an instructor; Marine Safety Office Juneau, Alaska where he was the Executive Officer; Ninth Coast Guard District Office, Cleveland, Ohio where he was the Chief of the Merchant Vessel Safety Branch, covering the Great Lakes.

For his service, Commander has earned a Meritorious Service Medal and two Coast Guard Achievement Medals.

Dispersant Application Plans for Prince William Sound, Alaska Rationale, Operational Deployment and Implications of Regulatory Controls

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Hillman, S.O. 1998. Dispersant Application Plans for Prince William Sound, Alaska: Rational, Operational Deployment and Implications of Regulatory Controls. In Trudel, B.K. (ed). Proceedings of the Conference, "Dispersant Use in Alaska: A Technical Update", Anchorage, Alaska, March 18 & 19, 1998, Prince William Sound Oil Spill Recovery Institute, Cordova, Alaska.

Abstract
This paper provides information concerning dispersant use in Prince William Sound, Alaska by Alyeska Pipeline Service Company (APSC), Ship Escort Response Vessel System (SERVS) group. The discussion is focused on three main topics: the rationale for use of dispersants, operational deployment information and the implications of regulatory control on real-time dispersant use. It contains information concerning: the nature of dispersants; their usefulness in the Prince William Sound area; information concerning logistics; operational application in the field using three types of systems; field monitoring and regulatory aspects of their use.

Introduction
Dispersant use has been an active part of oil spill response considerations world wide for more than 30 years. During this time, chemical countermeasures have run the gamit from being the single, most important response tool to being disallowed as a response tool. No response method has received as much focus or research. As with all response tools, however, we believe there is a time and a place. There are certain conditions where providing a chemical response to enhance and expedite the natural physical and biological degradation of the spilled oil is the best way to mitigate the impacts for the spilled oil. When these conditions exist, it is also imperative to the dispersant response that it be operationally viable. The equipment and chemicals must exist, the logistics and transport mechanics must be in place and orchestrated, and procedures to carry out the operation must exist for a successful mission. These conditions have been met by Alyeska Pipeline Service Company, Ship Escort Response Vessel System (SERVS) in providing dispersant response capabilities for Prince William Sound and the Gulf of Alaska areas.

What is being done in the areas of current dispersant use? With improved confidence and data, dispersants have seen increased use in US waters in the recent past. For instance, Todd Bridgeman, NOAA SSC reported in the results for several different operational uses of dispersants in US Waters during early 1998. These included the application of dispersants to

Figure 1a. Dispersant applied to M/V Red Seagull

Figure 1b. Dispersed slick

heavy oil slick from the M/V Red Seagull in January 1998 (see Figures 1a and 1b); and oil from the AMOCO pipeline spill approximately 50 NM off the Texas shores (See Figure 2).

Additional historical use examples of dispersant use in spill response in US waters include the Puerto Rican in 1984, the PacBaronnes in 1987, the Megaborg in 1990 and limited application in the Exxon Valdez in 1989. In addition, in 1995, the application was approved for dispersant use in the KPL spill in Cook Inlet, however, no dispersant was applied.

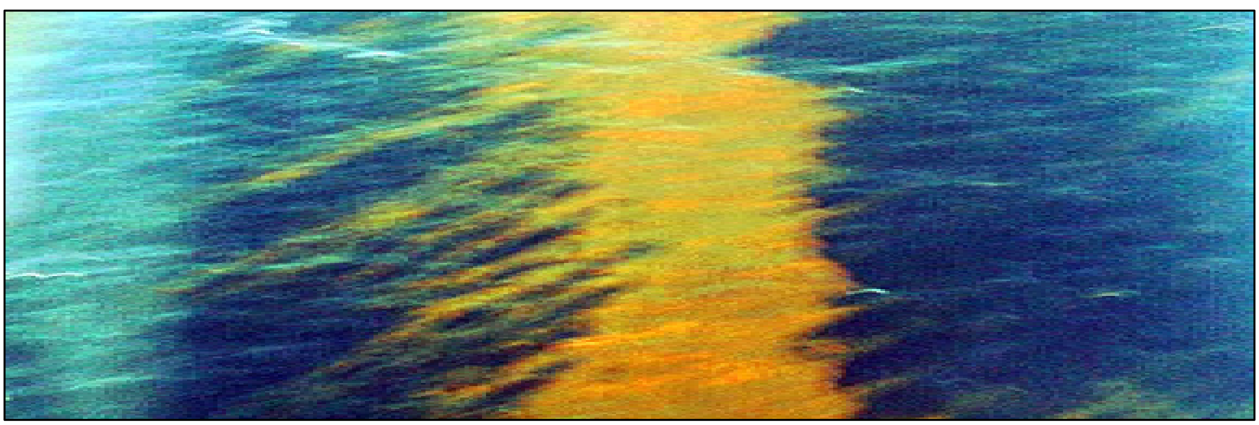


Figure 2. Dispersed slick from AMOCO pipeline spill

Part 1 - Why Use Dispersants?

This is an important question for understanding today's approach to dispersant use. First, dispersants are a proven technology supported by good scientific data from around the world, as well as Alaska specific science. Second, spill response requires different tools for different spills, depending on the incident, the receiving environment and the threatened and/or impacted resources. Third, dispersants are one of the right tools for mitigating the impacts from certain incidents. It is important to note that each of these three answers does not claim that dispersants are the sole answer, or dispersant use is automatic. This is where the technical evaluations and environmental considerations (often labeled "Environmental Tradeoffs") comes in to the decision making process.

Dispersant use does not hide or sink the oil, nor does it "recover" it. Dispersant use allows an environmental overload (oil spilled in the environment in a large quantity) to be mitigated by adding another chemical to the oil in a controlled dose so the resulting action may help to restore the physical and chemical balances within the receiving environmental system. The dispersant applied (assuming compatibility and effectiveness) adjusts the physical properties of the oil by changing the surface tensions, allowing the oil slick or film to break into smaller droplets that are quickly distributed in the water column throughout a larger area in smaller concentrations and which are kept in suspension in the near surface waters (generally the top 1-3 meters), as a result of mixing energy, local turbulence and specific gravity factors. This allows the oil to be assimilated by the natural degradation processes with the final result of breaking down to the original chemical components of water and carbon dioxides utilizing bio-degradation, dissolution, evaporation and photo-oxidation. The environmental mitigation decision is then based on reducing the pollutant overload in a relatively small area where natural degradation occurs very slowly to spreading the biologically degradable pollutant over a larger area in a much smaller does (generally 3 orders of magnitude less dose), which can be assimilated quickly by nature without causing significant adverse impacts.

An application device is used to distribute the dispersant chemical onto the slick, usually in a spray of tiny droplets. The objective is to get a smooth, even application (or multiple applications), with the right dispersant to oil ratio, for optimum interaction. Operational care must be taken to apply the dispersant only to the. Natural or artificial mixing energy promotes movement and dispersion of the fine oil droplets into the water column. The greater the available energy, the more natural dispersion and therefore, less dispersant is required, such as in the case of the Braer spill. The droplets of a freshly treated oil slick tend not to stick to each other or to other surfaces. Therefore, dispersed oil does not as readily adhere to bird feathers, marine mammals such as sea otters, harbor seals and sea lions and the shoreline surfaces such as gravel, cobbles and some of the beach sands (glacial silts may be exceptions). The surface tension modification that allows this repulsion, however may be temporary if other degradation processes do not start before the dispersant surfactant molecules migrate to the water (as they are generally more soluble in the water phase). This type of situation may be exhibited when the surface slicks re-coalesce after a dispersant application.

In an oil spill incident, the risk to the environment is heightened as the oil floats and spreads on the sea surface where it may persist in high concentrations for many days. These oil slicks pose a significant threat to organisms that live at or near the sea surface such as marine birds and mammals and planktonic life stages of certain fish species. In addition, these oil slicks can be transported considerable distances into nearshore habitats where the oil may affect species in shallow subtidal areas and may become stranded on shorelines where it poses an immediate hazard to intertidal communities and habitats. The oil, if left untreated, can mobilize and move to new areas, can persist for months or years and poses a longer term threat of low level contamination to inhabitants of the adjacent shallow, subtidal areas. The risk to the environment from the dispersed slick is in the upper portion of the water column. The species potentially exposed include phytoplankton, zooplankton, finfish and shellfish as well as critical habitats. Commercial fisheries of finfish and shellfish may also be at risk, based upon their use of the natural resources. The assessment of potential impacts as well as risk is then based on calculated exposures. Toxicity studies of chemically dispersed oil to date and water column measurements in real time dispersant applications have indicated the water column concentrations of dispersed oil do not exceed (in fact are generally one to two orders of magnitude below) the toxic threshold values for most species (National Research Council, 1989; SL Ross Report to RCAC 1997; PWS Tanker Oil Discharge Prevention and Contingency Plan, SID 15, 1995, ARRT Dispersant Use Checklist in Unified Plan, 1996, Lunel, 1997). The monitoring program associated with the Sea Empress spill contained no accounts of mortalities of fish or shellfish associated with dispersant use. For instance, finfish from the area did not appear to acquire measurable contamination or tainting and those fisheries that had been closed during the spill were also reopened quickly. Nor did there appear to have been any measurable contamination of the seabed in the area where dispersants were used (Lunel, 1998).

The objective of all cleanup methods of spill response including dispersants, mechanical recovery, and in-situ burning, is to mitigate the potential and real impacts of the oil. The oil, having left it’s original container, continues to spread as it moves throughout the environment due to it’s physical and chemical nature. The mechanical recovery efforts must continually work against these forces of nature, attempting to re-concentrate the oil into thicker slicks, then use mechanical means to physically remove the thin layer of oil from the water surface. This mechanical technology equates to low efficiency potential, and can be further complicated by bad weather and significant sea states. Dispersants, on the other hand, remain effective at higher sea states and may be deployed under many conditions where mechanical recovery tactics are limited. This is one of the reasons that dispersants are the primary offshore response technique in spills around the world. Dispersants can be applied at effective application rates using the high speed and large payload of Hercules C-130 type aircraft. Alternately, dispersants may be applied by large or small vessels and helicopter delivery systems to selectively treat portions of the slick that may be threatening an important or sensitive resource. Larger aircraft delivery system offer the advantage of response for spills that occur far offshore.

Dispersants often are not effective when the oil has become weathered, emulsified or formed into tarballs, though testing in the last few years on emulsified North Slope Crude with Corexit 9500 has had very favorable results (ACS, 1997). After a spill has occurred the natural processes of evaporation and emulsification cause increased viscosity and results in oil that is more resistant to both natural and chemical dispersion. These processes relate to the use of dispersants in a spill response because dispersant use remains most effective for fresh or relatively fresh oil. Dispersant operations may remain an effective tool for a few hours or several days, depending on the oil type, the weather and the dispersant used. Therefore, operational plans for the use of dispersants, regulatory controls and decision-making methods must be designed, operationally tested, logistically supported and finely tuned for expedited implementation.

Corexit 9527 is stockpiled in Anchorage by Alyeska Pipeline Service Company for use in the PWS and Gulf of Alaska areas. Alaska North Slope (ANS) crude oil is considered a good candidate for dispersion. Laboratory tests conducted on ANS crude oil and Corexit 9527 have shown levels of effectiveness that range from about 30% to 95%. These laboratory results corresponding to field tests and sea trials with results in the range from 30% to 80% (SL Ross 1997). These experiments simulated only single applications of dispersant to a slick. Some testing has indicated that greater levels of operational effectiveness could be achieved by repeat applications of dispersant onto the oil slick. Small spills of ANS crude oil should remain dispersible for many hours after being spilled. For large spills the time window is anticipated to be at least three days; and for continuing spills the time frame would appear to be consistent with the release. The key to success is to, once again, be able to effectively deliver the operation, (see Figures 3-5), as quickly as the decision is made and to be able to continue the operation in a safe and reliable manner, with an companion monitoring program to gather scientific and operational information to the extent feasible.

Figures 3 - 5 Three Operationally ready dispersant systems for Alyeska / SERVS

Part 2 Operational Deployment

The three operational challenges in a dispersant application are: 1) to have available a quantity of dispersant needed to treat the spill; 2) to apply the chemical to the slick using the proper platform, with the proper dose, and in the quantity needed for the response; and, 3) to monitor the results.

Dispersant Availability and Re-supply Systems.

Paramount to any dispersant mission is having available and accessible a sufficient quantity of dispersant chemical. A useful guideline for estimating the quantity of dispersants needed is to use one gallon of dispersant for each barrel of oil spilled (RRT Region 6 FOSC Pre approved Dispersant Use Manual 1995), so a 5,000 bbls spill would require 5,000 gallons of dispersant. Anchorage is Alyeska/SERVS' primary stocking point for dispersant primarily due to the large volume requirements of the ADDS Pack and secondarily based upon the availability of commercial bulk chemical storage facilities, chemical transfer ability and the availability of road and air cargo handlers. Alyeska contracts for bulk chemical storage with Van Waters and Rogers at their bulk chemical facility in Anchorage. Alyeska/SERVS maintains a minimum stockpile of 60,000 gallons of Corexit 9527 at Van Waters and Rogers along with the IMO tanks, empty drums and some full drums of dispersant. Dispersant quality is tested on a routine basis, and the stored chemical is circulated on a regular schedule to maintain quality criteria.

When the dispersant operations are staged from Anchorage, the Alyeska owned transportation (IMO approved) tanks stored at the bulk chemical facility in Anchorage are filled from bulk storage tanks and transported to the Anchorage airport to fill the ADDS Packs. The pump skids are attached to the IMO tank trailer prior to the truck's departure (See Figure 6). If the dispersant operation is to be staged from Valdez, the IMO tanks stored at the Alyeska Mineral Creek Road Annex are trucked to the staging area. Additional chemical can be filled in Anchorage IMO based tanks and/or drums and transported to Valdez for re-supply. This dispersant would then be used to support vessel and helicopter operations. If operations are to be conducted from Cordova, Kodiak or elsewhere, the chemical will be drummed and flown as air cargo to the appropriate staging area. Also staged in Anchorage is an ADDS Pack support trailer. This trailer is outfitted with spare parts, tools, Personal Protective Equipment (PPE) and other equipment needed to effect depot level, on-site repairs of the ADDS Pack systems. This trailer is designed to fit within a C-130 it can be flown into the staging area from which ADDS Pack operations are being conducted. Due to FAA regulations regarding ADDS Pack operations, this support trailer can not be flown in the same plane as the ADDS Pack, when the ADDS Pack is loaded with chemical.

In Valdez, an initial stock of approximately 4,000 gallons of COREXIT 9527 is contained in a heated IMO tank at the SERVS Annex. This stock is intended to supply the Helitask (Helicopter spray bucket system) and portable vessel Spillspray system. It can also be used as a limited re-supply stock for the other vessel spray systems. Also stored at the SERVS Annex in Warehouse #4 is a complete dispersant transfer system that enables the pumping of dispersant from the IMO tank to any of the SERVS dispersant application equipment. The Crowley tugs which make up a portion of the Alyeska/SERVS Marine fleet include one vessel with an on-board quantity of approximately 1,000 - 1,500 gallons and the 2 additional tug vessels with portable dispersant systems of approximately 1,000 gallons each. Re-supply stock would arrive from the Valdez based IMO tanks initially followed by re-supply from Anchorage as described above. To re-supply vessel tanks COREXIT would be transferred in bulk from IMO tanks. Because of permit restrictions (protection of the sensitive duck flats habitat adjacent to the SERVS Base), this chemical transfer takes place at the Valdez City Dock. Both the ADDS Pack and Helitask can be re-supplied from IMO tanks at the airport without restriction. Palletized, drummed dispersant can be loaded on vessels. SERVS also stores 470 gallons of COREXIT 7664, 220 gallons of COREXIT 9550 and 110 gallons of COREXIT OC-5 at the SERVS Annex Warehouse #4.

Dispersant Operational Tactics.

Dispersant operations are often described in current literature by the deployment equipment or platform. However, the best tactical description should be based on what type of dispersant treatment is planned. The deployment system can then be chosen to fit the environmental conditions, the distance from re-supply, and the amount of area to be treated. The tactics can then be described for each of these three conditions:: thick/thin slick treatment, leading edge slick control and streamers, mats and escaped oil treatment. The following three sections describe each of these tactics

Thick/Thin Slick Treatment Tactic. Although an oil slick appears to have a uniform thickness, recent studies have shown that as much as ninety percent (90%) of the oil volume may be contained in as little as ten percent (10%) of the slick area. Accurate dispersant application to this area of thick oil can treat large quantities of oil in short periods of time. Each dispersant application system is well suited for this type of response. Task Forces would be employed in the following ways:

- **Task Force Type:** Aerial or Surface
- **Dispersant Dosage:** 5 gallons/acre or higher, if necessary. Multiple passes also possible if slick thickness prevents timely dispersion
- **Aerial Coverage Rate**: 0.5 to 50 acres/minute depending on Task Force configuration.
- **Support Equipment Considerations**: Spotter and aircraft are paramount in order to direct dispersant platforms to the thick oil areas. Weather conditions and remote spill sites may preclude the use of monitoring vessels. Dispersant re-supply becomes critical due to the large amounts of chemical necessary to effectively treat thick slicks.
- **Variations:** Combined task forces (i.e. two ADDS Pack Task Forces combined in a “race track” configuration or several vessel systems in a staggered line).
- **Response Considerations:** If many assets are operating in a restricted spatial area air traffic control is pivotal to a successful operation. Large spills in remote areas of Prince William Sound or the Gulf of Alaska may be too distant to support helicopter operations. Aerial operations must be conducted during daylight.

Leading Edge Slick Control**.** On large, uncontained spills where the oil slick threatens shorelines or particularly sensitive environmental areas, large scale dispersant application at the slick’s leading edge can eliminate the oil before it impacts a particular sensitive area. The ADDS Pack with its high speed and large payload is well suited for this type of response. The Helitask heli-bucket is valuable during spills in spatially restricted areas like the Port of Valdez to protect such sensitive areas as the Duck Flats and the Valdez Small Boat Harbor.

- **Task Force Type**: Aerial or surface
- **Dispersant Dosage**: 3-5 gallons/acre or higher, if necessary
- **Aerial Coverage Rate**: 0.5 to 50 acres/minute depending on task force and configuration.
- **Support Equipment Considerations:** Spotter and aircraft, monitoring vessel and dispersant re-supply.
- **Variations**: Combined task forces (i.e. ADDS Pack task forces combined in a “race track” configuration or several vessel systems in a staggered line).
- **Response Considerations:** Many assets may be operating in a restricted spatial area. ADDS Pack Task Forces may not be able to operate in narrow areas such as the Valdez Narrows or the Port of Valdez during some wind conditions. Large spills in

remote areas of Prince William Sound or the Gulf of Alaska may be too distant to support helicopter operations. Aerial operations must be conducted during daylight.

Streamers, Mats and Escaped Oil Treatment**.** The third response operation is to treat streamers, mats or slicks that have escaped mechanical containment, as well as the thick oil areas near the source of a continuous release:

- **Task Force Type**: Aerial or surface
- **Dispersant Dosage:** 5 gallons/acre
- **Aerial Coverage Rate:** 0.5 to 50 acres/minute depending on task force
- **Support Equipment Considerations:** Spotter to aircraft, and spotter to command center communications must be good in order to align application units, track volume of oil treated, treat areas, etc. Monitoring vessel(s) must be able to sample geographically separated treatment areas.
- **Variations:** Additional surveillance aircraft may be necessary to identify and prioritize oil patches and then relay that information to the spotter in order to sustain operations by minimizing time between spray runs.
- **Response Considerations:** Weather may be breaking the slick into streamers as the dispersant window of opportunity approaches an end. Emphasis must focus on successfully applying enough dispersant in areas where it will do the most good. Streamer and escaped oil operations must be conducted during daylight.

Once the tactic has been decided upon, the permit or ARRT approval for dispersant application is completed and submitted for approval. Upon acceptance by the FOSC for dispersant operations and the granting of an approval to carry out the mission, a form is completed to outline the mission requirements for operations. Table 2 reflects this form. The information is then passed from the Incident Commander designee (Operations Section personnel) to the Pilot-In-Command of the spraying aircraft or Master of the spraying vessel, the Pilot-in-Command of the spotter aircraft and the Master of the monitoring vessel.

Table 2 Mission Requirements

Spill Name and Location: Name: ____________________________________
Lat.____________________ Long.____________________

Bearing:________ ° T Range______________from Common Geographic Point

Estimated Volume to be Treated: _________________bbls

Slick Area:____________________(sq mi/sq ft/sq acres), Coverage:____________%

Release Status: Continuous:______ Intermittent:______ Stopped:_______

On-Scene Weather:

Temperature:Air:_______________ Water:_________________
Cloud Cover: Percentage:_________ Ceiling:___________(ft)

Wind: Speed:________(kts) Direction:_______________

Turbulence: Surface:____________ Altitude(ft):________________

Sea State: Feet:_______________

Spraying Area:

N_______________ W_______________ (Corner Points)

N_______________ W_______________

N_______________ W_______________

N_______________ W_______________, or

Length (ft/miles):____________Orientation (Degrees T):_________________

Dispersant Dosage: Gal/Acre _______________ or Dispersant to Oil Ratio_______________

Dispersant Pump Rate: Gal/Min____________________ # of Nozzles:________________

Spray Mission Start Time:_________________

Spotter Aircraft Designation: Frequency: Primary MHz_________________

(Secondary) MHz_________________

Monitoring Vessel Designation: Frequency:Primary MHz:_________________

(Secondary) MHz_________________

Recommended Spraying Speed & Altitude (Pilot's discretion): Knots:________Feet:_____

Aircraft Loitering Area and Altitude: NAVAID_______________,Bearing (°T)_____________

Range:_____________(miles) Altitude:_____________(ft)

Post Mission Actions (i.e. reload for subsequent mission, refuel, etc.):

Spraying Systems and Platforms.

The different types of dispersant application systems and platforms are generally classified by Alyeska/SERVS by air delivery capabilities or surface delivery. The air delivery platforms include the helicopter-based systems called the Helitask and the large fixed-wing C-130 type ADDS Pack systems. The surface delivery systems include the units for vessel application and are generally Frank Ayle type systems. Additional variations of these systems as well as small aircraft type systems are also available in Alaska within other oil spill coop groups or commercial applications. The most critical criterion for selecting a spraying system is the capacity to deliver the quantities of product required in the time frame needed.

Air Delivery**.** These systems are based on large, multi-engine aircraft with a large cargo capacity. The Lynden Aircraft contract maintained by Alyeska provides us with the contracted services of the Hercules type aircraft with the associated Alyeska owned ADDS Pack systems (2 each) (See figures 6 and 7). These systems have the advantage of very high delivery capacity and long range and are well suited for responding to very large spills, or spills that may be at some distance from their base of operations (Figures 8 and 9). In Prince William Sound, we have in place two ADDS Packs, a sizable dispersant stockpile and have arranged for the C-130 aircraft to be available within hours to deploy them.

The helicopter based air delivery systems are essentially bucket systems that are slung beneath the helicopter (Figures 10 and 11). SERVS calls our system the Helitask. These systems are ready for rapid deployment in many places. The Helitask fills contingency plans for dispersant response in PWS for small spills and for treating the leading edges of spills near sensitive locations where fine control over the spray is required. Like all aircraft-based systems, because of their high speed and low pumping rate, helicopter systems are only capable of low application rates and therefore require multiple passes to provide higher doses to the thick oil patches. Logistics section discusses the capability to supply the Helitask off of the nearshore response barge in Prince William Sound called the *Responder 500-2* barge, which has a built in helicopter deck and operating procedures for helicopter operations.

Surface Delivery**.** Surface delivery is accomplished by Alyeska/SERVs using vessel-based systems (Figures 12, 13 and 14). The system employs nozzles on spray booms, and utilizes both internal and external pumps depending on the vessel configuration. Fire monitor systems are also available on many of the marine contracted vessels in the SERVS fleet and these types of spray systems have a growing body of research and field application technology, though we have not yet developed the operational details for this type application in this location. Vessel-based systems have the advantage of applying dispersants with greater accuracy and at higher dispersant-to-oil ratios, enabling the full treatment of thick slicks in only one pass. Larger vessel-based systems are most useful in dealing with spills close to their base of operations, or in significant weather conditions which limit aircraft support and may also limit mechanical response. As with the larger aircraft, vessel-based systems often utilize a spotter aircraft to enhance targeting maximum concentrations of oil for effective and efficient operations. Existing PWS plans envision using vessel-based systems to treat spills close to their source when slicks are thick and high treatments rates may be applicable.

Figure 6. IMO tank delivery to aircraft

Figure 7. ADDS Pack being loaded into aircraft

Figure 8. ADDS Pack spray seen from inside

Figure 9. Lynden dispersant delivery system

Figure 10. Helicopter and spray bucket

Figure 11. Helibucket

Figure 12. Dispersant pump

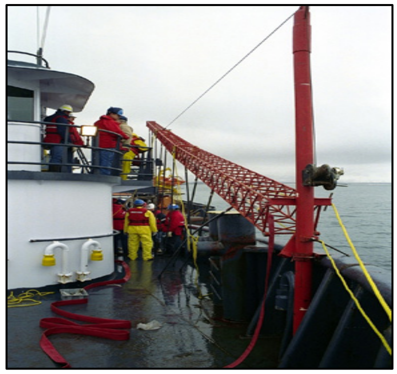


Figure 13. Deployment of spray arms

Figure 14. Dispersant spray vessel

Logistics
Sustained, effective dispersant response requires a well organized logistic system. The logistic requirements of the ADDS Pack, Helitask or Spillspray are different, though each system must have access to a range of similar support requirements. This discussion centers around dispersant response in Prince William Sound and the northern Gulf of Alaska, though our actual operations and support could occur in other regions. Logistic support is much broader than the dispersant spraying platform and equipment. Other facets of the response include (but may not be limited to) spotter/command and control aircraft, air crew support, replacement parts and re-supply availability, medical facilities, inclement weather plans, shelter, response personnel, PPE, etc. These must all be taken into consideration. All application methods use the following major categories of logistics support.

<u>Staging Areas.</u> Each mission must have an identified base from which the mission is supported. For the Prince William Sound and northern Gulf of Alaska region, the following staging areas have been established:

- Valdez
- Cordova
- Anchorage
- Kodiak
- Barge *Responder 500-2*

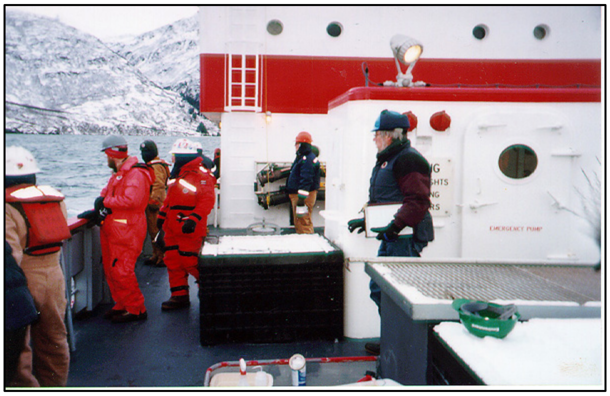
Except for the *Responder 500-2*, these locations were selected for their airport facilities, support services, materials handling equipment, port/dock facilities and proximity to the operating area. The *Responder 500-2* was selected due to the ability to support and sustain helicopter and vessel based operations. Sufficient quantities of fuel and dispersant would have to be brought to the barge; however, its proximity to the spill site and attendant reduction in ferry distance, command and control ability, as well as on-board berthing, messing and medical facilities make it particularly well suited. Sites such as Cordova and Kodiak would be selected based upon the proximity to the spill. Any of these sites could be used as re-supply depots. Although runway lengths, fuel supplies, personnel support facilities, etc. are generally sufficient, equipment such as pumping systems, material handling equipment, PPE etc. may have to be brought in as well or procured locally, if available. All dispersant chemical would have to be drummed, then flown into these locations. SERVS also owns a compact drum pumping system that would be included with the re-supply chemical. The transportation of drums and their subsequent emptying can be time consuming depending on the application system being supplied.

Dispersant Mission Spotting (Tactical Air Control and Evaluation of Treatment) The spotter is tasked with coordinating the dispersant operation. It is imperative that the spotter be able to recognize, characterize and document oil on water. Depending on the tactic to be employed the spotter also aligns dispersant application platforms along the major axis and into/over the slick to be treated (i.e., axis of streamer, leading edge direction, etc.). The spotter is always someone other than the pilot-in-command of the spotter plane. Fixed wing aircraft equipped with large windows, high endurance and fairly slow speed are best for spotter operations. Helicopters can be used with other helicopter and surface task forces; however, most helicopters are too slow with limited endurance to be able to sustain continuous operations with ADDS Pack equipped task forces.

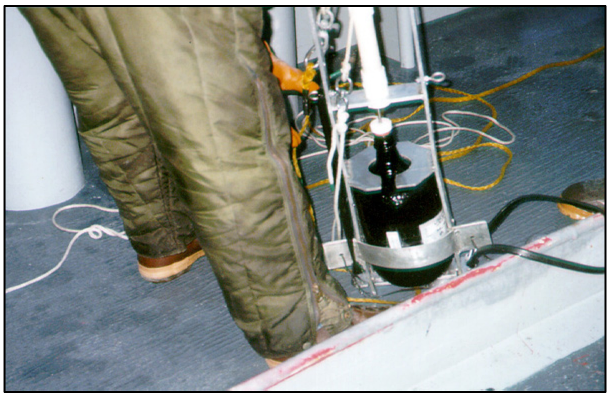
Another duty of the spotter is to coordinate the altitude separation and tactical control of all aircraft assigned to that task force. The spotter, or Tactical Air Traffic Controller during periods of elevated flight activity in a particular area, “owns” the airspace around which the dispersant operations is being conducted. When two task forces are combined, as in the case of two ADDS Pack units operating together in a “race track” pattern, the duties of the spotter with regard to tactical control can become intense. The spotter ensures proper altitude separation between aircraft appropriate distance spacing between assets at similar altitudes, as well as the proper alignment of the operating assets. Additionally, the spotter directs the offset of successive passes over the slick, especially with regard to dispersant drift when spraying in cross wind conditions.

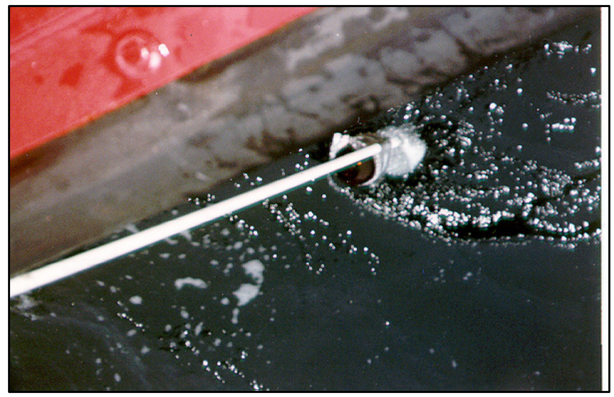
The key to successful dispersing is providing the proper dosage. This translates to using the right size droplets, the sprayed from the proper elevation in the correct depositional pattern creating the accurate at the dose. The spotter is charged with evaluating the effectiveness of the spray run and the subsequent dispersion. The spotter evaluates and adjusts the path of the applying systems to maximize the amount of chemical that hits the oil. After the dispersant is applied the spotter evaluates the effectiveness of the dispersant application. If some operational facet of the treatment such as the dispersant dosage, applying speed, swath width etc. needs to be adjusted, the spotter is charged with calculating that adjustment and relaying the changes to both the applying platform and the Incident Commander. The spotter evaluates the dispersed oil plume, estimates the amount of oil dispersed and notes any other changes to the slick such as herding, re-coalescing or emulsion breaking.

Dispersed Oil Monitoring.
SERVS has a detailed plan in place for monitoring dispersant effectiveness (Hillman et al. 1997). Monitoring will always be done by visual means. In addition, SERVS will collect samples of dispersed oil in water for laboratory analysis. Analysis is conducted in two ways. Fluorometric Sampling and water quality grab sampling.



Fluorometric Sampling. The fluorometer is a device that provides on-site measurements and tracking of polynuclear aromatic hydrocarbons (PAH) in the water column (Figures 15 and 16).





The fluorometer measures the concentration of oil in the water column using the fluorescent properties of the oil's aromatic components. The fluorometer beams a specific wave length of light to excite fluorescent compounds which in turn emit light at a different wave length. The intensity of the emitted light is proportional to the concentration of the fluorescent compounds.

Tests standards of a mixture of Alaska North Slope Crude Oil and COREXIT 9527 dissolved

Figures 15 and 16. Dispersant monitoring field exercise utilizing fluorometer

Figure 17 and 18. Water sampling by grab sampler

water. Dispersant itself does not have a significant fluorescent signature but the dispersant does appear to quench the crude oil signal slightly.

Samples are collected at specific depths and processed on-scene through the fluoroscope. From this sampling base line, data can be developed to show the relative amount of hydrocarbon suspended in the water sample and hence dispersion.

Grab Sampling. Grab sampling instruments collect water samples at prescribed depths (Figure 17 and 18). The choice of instrument depends on the collection depth. The sampling instrument is prepared for deployment on deck. A Valskon grab sampling instrument collects water directly into the sample bottle that will be sent to the laboratory. The bottle's cap is removed and protected from contamination. The bottle is then fitted into the instrument and the decontaminated stopper mechanism is lowered over the mouth of the bottle to close it. The end of the line that suspends the instrument is secured to the boat. If oil is present on the water surface, a boat wash hose is used to disperse the sheen or slick before deployment.

Part 3 - Implications of Regulatory Control And Their impact on Operations

The aspects of regulatory oversight include such issues as public concerns, toxicity reviews, use of the Alaska Regional Response Team checklists, responses processes, national and international scientific and economic interests. Upon first notification of a spill that may require the use of dispersants, the Federal On-Scene Coordinator (FOSC) should be advised that formal approval for dispersant use is being pursued. The Incident Commander is expected to make the decision as to whether dispersant use is appropriate for the spill response. This decision will be based on information assembled by the Planning and Operations Sections which should be developed as soon as possible following the report of the spill. For all spills where dispersant use is requested, an Alaska Regional Response Team (ARRT) Oil Spill Response must be used. This form will be used by the FOSC to give final approval in Zone 1 and as a supporting document in requesting ARRT approval for dispersant application in Zones 2 and 3.

Three immediate actions are initiated by the Planning Section Chief. 1) Place dispersant application crews and equipment managers on standby for immediate launch if application plan is approved. 2) Obtain data and complete ARRT Oil Spill Response Checklist. 3) Develop dispersant application plan for spill at hand. In parallel with the above actions, the Operations Section Chief should initiate preparations of surface delivery systems for dispersant application (see mission planning section). On-scene spill containment and mechanical recovery progress should be continuously monitored during this time and reported to the Incident Commander. If these operations are observed to be inadequate to successfully manage the spill, aerial and/or vessel dispersant equipment should be mobilized. The request for this support should be made to the Logistics Section Chief with Incident Commander approval.

Dispersant Use and Approval Guidelines

Deciding Whether to Use**.** The Incident Commander in consultation with the Contracting Party will make the decision as to whether dispersant use is appropriate. Alyeska has developed a computerized Tactical Oil Spill Model (ATOM) that will assist in analyzing oil spill trajectories and in outlining appropriate spill responses.

It is also advisable for the Planning Section Chief, in consultation with the Scientific Support Coordinator to the ARRT, to complete the ARRT Decision Matrix, included in this section (*Figure 7-4*). This is the matrix that the FOSC will consult first, once contact has been made requesting dispersant use. Note, however, that in Zone 1, the FOSC may authorize dispersant use prior to consulting the ARRT. In addition, if the spill is in Zones 2 or 3, as indicated in the ARRT map (*Figure 7-3*) it is advisable for the Planning Section Chief to complete the computerized Environmental Protection Agency (EPA) Decision Matrix (*Figure 7-5*). This is the matrix that the FOSC and the EPA representative to the ARRT should rely on to evaluate spills in Zones 2 or 3. It is not necessary for Alyeska personnel to send completed ARRT or EPA decision matrices to the FOSC. The purpose of completing them is to anticipate the actions of the FOSC and ARRT and be prepared to respond.

Alyeska's ATOM can be helpful in completing the ARRT and EPA decision matrices. The matrix decision points require a fairly detailed knowledge of relevant factors and the ATOM can be helpful in this regard.

Procedures for Requesting Approval.
Requests for approval for dispersant use are initiated by the Incident Commander or his deputy and are routed to the FOSC. Depending on the location of the spill, the FOSC may or may not have to consult the ARRT. The Alyeska Environment Unit Leader will be responsible for preparing the necessary information that must accompany the request to the FOSC. The information that must accompany the request will be contained in the completed ARRT Oil Spill Response Checklist (unified Plan, 1996).

It is critical that requests for dispersant use be made as soon as dispersant use is determined to be a desirable option. It is also crucial that the regulatory agencies make rapid approval decisions because oil weathers rapidly to a condition where dispersant effectiveness is greatly reduced. Unnecessary delay could result in losing dispersant application as a viable spill response alternative.

Federal dispersant use guidelines are established by the *National Oil and Hazardous Waste Substance Pollution Contingency Plan* (NCP). The NCP is outlined in 40 CFR, Part 300. In addition, only the dispersants and chemical agents listed on the EPA approved NCP product schedule may be used. The NCP establishes the framework for the dispersant use approval process. The ARRT guidelines detail the approval process that must be followed in Alaska. The ARRT Guidelines are included as *Section 7.10 "Guidelines for Dispersant Use in Prince William Sound"*.

The ARRT guidelines require that the use of dispersants be approved in all cases by the Coast Guard representative designated as the FOSC. The FOSC is pre-authorized to unilaterally approve the use of dispersants in two cases. These cases are:
1) When human life is endangered and the use of dispersants will mitigate the danger.
2) When the spill occurs in Zone 1 areas, as designated by the ARRT for Prince William Sound and Cook Inlet.

When spills occur in Zone 2 or 3 areas, the FOSC must receive approval from the EPA representative to the ARRT and the Alaska Department of Environmental Conservation (ADEC).

Zones 1, 2 and 3 are defined and differentiated according to the following criteria:

- Physical parameters such as bathymetry and currents.
- Biological factors such as sensitive habitats and wildlife concentrations
- Nearshore human use.

- Time needed to respond to the spill.

The ARRT guidelines characterize each zone as follows:

Zone 1: Dispersant use should be considered to prevent oil from damaging shoreline or other sensitive resources.

Zone 2: Dispersant use conditional but should be considered only if it will protect sensitive resources.

Zone 3: Dispersant use not recommended.

The dispersant use guidelines for Prince William Sound focus on the tanker traffic lanes and reflect the remoteness and fjord geomorphology of the Sound. Designation of the tanker lanes primarily as Zone 1 was deemed desirable due to:

- The large volume of oil transported through the sound via these lanes.
- The difficulty in mechanically containing and removing spilled oil.
- The likelihood that dispersant use would assist in minimizing the environmental effects of a spill, particularly oil contamination of sensitive coastal resources and habitats.

Most of the area outside the tanker lanes has been designated as Zone 3 due to the variety and abundance of biological resources in Prince William Sound. The general rationale for the guidelines is presented below

Port of Valdez and Valdez Arm (North of Latitude 60° 47')

1) Zone 3. Tatitlek Narrows and Columbia Bay are designated as Zone 3.

2) Zone 2. In general, the areas inshore of the 100-fathom isobath and north of Rocky Point and Point Freemantle are designated as Zone 2.

3) Zone 1/Zone 2 (Seasonal Designation)

This small portion of Prince William Sound consists almost entirely of tanker traffic lanes and includes the tanker loading berths at the terminus of the Trans-Alaska Pipeline. The Port of Valdez and Valdez Arm also support sensitive fisheries resources, such as out migrating juvenile salmon, herring spawning and rearing areas, immigrating adult salmon; and commercial fishing activities. Consequently, this portion of the Sound has been designated Zone 1 from October 16, to February 28, when fisheries resources are least abundant; and Zone 2 from March 1 to October 15, when fisheries resources and harvest activities are at a peak. The Zone 2 designation will allow a case-by-case decision on dispersant use. Such a decision will be based on the potential for impact(s) to environmental resources.

Main Body of Prince William Sound

1) Zone 3.
The majority of the waters within this section of Prince William Sound are designated as Zone 3. This provides protection for abundant and diverse biological resources of these areas and eliminates the procedural difficulties of classifying the complicated and extensive shoreline.

2) Zone 1.
The tanker traffic lanes and a variable extending on either side of these lanes are designated as Zone 1. The width of this zone is determined by the need to minimize adverse effects on sensitive resources and the morphology of the Sound.

Hinchinbrook Entrance

1) Zone 1/Zone 3
Hinchinbrook Entrance, which is included in the tanker traffic lanes is designated Zone 1, with the exception of an area one nautical mile in radius around Seal Rocks. The area around Seal Rocks is designated as Zone 3, reflecting the importance of this area to marine mammals and sea birds.

The area inshore of the three-mile (statute miles) territorial limit along the coast from Cape Hinchinbrook to Kayak Island is designated as Zone 3. This wide Zone 3 designation provides protection for the coastal resources and sensitive marsh and tidal flat habitats of the Copper River Delta area.

2) Zone 1
Zone 1 is identified as an approximately five nautical mile wide buffer extending seaward of Zone 3. This width should provide adequate time to conduct a dispersant response to oil entering the sensitive Zone 3.

3) Zone 2
The waters seaward of Zone 1 are designated as Zone 2.

Montague Island (West of Hinchinbrook Entrance)

1) Zone 3
Zone 3 occurs inshore of a line drawn approximately one nautical mile off the outside coasts of Montague and Elrington Islands and extending east to Cape Junken. In this area, the water depth increases rapidly with distance offshore. A distance of one nautical mile should provide sufficient depth for adequate mixing and dilution of dispersed oil.

2) Zone 1

Zone 1 is identified as an approximately five nautical mile wide buffer area extending seaward of Zone 3. This designation will allow for a rapid decision on dispersant use to minimize adverse effects on the sensitive resources in Zone 3.

3) Zone 2
The waters seaward of Zone 1 are designated as Zone 2.

4) Zone 1/Zone 2 (Seasonal Designation)
The southern end of Montague Strait, south from a line drawn from the northern end of Latouche Island to Point Bazil and to a line drawn between Point Cleare and a point 0.5 nautical miles south of Point Elrington (59° 55' latitude and 148° 15' longitude)--is designated as Zone 1 from October 1 to March 31 and as Zone 2 from April 1 to September 30. This dual designation is due to the presence of fisheries resources and commercial harvest activities as well as the potential use of the area by oil tankers.

Strategy and Decision Making.
Dispersant decisions are among the most important strategic and operationally important for the incident response. Considerable effort has been made on the part of all interested parties in Alaska to provide an coordinated team approach to the use of dispersants as a response strategy. Each entity must maintain it's separate responsibilities: the responsible parties (RP) response, state response, federal response and local interest representations. In addition, it is our position that the process for the responding party decisions must be up front, and must address the professional question "Is this the right response tool to be using in this circumstance? Will it provide the best mitigation tool for this spill with these resources in the spill area which is threaten and with the water depths, circulation patterns and spill product and quantities from this particular incident. Also, the RP can use modeling tools to assist in decision making.

The public needs dispersant use capability as one of the viable spill mitigation tools and the response action contractors and RP need recognition and acceptance within the approved planning permits and processes to maximize the total response effectiveness.

Conclusion

Dispersant applications are a real part of the PWS response plan. The use is supported by proper equipment, techniques, logistics, monitoring and safety procedures. Dispersant use is one of the important tools needed for effective management of response incidents and the capability to carry out these missions is real, tested and viable. Protection of the precious resources of Prince William Sound is critical, and importantly balanced with the nations need for petroleum.

With the existing capability, we do not believe it is time to stop the clock and wait. We support continuing the reviews of the techniques and technology; Maintaining testing and operability for all types of operational platforms and distribution systems and maintaining pace with science, modeling, real use applications and monitoring activity and science results on an on-going basis.

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Dispersant Effectiveness Issues

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

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Abstract

The paper summarizes the recent report for Prince William Sound Regional Citizens' Advisory Council (PWS RCAC) which evaluates the effectiveness and environmental effects of using chemical dispersants, especially Corexit 9527, on spills of Alaska North Slope (ANS) crude in Prince William Sound and the Gulf of Alaska. Only the subject of "dispersant effectiveness" is covered in the paper; "environmental effects" are discussed elsewhere in the proceedings. The report for PWS RCAC summarizes and assesses recent literature on the subject of dispersant effectiveness, including reports of: (1) experiments with Corexit 9527 and ANS crude in the field, in test tanks and in the laboratory; (2) dispersant effectiveness trials that took place in the North Sea from 1991 to 1995 involving different dispersant/oil combinations; and (3) dispersant-use activities at the *Sea Empress* spill off Wales in 1996. The report contains a detailed review of factors that reduce dispersant effectiveness in the field, such as poor application methods and spill emulsification, and assesses the extent to which these factors can be mitigated. The study concludes that, if used properly, Corexit 9527 should be reasonably effective on spills of ANS crude in Prince William Sound or the Gulf of Alaska. The exact value for dispersant effectiveness is impossible to predict. Values in the literature derived from experiments range from about 30 to 80 percent. Using an oil spill behavior model, and the results of previous laboratory testing of the properties of weathered ANS crude, the study demonstrates that ANS crude oil spills in the area will remain dispersible and relatively non-viscous and unemulsified for up to three days of environmental exposure. It is calculated that dispersant-use equipment, chemicals and aircraft available in the area could fully treat 81 percent of a 63,000 barrel (10,000 m^3) spill in the Gulf of Alaska (at a dispersant-to-oil ratio of 1:20) if the spill occurred in the summer, but only 21% in winter (because of the long periods of darkness).

Introduction

In May 1997 a detailed report entitled, "A Review of Dispersant Use on Spills of North Slope Crude Oil in Prince William Sound and the Gulf of Alaska", was completed for the Prince William Sound Regional Citizens' Advisory Council (SL Ross 1997). The report synthesizes recent technical literature related to oil spill chemical dispersants with a view toward determining whether there are environmental advantages to using dispersants against spills of North Slope crude oil in Prince

William Sound (PWS) and the Gulf of Alaska (GOA). The report attempts to answer the following two questions:

> *Will modern dispersant products be effective in dispersing North Slope crude oil spills in Prince William Sound and the Gulf of Alaska?*
>
> *Do dispersants offer environmental advantages in PWS / GOA considering the possible detrimental effects of intentionally driving oil into the water?*

This summary paper deals with the first question. The second question is addressed elsewhere in these proceedings (Trudel 1998). The structure and order of topics in the paper are identical to those in the technical report.

How Can We Determine "Dispersant Effectiveness"

The question is whether North Slope crude oil, if spilled in the cold waters of the area, will be truly amenable to chemical dispersion, or whether the oil will resist chemical dispersion for whatever reason. In other words, will dispersant effectiveness be high or low. "Dispersant effectiveness" as used here means the effectiveness of the dispersant under field conditions. Unfortunately, most quantitative information on dispersant effectiveness comes from a number of laboratory tests, which are useful in providing a relative indication of dispersant effectiveness, but cannot be relied upon to predict actual values of dispersant effectiveness in the field. The problem is shown in Table 1, which provides the results of the five most popular laboratory tests when considering North Slope crude oil and Corexit 9527 (the primary dispersant available today for use in Alaska and the rest of the U.S).

There is little solid information on the effectiveness of dispersants when used in the field. The situation is changing somewhat as a result of field trials in Europe that are producing quantitative data on dispersant effectiveness. For example, see Lewis 1998 and Brandvik 1998 in these proceedings. Nevertheless, at this time it can be said that predicting dispersant effectiveness in the field for a given oil spill situation is not an easy and mechanical task; rather the process is inexact and based on a range of both objective and subjective thinking. This paper works its way through this thought process.

Fate and Behavior of Untreated Oil Spills: The Baseline Case

When oil is spilled at sea it is subject to several so-called "weathering" processes. The ones of some importance to dispersant use or dispersant effectiveness are spreading, evaporation, natural dispersion of oil in water, and emulsification.

Slick Spreading. At one time it was believed that oil spills, although initially very thick, spread quickly to cover a huge area of uniform oil thickness in the range of 0.10 mm. The current expert view is that oil spills spread as thick patches that contain most of the spill's volume and that these patches are surrounded by sheen. Although the phenomenon of thick/thin spreading is widely accepted today, and there is much remote sensing and photographic imagery to support the notion of slicks being composed of thick and sheen portions, there is surprisingly little quantitative information available in the literature on the subject. Nonetheless, some very well documented experimental spills have involved measurement of either thickness or volume/area (Mackay and Chau 1986, Lunel and Lewis 1993, Lewis et al. 1995, Walker et al. 1995, Brandvik et al. 1996) and these indeed show that oil spills at sea, even relatively small ones, do tend to stay relatively thick (> 1 mm) for reasonable periods of time. The rule-of-thumb is that 90 to 95 percent of the spill's volume is contained in 5 to 10 percent of the spill's area.

Evaporation. Evaporation is one of the most important processes that affect the properties and therefore the behavior of spilled oil. The major effect on dispersant effectiveness is that evaporation advances the point at which spilled oil "emulsifies". This greatly increases the viscosity of the residual oil and its resistance to chemical or natural dispersion.

Table 1
Effectiveness of Corexit 9527 on North Slope crude oil as determined by five different laboratory tests

Laboratory Test	Effectiveness, %
Swirling Flask (*)	19
Labofina/WSL	40
IFP	67
MNS	76
EXDET	93
AVERAGE VALUE	59%

(*)The Swirling Flask test is the only dispersant effectiveness test recognized in the National Contingency Plan. See *Federal Register*: 59(178): 47384 - 47495.
Source of table: SL Ross 1997

Natural Dispersion. The dispersion of oil into the water by natural forces is an important process controlling the long-term fate of oil slicks at sea. In conjunction with evaporation, this process reduces the volume of oil on the water surface, thereby influencing the potential extent of surface and shoreline contamination. The idea behind chemical dispersion is to greatly increase the natural rate of oil dispersion by reducing the cohesion of the oil.

In slick dispersion, oil droplets are dispersed from the slick into the water by oceanic mixing. The larger of these droplets, which are buoyant, resurface quickly and rejoin the slick. The smaller droplets remain in suspension in the water-column. Clouds of the entrained oil then diffuse and dilute quickly. When chemical dispersants are used, the process tends to produce a much higher proportion of the very small droplets that tend to stay in permanent suspension in the water.

Sea state is also an important factor controlling the rate and amount of dispersion. Even light, non-viscous oils do not rapidly disperse under calm conditions, yet even the heaviest, emulsified oils can disperse over a period of time in heavy seas with frequent breaking waves.

Emulsification. Oil spill emulsification is one of the most important processes affecting spill dispersion and dispersant effectiveness. The process occurs when wave action causes seawater to be mixed into the oil in the form of microscopic droplets. Fully emulsified oils can contain 75 to 85% water. The uptake of water results in a significant increase in the bulk volume of the oil, greatly increasing the amount of oily material that can contaminate shorelines and biological resources. Also, there is a marked increase in fluid viscosity (up to a 100-fold increase or more) and this greatly inhibits the chemical or natural dispersion of oil.

Spills of some crude oils will start to form emulsion within a few minutes of environmental exposure, and will form a highly viscous and stable emulsion within hours. This has been recorded many times during actual and experimental spills. On the other hand, a few crude oils and most refined petroleum products do not emulsify at all. Testing and modeling of Alaska North Slope crude oil (SL Ross 1994,1997; Strøm-Kristiansen et al. 1994) indicates that it emulsifies, but not very quickly, as discussed later.

Results from recent field trials off the U.K. and Norway indicate that modern dispersants are relatively effective against weakly-formed or freshly-formed emulsions and in fact actually seem to cause emulsions to separate or “break” into their original oil and water phases (Walker and Lunel 1995, Lewis et al. 1995, Brandvik et al. 1995).

How Dispersants Work

When oil is spilled on water, it exhibits a cohesiveness or resistance to break up. This cohesive strength is due to the interfacial tension or contractile skin between the oil and water. A chemical dispersant acts at the oil-water interface to greatly reduce this interfacial tension. This action promotes the break-up of the oil film into droplets that disperse into the water phase. If the droplets are small enough they will have little buoyancy and will be carried away and diluted by normal ocean current and movement.

Despite the great decrease in interfacial tension, mixing energy is still needed to promote movement and dispersion of the fine oil droplets into the water column. This energy can be supplied either by the natural motion and currents of the sea or by mechanical means such as work boats. The more energy that is available, the less dispersant that is required. It has been shown in numerous field trials that when the small oil droplets enter the water they dilute quickly to concentrations in the range of 1 to 10 parts-per-million immediately under the treated slick. After spraying stops, concentrations decline rapidly towards background levels.

Problems in Obtaining High Dispersant Effectiveness in the Field

It is known from a handful of experimental spills in the field that a non-viscous oil, when thoroughly pre-mixed with dispersant, and spilled on the ocean under average sea conditions, will completely disperse from the surface and will do so relatively quickly compared with the same oil if left untreated (Daling and Lichtenthaler 1987, Delvigne 1985, Fingas 1985, Sørstrøm 1986). This provides the strongest possible evidence that chemical dispersants have the potential for being very effective on spills at sea. There are problems in realizing this with actual spills, however. This is because chemical addition to accidental marine spills takes place after the oil is spread on the surface and not before, and achieving good contact and mixing between the applied dispersant and the oil is very difficult at this stage. It is clear that applying the dispersant in the proper amounts, in the proper way and at the proper time is crucial in ensuring that the chemical has an opportunity to do the job that it is capable of doing.

In the 1970s and 1980s about a dozen field trials were conducted to evaluate dispersant effectiveness. Values ranged from 0% to 100% and the average was in the range of 20 to 30 percent. (Nichols and Parker 1985; Fingas 1985, 1988) . This range is not dismal by mechanical recovery standards, but one might wonder why values were not higher considering that most experiments were designed to simulate best-case conditions, including the use of unemulsified and relatively non-viscous oils. It is now believed that the main reason was that most experiments involved poor contact and mixing between the sprayed dispersant and the oil slick, resulting in a quick loss of the dispersant to the water phase. Some of the factors that caused poor chemical/oil mixing were not known at the time, but are now. The following is a quick review of the major issues.

Dosage Control. Until the mid-1980s most specialists considered that marine oil spills spread uniformly and reached an average thickness of about 0.10 mm in several hours of spreading. This thickness is mentioned often in the dispersant literature in the 1970s and 1980s as the thickness to consider in the design and implementation of a dispersant response operation. Belief in the number led to the concept of a one-pass (carpet-sweeping-like) mode of dispersant application (Lindblom 1979,1981; Exxon 1992, 1994; Allen and Dale 1995).

Today it is known that slicks invariably are composed of very thick portions in a relatively small area surrounding by much larger areas of very thin sheen. It is clear that if the entire slick is sprayed uniformly, the thicker portion, representing most of the spill volume, will be vastly underdosed and the sheen greatly overdosed. This is what happened at many of the earlier field trials, explaining the poor results (Mackay and Chau 1986, Chau and Mackay 1988). The recommended strategy today for applying dispersant, and the strategy used at the *Sea Empress* spill (Lunel 1997, 1998), is for remote sensing planes to direct spray aircraft to areas of thickest oil and for the spray aircraft to repeatedly pass over the region of thickest oil until the surface oil has been dispersed.

Oil Viscosity. The singular most important factor that causes poor dispersant effectiveness in the field is the viscosity of the spilled product at the time the chemical is applied; if the viscosity is extremely high, the dispersant will not mix properly with the oil. When an oil spill is highly viscous the applied chemical may simply "roll off" the oil or will not penetrate and mix with the mass of oil. Generally, dispersant effectiveness for most products is believed to begin to drop when the oil viscosity reaches about 2000 cP and to become almost zero when the viscosity increases beyond 10,000 cP. (By way of comparison, the viscosity of water = 1 cP, glycerin or castor oil = 1000 cP, and molasses =100,000 cP.) Recent field evaluation of a new dispersant, Corexit 9500, suggests that this product may be more effective than most against viscous spills (Lewis 1998).

Emulsification. For spilled oils that are highly viscous to begin with, like heavy bunker oils and extremely heavy and viscous crude oils, it has been understood for some time that attempts at chemically dispersing the spill will prove futile. Not as well understood until recently is the process of water-in-oil emulsification and its effects on dispersant effectiveness. As noted earlier, this process is responsible for the largest hindrance to effective dispersant use of any process or any factor. Almost all crude oils emulsify and become viscous, and the evidence seems to suggest that the process can start early in a spill's history and, once started, can proceed rapidly. It is not uncommon for heavily weathered emulsions to become as viscous as ketchup or mayonnaise. It is claimed that the new product, Corexit 9500, may be effective against highly viscous emulsions, but this remains to be proved.

Herding and Dispersant Drop Size. Dispersants, by their nature, have a higher spreading force than does oil. This means that a thin slick of oil surrounded by a layer of dispersant will be herded into a narrow ribbon of oil. This will happen if the applied dispersant misses its target of oil and falls on the water in proximity to the oil. As viewed from the air, the ribbons of oil thus formed are barely visible, so the operations looks as if the dispersant was very effective in clearing oil off the surface. The water will continue to look clear until the dispersant on the surface is naturally mixed into the water phase, and the oil re-spreads on the surface. This might take about 15 minutes (Fingas 1985). This herding phenomenon has fooled observers into thinking that the dispersant has worked, whereas quite the opposite has occurred. One indication that dispersants are working is seeing the coffee-colored cloud of dispersed oil in the water column.

Another way herding occurs is if applied dispersant droplets crash through the slick to the underlying water surface and start herding the oil at that time. This will happen if the dispersant droplets are much larger than the slick thickness. For example, if the dispersant droplet has a diameter of, say, 0.5 mm and the slick thickness is 0.1 mm, the dispersant drop will likely break through the slick and cause it to herd. This is problem enough, but the worst of it is that the first few droplets of a dispersant application will immediately and greatly reduce the area of oil slick and increase the water surface area so that subsequently falling droplets will miss the oil entirely, fall on water, and gradually enter the water column. This problem can be avoided by ensuring that only relatively thick slicks are targeted for treatment so that the dispersant droplets are always smaller than the thickness of the targeted oil.

Sea Energy. Sea energy is of obvious importance to the dispersion of marine oil spills. Many historical spills, even very large ones such as the *Braer* tanker spill off Scotland in 1993, dispersed quickly in rough sea conditions (Thomas and Lunel 1993, Lunel et al. 1998). It is more usual for spills in moderate seas to disperse only slowly. The goal of using chemical dispersants is to speed up the natural dispersion process and treat the oil before it emulsifies and becomes highly viscous. For both natural and chemically-induced dispersion, the higher the sea states, the better. In this sense dispersant-use complements the other two approaches to marine oil spill control, mechanical recovery and in-situ burning, which work best in calm seas.

Dispersant Type. There are literally hundreds of dispersant products on the market that claim to be effective, but most have been shown to be relatively ineffective in laboratory tests and, in any case, are not available in large quantities on an emergency basis. Only a handful are truly effective and supplied by reputable manufacturers who have been in the business for many years. The most commonly stockpiled product in North America is Corexit 9527, which has done well in comparative testing against other products. A relatively new product on the market, Corexit 9500, is claimed to be substantially more effective than Corexit 9527, especially on viscous oils, and recent trials seem to bear this out (Lewis 1998). This product apparently has the same formulation of Corexit 9527, but the solvent has been changed. Both Corexit products are designed for salt-water use only and are relatively ineffective when used on spills in fresh or brackish water.

Temperature: There is a general misconception that temperature, *per se*, is a problem in dispersant effectiveness, and that dispersants should not or cannot be used in cold climates. This is not true. Temperature simply increases the viscosity of the dispersant product and the spilled oil. Dispersant products have been formulated to be non-viscous in cold temperatures, so this is not a problem. The viscosity of the spilled oil will become higher at low temperatures, but perhaps not too high for effective chemical dispersion. An example of this is seen in the dispersant effectiveness results shown in Table 2 of laboratory work done on weathered North Slope crude treated with various dispersants at two temperatures, 0°C (32°F) and 10°C (50°F).

Table 2
Effect of Temperature on Dispersant Effectiveness(*)

Dispersant	Dispersant Effectiveness, %	
	50°F	32°F
A	60	62
B	19	34
C	64	63
D	46	49
E	50	60
F	35	33
G	82	78

(*) Labofina Test with 11% Weathered North Slope Crude
Source of table: Byford et al. 1983

How to Maximize Dispersant Effectiveness

As mentioned earlier, the results from several experimental spills have shown that an oil pre-mixed with a relatively effective dispersant product and discharged on the ocean surface will disperse thoroughly at sea. In an actual spill situation the closer one can approach this good mixing of dispersant with oil, the better are the chances of effective dispersion. Good dispersant/oil mixing can be helped by:

- responding to the spill as quickly as possible while the oil is unemulsified and relatively small in area and large in thickness; and
- targeting only the thick portions of the spills and dosing these continuously until the proper dosage is achieved and the oil is dispersed or is no longer responsive to treatment.

Even with a rapid and well-executed dispersant application, perfect mixing of the dispersant with the oil, and hence complete dispersion of the oil, cannot be expected in an actual spill situation unless sea states are high.

Emulsion Inhibitors

Aside from marine spills, water-in-oil emulsions are commonly formed during petroleum production when crude oil is unavoidably mixed with produced water. Special chemicals, called emulsion breakers or demulsifiers, are often added to produced crude oils in low concentration to prevent emulsion formation or to "break" already-formed emulsions. In the spill control business the use of demulsifiers to treat oil spills has only recently become a subject of focused attention. Research has shown that: (a) demulsifiers can be sprayed onto oil spills in low concentration to prevent emulsion formation and even to break weakly-formed emulsions; (b) certain demulsifiers are of very low toxicity; and (c) certain demulsifiers are highly oleophilic, meaning that they will tend to stick to oil slicks once applied and not leach into the water column. The advantages of preventing spills from emulsifying has been suggested earlier: spills will be less persistent and will disperse naturally much more quickly, and spills will be more amenable to chemical dispersion.

Research on emulsion inhibitors for oil spills started about the mid-1980s and continued in field trials in the early 1990s, as summarized below. Now that it has been discovered that the better dispersants, such as Corexit 9500, have significant emulsion-inhibiting and emulsion-breaking powers, the research trend seems to be away from the two-step treatment approach of applying emulsion inhibitors first and dispersants second.

Effectiveness Results from European Field Trials, 1991 to 1995

Seven offshore dispersant trials took place in Europe from 1991 to 1995. These are of special relevance to this analysis because, although involving oils other than North Slope crude and dispersants other than Corexit, these well-run experiments made breakthroughs in measuring dispersant effectiveness in the field quantitatively, and in evaluating the effectiveness of demulsifiers under field conditions. Each of the experiments consisted of several large spills in the size range of 10 m^3 to 20 m^3 (63 barrels to 126 barrels). Most involved spilling two identical batches of oil, one to leave alone as the control, and the other to treat with either demulsifier or dispersant, or both.

The experiments involved two kinds of spills – batch spills and continuous-discharge spills. First, the results of the batch spill experiments are summarized and then the results from the continuous-discharge spills.

Batch Spill Experiments

The following is summarized from: McDonagh and Colcomb-Heiliger 1992, Lunel and Lewis 1993, Lunel 1994a, Lewis et al. 1995, Brandvik et al. 1995, and Walker and Lunel 1995.

For the batch-spill trials where **dispersants alone** were used the results showed that:

- there was a reduction in the oil slick's water content and viscosity immediately following treatment with dispersant, and the treated slick spread more rapidly than the control slick;

- the volume of oil dispersed below the treated slick was as much as 16 times greater than below the untreated slick.

For batch-spill trials where **demulsifiers alone** were used the results showed that:

- the treated slicks spread quickly to a greater area than the control slicks, and dispersed faster;

- the control slicks formed a more viscous emulsion and was much more persistent than the treated slicks;

- treatment with demulsifier slowed down or reversed the formation of emulsion. This led to a reduced slick area which dispersed faster than the control slick;

- the demulsifier-treated slicks resulted in maximum oil concentrations in the water that were five times higher than the control slick and spread over 10 to 20 times as large an area.

For batch-spill trials where **demulsifiers and dispersants in combination** were used the results showed that:

- dispersant treatment at low dose rates, estimated as 1:300 to 1:700 (dispersant to emulsion) destabilized the emulsion that had been formed and led to increased oil spreading and an enhanced rate of natural dispersion;

- The dispersion process was relatively slow, but the rate of dispersion was significantly enhanced compared to that of the control slick. The dispersant treated slick was totally removed from the surface about 4 hours after treatment, while the control slick persisted for a total of 30 hours;

- the enhanced dispersion rate for the slick treated with a low dosage of dispersant (Corexit 9500) was approximately ten times higher than for the untreated slick;

- the water content of the emulsified spills dropped significantly after either the demulsifier or the dispersant application. Such behavior is attributed to similar chemicals used in both demulsifiers and dispersants;

- the combined demulsifier/dispersant operation resulted in a five- to 10-fold increase in the amount of oil dispersed compared to that dispersed from the untreated slick.

Continuous Discharge Spills

Lunel proposed in the early 1990s that the best method for assessing dispersant effectiveness quantitatively in field experiments was to use a continuous, steady-state discharge rather than a “batch” discharge. A set-up to do this was designed and used in field experiments off the U.K. Results of various dispersant/oil combinations from trials in 1993 and 1994 are shown in Table 3 (from Lunel 1994 and Lunel et al. 1995).

The data in the table show:

- there is a clear ranking in the percentage of oil that different dispersants will disperse in the field. Although this ranking has been well documented for laboratory tests, this is the first set of field data where this ranking has been quantified;

- dispersant type is the most significant factor affecting the percentage of dispersed oil but smaller differences do exist for the two different oil types;

- The tested dispersants increased the rate of dispersion by three- to 10-fold compared with natural dispersion.

The *Sea Empress* Spill in 1996

On February 15, 1996 the tanker *Sea Empress* grounded at the mouth of Milford Haven, Wales, and spilled 72,000 tonnes (19 million gallons) of Forties Blend crude oil and 370 tonnes of Heavy Fuel Oil. This spill is of particular interest because a major component of the response to the spill involved the application of dispersants. Papers by Lunel et al. 1997 and Lunel 1998 (these proceedings) cover the subject in detail. The following is a summary of the 1997 paper.

Assessments of dispersant effectiveness and decision making at the spill were aided by the fact that the spilled crude oil, Forties Blend, has been used extensively in field trials in the North Sea (the ones summarized above). These field trials showed that: (1) Forties Blend forms emulsions readily and that in the absence of treatment these emulsions can be relatively persistent; and (2) Forties Blend tends to be amenable to treatment both by dispersants and demulsifiers.

In response to the grounding, the U.K. national contingency plan was activated and two surveillance aircraft were deployed to fly over the vessel to monitor the extent and movement of the spill. Seven DC3 dispersant aircraft were loaded with dispersant and dispatched to the scene.

The bulk of the oil was released over a 4-day period. In total seven different dispersant products were applied to the spill. Around 400 tonnes (about 3000 barrels or 130,000 gallons) were applied using the DC3 spray aircraft. Another 45 tonnes (about 13,000 gallons) were applied via an ADDS-pack system.

Table 3
Summary of the Dispersant Efficiency Data for Sea Trials in 1993 and 1994

Energy Regime	Wind Speed, kts	Oil/Dispersant	% Dispersed
Low	6	MFO/none	0.8
Low	10	MFO/Slickgone	8
High	20	MFO/none	2
High	14	MFO/none	4
High	14	Forties/none	5
High	20	MFO/1100X	10
High	10	MFO/Slickgone	17
High	12	MFO/Slickgone	16
High	12	Forties/Slickgone	16
High	14	MFO/Corexit 9527	26
High	20	MFO/OSR5	30

MFO = Medium fuel oil; Forties = Forties Blend crude oil;
Slickgone, 1100X, OSR5, and Corexit 9527 are commonly used dispersants in the U.K.
Source of table: Lunel et al. 1995

A notable feature of the spray response was the targeting achieved by the use of remote sensing aircraft positioned above the spray aircraft to direct the spray pattern. This operation is well tried and practiced in the U.K. and allowed the DC3 aircraft to hit ribbons of oil as narrow as 10 to 20 m (30 to 60 feet). The strategy used at the *Sea Empress* spill for applying dispersant, and the strategy used generally in the U.K., is for remote sensing planes to direct spray aircraft to areas of thickest oil and for the spray aircraft to repeatedly pass over the region of thickest oil until the surface oil has been dispersed. It is estimated that the actual dispersant to oil ratio used was between 1:50 and 1:150. Even at this very low dose rate the dispersant resulted in an effective dispersion.

Table 4 is the estimated oil budget for the 72,000 tonnes of Forties crude that were spilled.

The "dispersed" value is an estimate that was not measured, but deduced by subtracting the other losses from 100%. Thus, using an estimate of 40% of the spill was evaporated, 3% was recovered at sea, and 7% impacted the shoreline, then, by difference, 50% of the oil was likely to have dispersed, by either natural means or with the assistance of chemical dispersants.

Table 4
Proposed Oil Budget for the *Sea Empress* Spill

	Considering dispersant operation deployed at the *Sea Empress*	Estimate in the absence of dispersant use
Recovered at sea	3%	10%
Impacting to shoreline	7%	40%
Evaporated	40%	40%
Dispersed	50%	10%

Source of table: Lunel et al. 1997

In summary, as a result of the grounding of the *Sea Empress*, 72,000 tonnes of Forties Blend oil were released into the environment making this incident among the 20 largest oil spills of all time. With up to 45% evaporating the potential was for 40,000 tonnes of oil to come ashore. Since Forties Blend oil rapidly emulsifies to produce a 70% water-in-oil emulsion, this could have translated into 130,000 tonnes of emulsion impacting the South Wales coastline if dispersants and mechanical recovery had not been used. The result of the combined dispersant and mechanical recovery operation was that only around 10,000 to 15,000 tonnes of emulsion impacted the shoreline. The mechanical recovery operation accounted for around 2,000 tonnes of oil (4,000 tonnes of emulsion) while it is estimated that 36,000 tonnes of oil was dispersed.

Field Experiments Using Corexit 9527 on North Slope Crude Oil Spills

Corexit 9527 was used on a trial basis a few times during the *Exxon Valdez* spill, but, unfortunately, the results were uncertain (U.S. Coast Guard 1993). Results are available, however, from four independent oil spill experiments that were conducted from 1978 to 1992 at the intermediate-scale level or in the field with North Slope Crude (or Prudhoe Bay Crude) treated with Corexit 9527. The experiments were performed using wave energies that ranged from moderate to very high, and dispersant-to-oil ratios that ranged from 1 to 1 to 1 to 160. Table 5 summarizes the results of these trials as reported by the experimenters. It is believed that the dispersant effectiveness values of the last three sets of experiments could be somewhat exaggerated for various reasons, as discussed in SL Ross 1997.

Likely Dispersant Effectiveness for Spills in Prince William Sound

If the results and analysis for all the large-scale dispersant experiments and for the *Sea Empress* spill in 1996 are accepted as reported, dispersant effectiveness values from about 50 percent to 80 percent are possible depending on a number of factors. The factors that tend to yield the higher numbers are: (1) higher sea states, (2) repeatedly dosing only the thick parts of the spill, and (3) higher dispersant-to-oil ratios.

Dispersant effectiveness values for real spills of Alaska North Slope crude in the Prince William Sound area may be lower or higher than the ones noted above. The determining factor is whether the spill can be treated while the oil has a relatively low viscosity, thus improving the chances of dispersant mixing well with the oil. Another key issue relates to whether or not the application of dispersant will affect the "long-term" fate of the treated oil. All the above-reported experiments measured short-term dispersant effectiveness as a result of a single treatment of dispersant on a targeted slick. Higher values will likely occur at real spills in the field if long-term effects happen that enhance oil dispersion. These effects cannot be measured in short-term, confined experiments. What might occur are the following long-term effects, all noted in the recent European trials: (1) increased spreading of the surface oil after dispersant treatment, leading to faster natural dispersion of the surface oil; (2) inhibition of emulsion formation by the presence of dispersant, again leading to faster natural dispersion in the long-term; and (3) increased spill dispersion through additional applications of dispersant on oil not dispersed by the first application. This latter effect necessarily involves the use of more dispersant, and a higher dispersant-to-oil ratio than used in most of the experiments, but it is a parameter that will lead to large gains in oil dispersion.

Table 5
Dispersant Effectiveness Reported at Four Intermediate-Scale Experiments Involving Corexit 9527 and Alaska North Slope Crude Oil

Experiment Location and Time	Spill Size, gallons	Average Dispersant-to-Oil Ratio	Wave Energy	Average Effectiveness, %
a. Ocean, off B.C., 1978	50 to 100	1 to 1	Moderate	55

b. Ocean, off California, 1979	400 to 800	1 to 20	Moderate	61
c. Wave Basin, Calgary, 1987	17	1 to 30	Moderate to High	55
d. Wave Basin, Calgary, 1991/2	10	1 to 160	Very high	81

Source of table: SL Ross 1997. Original references are: (a). Green et al. 1982; (b) McAuliffe et al. 1981; (c) Brown and Goodman 1987; and (d) Mackay 1995.

Dispersant-Use Scenarios in Prince William Sound and the Gulf of Alaska

To repeat, it is believed that dispersants may be reasonably effective on spills of North Slope crude oil in Prince William Sound or the Gulf of Alaska if the spilled oil at the time of treatment is unemulsified and relatively non-viscous and if the thick portions of the spill are properly dosed. Whether these two conditions are satisfied will depend on: (1) the circumstances of the spill (size, season, and weather conditions) which determine the time window for effective action before the spill becomes too viscous and widespread; and (2) the response capability which depends on a number of factors (amount and availability of dispersant product and application systems, location of the spill relative to staging areas, time of day of accident, and the like).

To determine if both these conditions can be met in terms of either existing or potential capabilities, a number of oil spill behavior and response scenarios were developed and the results analyzed. The objective was simply to determine if there is a good chance of being able to treat (and disperse) a significant portion of oil from spills of various size.

A computer model was used to describe a series of hypothetical spills in Prince William Sound and the Gulf of Alaska at different times of the year. The behavior and properties of the slicks were predicted, based on a laboratory analysis of the spill-related properties of North Slope crude oil. The resulting predictions of slick characteristics were then used to estimate the rates at which countermeasures systems could apply dispersant to the spills and remove oil from the water surface.

The "time windows" for effective dispersant action are largely determined by the time taken for a given oil spill to emulsify to dispersant-resistant viscosities. These were derived from laboratory testing of Alaskan North Slope crude oil using standard emulsification tests (SL Ross 1994). The results show that the oil will not form a stable emulsion until approximately 25% of its volume is lost through evaporation. Because the viscosity of the crude remains less than 2000 cP at all times and in all of the selected spill scenarios before the emulsification process sets in (and proceeds rapidly thereafter), it is assumed that the time window for each scenario is simply the time for each spill to evaporate 25% by volume.

The results of the dispersant logistics modeling are shown in Table 6 for a large spill of 63,000 barrels (2,600,000 gallons or 10,000 m^3) that is presumed to take place in the Gulf of Alaska. Both January and July spills are considered. The spills are assumed to place about 40 miles from Valdez and 15 miles from Cordova. In the exercise the dispersant response is limited to two Hercules C-130/ADDS aircraft, operating out of the Anchorage airport. In the dispersant operation itself, it is assumed that dispersant is applied repeatedly to a section of slick until it reaches a dosage of 1:20; then the operation moves to a new area. Note in the table that the major differences between the two scenarios are: (i) good flying conditions (including daylight considerations) are available only 17% of the time in January compared to 47% in July; and (ii) because of rougher sea conditions in January, the oil spill emulsifies faster: the window of opportunity is only 59 hours in January compared to 81 hours in July.

For the July spill the table clearly shows that there should be no insurmountable problem in treating much of the spill at the recommended dosage (dispersant-to-oil ratio of 1:20) before the oil emulsifies. The amount of dispersant will depend on what the dispersant effectiveness might be under the circumstances (at a dispersant-to-oil ratio of 1:20). As seen in the table, if 100% is assumed, then 48,000 barrels of the 63,000-barrel spill could be dispersed (75%). If the dispersant effectiveness is taken to be 50%, the amount of oil dispersed becomes 24,000 barrels, or 38% of the amount spilled.

The situation is much worse in the winter scenario, not because the spill emulsifies very quickly (it remains potentially dispersible for almost three days), but because aircraft cannot respond due to the prevalence of darkness in January (70% of time). For 100% dispersant effectiveness, only 14,000 barrels could be dispersed (22% of the amount spilled).

It is important to emphasize that the analysis is highly idealized and has been performed for illustrative purposes only. But it should be understood that when aircraft can fly a dispersant operation for any spill of Alaska North Slope crude oil in Prince William Sound or the Gulf of Alaska is likely to be successful in removing significant proportions of oil from the water surface, even if dispersant effectiveness (volumes oil dispersed/volumes of dispersant applied) is not as high as what one would like. The reason is that all of the hypothetical spills have reasonable time windows for dispersant application, even spills in winter. This is not often the case for other crude oils that tend to emulsify faster than does North Slope crude.

Summary of Main Issues related to Dispersant Effectiveness

The large technical report on which this paper is based (SL Ross 1997) began with a list of questions or concerns expressed by Alaskan citizens regarding the use of dispersants on potential spills of Alaska North Slope crude oil in Prince William Sound and the Gulf of Alaska. The following repeats the questions that relate to dispersant effectiveness, and summarizes the efforts made in the technical report to answer them.

What is the effect on dispersant effectiveness of physical (environmental and weather conditions) found in Prince William Sound and the Gulf of Alaska?

There should be no major effect of environmental factors or weather factors on dispersant effectiveness for spills in the area. Temperatures are low, but still not low enough to cause the freshly spilled oil to gel and thus become highly viscous. There is no evidence in the literature to indicate that temperature by itself affects dispersant effectiveness, but the low temperatures will make the oil more viscous than it would otherwise be, and this might have some minor effect on dispersant effectiveness. ANS crude is an oil that has reasonably low viscosity even at 32°F so dispersant effectiveness should not be very much affected by the increase in viscosity that is caused by the low temperatures. In terms of weather conditions, there should be no significant problems regarding limitations regarding sea states, flying conditions and visibility. Dispersant-use, like all spill response methods, cannot be safely conducted in darkness, so spills in winter will be dealt with less effectively than those in summer.

Table 6
Dispersant logistics for 63,000 barrel spill in the Gulf of Alaska in January and July

	January Scenario	July Scenario
Mobilization time, hrs	8	8
Total time per sortie, hrs	3.6	3.6
Oil-viscosity-based time window for dispersant operations, hrs	59	81
Percentage of daylight and good flying conditions	0.17	0.47
Total sorties possible per unit	3	10
Payload of platform, gallons	5000	5000
Number of units available	2	2

Total possible dispersant that can be applied, gallons	30,000	100,000
Oil Dispersed, assuming 100% Effectiveness @ DOR=1:20, barrels	14,000	48,000
Oil Dispersed, assuming 50% Effectiveness @ DOR=1:20, barrels	7,100	24,000
Oil Dispersed, assuming 25% Effectiveness @ DOR=1:20, barrels	3,600	12,000

Source of table: SL Ross 1997

Are dispersants currently stocked by responders in Prince William Sound and the Gulf of Alaska effective on Alaska North Slope Crude in cold PWS/GOA water?
As noted above, the coldness of water should not be a major factor for North Slope crude oil spills. It is impossible to predict what the actual dispersant effectiveness might be of Corexit 9527, the main dispersant product available in Alaska, on real spills in Prince William Sound or the Gulf of Alaska. Laboratory, wave-basin and field experiments with this dispersant/oil combination report values that range from about 30% to almost 100%. These experiments considered only a single application of dispersant onto a slick. Recommended practice in the U.K. is to keep trying to disperse oil slicks until they disappear or until the oil becomes too emulsified to be affected by dispersants. The results of spill modeling in this report suggest that spills of North Slope crude should stay unemulsified for many hours, and even for almost three days for large spills. This strongly suggests that a significant proportion of ANS crude oil spills should be chemically dispersible, if operations are timely and well organized.

Are dispersants or other related chemical products <u>not</u> currently stocked by responders in Prince William Sound and the Gulf of Alaska effective on Alaska North Slope Crude oil in cold PWS/GOA water?
There are other commercially available dispersant products that are as effective or even more effective than Corexit 9527 on ANS oil spills in cold water. One product might be Exxon's new product Corexit 9500. There are other products used in Europe and elsewhere that seem to perform better than Corexit 9527 on certain oils and with certain laboratory tests, but only marginally. Corexit 9527 generally performs well in comparison to other products.

What are the impacts on other recovery techniques on non-dispersed remnant oil?
The evidence suggests that the beneficial effects of dispersant-use are that (1) small droplets of oil are immediately formed in the water column and many of these do not re-surface and (2) the treated surface oil spreads out faster than it normally would, leading in the long-term to faster natural dispersion of the oil. It is likely that after a short period all dispersant leaches from both the dispersed droplets and the remnant surface oil. This is an educated guess; more research is needed in this area.

In any case, there are two major factors to consider when planning a joint operation involving dispersant-use, mechanical recovery and in-situ burning. First, voluminous spills are usually large in area, and different operations can take place on separate portions of the spill without mutual interference. Second, the thick surface oil remaining after a dispersant operation is oil that has resisted treatment because it is viscous, either because it is heavily emulsified or because it was viscous to begin with and the dispersant was not able to penetrate the oil. In either case, one can assured that these viscous products will be amenable to conventional mechanical recovery approaches.

Conclusions and Recommendations

The following are the conclusions and recommendations of the study that relate to dispersant effectiveness and dispersant operations.

Dispersant Effectiveness

Conclusion No. 1: If used properly, the dispersant Corexit 9527 is likely to be reasonably effective on spills of North Slope crude oil in Prince William Sound and the Gulf of Alaska. There is uncertainty, however, about exactly how effective the dispersion process might be under various conditions. At this time, laboratory tests are not able to predict dispersant effectiveness in the field. Even tank tests are of limited value because of their general inability to simulate the medium-term and long-term aspects of the dissipation and dispersion process.

Recommendation No. 1a: Field experiments should be performed to evaluate the effectiveness of dispersants in conditions similar to those that are likely to exist during spills in Prince William Sound and the Gulf of Alaska. It is recommended that these trials take place in Alaska. The scientific and experiential benefits will far outweigh the possible detrimental effects of the spills.

Recommendation No. 1b: Laboratory experiments should be performed to test dispersant effectiveness on North Slope crude. The objective would be to assess the <u>relative</u> effects of a number of variables such as the weathered state of the oil, dispersant-to-oil ratio, dispersant type, temperature, water salinity, and the like. The program need not be large or expensive because there is only one oil of interest. At a future date, if and when quantitative data are developed in field experiments, attempts should be made to correlate the lab results with the field results.

Recommendation No. 1c: The most important factor that determines the effectiveness of a dispersant operation is the so-called "time window" for effective chemical dispersion, which is a function of the oil spill's rate of emulsification. A program should be initiated to study the emulsification of Alaska North Slope crude oil under a number of spill-related conditions. The properties and emulsification potential of ANS crude will change over time, so it is important to check these on a regular basis.

Conclusion No. 2: Corexit 9527 is one of the best dispersant products in the world on a wide range of oils, and the new Corexit 9500 may be even better. As a research exercise, however, it may be challenging to see if it is possible to develop a custom-formulated product for Alaska North Slope crude oil that is even better than the above two existing products. One objective would be to produce a product that has stronger demulsifying properties, thus allowing for a larger time window for dispersant operations. It is generally not profitable or sensible to develop customized dispersants for specific oils because there are literally hundreds of crude oils produced and transported internationally. However, it may make sense in this instance because North Slope crude is of singular importance to Alaska and almost as important to other areas of the western United States that are exposed to tanker traffic of ANS crude.

Dispersant Operations

Conclusions: The oil industry in Alaska have one of the best dispersant-use plans in the U.S., developed over many years, and the government has one of the best set of procedures to expedite dispersant-use decision making. Some deficiencies exist, however, with respect to dispersant spraying tactics and equipment, and programs to monitor dispersant effectiveness in the field.

Recommendation No. 1: Alyeska's dispersant-use plan (and most others in the U.S.) must be changed in all parts that consider the notion that major marine oil spills will spread uniformly, that dispersant dose rates of 5 to 10 gallons per acre are ideal, and that one-pass applications of dispersant by aircraft are adequate. Multi-pass applications on thick portions of spills is now the recommended approach.

Recommendation No. 2: Alyeska's vessel-based dispersant application designs and systems should be re-worked to deal with thicker slicks. Consideration should be given to the use of fire monitors for application of undiluted dispersant.

Recommendation No. 3: Alyeska's dispersant-use plan and the government's plans should include programs for real-time monitoring of dispersant effectiveness in the field. Experience gained in the field experiments should help in this regard.

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Sea Empress Spill: Dispersant Operations, Effectiveness and Effectiveness Monitoring

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Abstract
During the *Sea Empress* spill, monitoring teams were mobilised to measure concentrations of oil as part of the response. As a result, the oil budget and the contamination have been more fully characterised than for most previous spills. Monitoring the natural fate of the oil and the effects of the response has considerable operational benefits, for example in providing real time in-situ information on the effectiveness of the response operations. Monitoring showed that the recovery operation at sea and on the shoreline accounted for 2-5 % of the total oil spilt within the first month following the spill. A further 2-6 % was removed from the shoreline more gradually over a 12 to 18 month period through a combination of response operations and natural removal and degradation. Thus, 90% or more of the oil released onto the sea surface was partitioned into the atmosphere by evaporation and into the water column by dispersion. Natural processes of evaporation and dispersion accounted for half to two-thirds of this partitioning, with the use of dispersants accounting for one-third to a half. The environmental impact of the spill was not as severe as might have been expected considering the large volume of oil spilt and the sensitivity of the local environment, this was due to the offshore winds which forced the oil away from the coastline and the rapid and effective dispersant operation.

Introduction
The South Pembrokeshire region is characterised by a large tidal range (e.g. 7.6 m tide in Milford Haven on 20 February 1996), well mixed coastal waters, strong currents and a region of rapidly changing water flows in the mouth of Milford Haven.

The behaviour of every crude oil type will be different because each has a specific composition. However, in the case of Forties Blend, it was fortunate that a good deal of research had taken place on this crude oil, both in the laboratory and more importantly through controlled experiments at sea. Therefore, the properties of this blend of crude oils were well understood before the spill took place.

This paper firstly draws together the information available on the mass balance for the *Sea Empress* spill. It then assesses the role played by the dispersant response in influencing the mass balance and the efficiency of the dispersant operation. Finally, it considers the fate of the proportions of the oil entering the water column, the sediments and stranding on the shoreline.

Mass Balance for the Forties Blend Crude Oil

It is important to note that even though there was greater monitoring of the response operation during this spill than other previous spills, any budget estimates will be subject to a number of assumptions which will be listed under each section. Around 59,000 tonnes Forties Blend crude oil cargo was transferred to the Texaco refinery once the *Sea Empress* had been brought alongside a jetty in Milford Haven. The oil budget considered here, therefore, refers to the 72,000 tonnes of cargo which was spilt at sea. Initially all the oil spilt floated on the surface of the sea. However, the following processes removed oil from the sea surface over the first month of the spill.

Evaporated - Range 35-45%: Evaporation of the lighter components of crude oil is one of the most important processes that removes oil from the water surface. In addition, it has a profound effect on the way oil behaves, by encouraging the formation of a persistent water-in-oil emulsion. It also reduces the acute (short-timescale) toxicity of the oil remaining on the sea surface since the most toxic components have been lost to the atmosphere. The volume of oil evaporated is calculated by examining the composition of the oil remaining on the sea surface. Due to the rough sea conditions and the emphasis on measurements of dispersed oil concentrations, only 8 surface emulsion samples were taken during the early stages of the *Sea Empress* spill. These samples were from oil which had been on the sea surface for between 9 and 37 hours, and showed that between 35% and 45% of the volume of the oil had evaporated (Table 1).

Table 1. The volume percent that had been lost through evaporation in the samples collected during the *Sea Empress* incident

Date	Time at which samples were collected (GMT)	Estimated time on the sea surface (hrs)	% Evaporative Loss
16/02/96	10:15	13	**41**
17/02/96	13:08	37	**45**
17/02/96	13:10	37	**45**
17/02/96	13:18	37	**45**
21/02/96	10:30	9	**35**
21/02/96	13:20	12	**37**
21/02/96	14:58	14	**36**
22/02/96	15:27	27	**40**

Figure 1 shows the rate of evaporation from the *Sea Empress* samples superimposed on the more intensively sampled slicks from previous field trials with Forties Blend crude oil. The figure shows that the samples correlate well with previously observed data for Forties Blend crude oil and allows extrapolation of the data for the first 37 hours after each pulse of oil is released. This fraction of 35-45% evaporated is higher than many other incidents (20% evaporation at the *Braer* and *Exxon*

Figure 1. Rate of evaporation of Forties Blend crude at the *Sea Empress* incident

Valdez incidents where Gullfaks and Alaskan North Slope crude oils were spilt) and reflects the fact that the Forties Blend crude oil contains a larger proportion of volatile components and is not due to the different response techniques used.

Oil recovered at sea - Range 0.5-1.5%: The intensive time period for response at sea was the first two weeks, and by the end of February 1996 the operations at sea had been gradually wound down. Texaco reported that approximately 7,260 tonnes of liquid waste was removed at sea by skimming operations and transferred to the Texaco refinery. At sea recovery normally results in the removal of a large volume of water in addition to the oil. For example, on the 23 February during the transfer of 192 tonnes of oil/water recovered by the Sefton Supporter to the Forth Explorer, the recovered material was described as 85% water. Using a value of 10-20% oil in the liquid waste recovered at sea gives 730-1450 tonnes of oil (1-2% of the total oil spilt).

Oil stranding on the shoreline - Range 5-7%: The estimate of oil stranding on the shoreline is based on the two Countryside Council for Wales (CCW) shoreline surveys which categorized the levels of oiling into "heavy", "moderate", "light" and clear of oil. This was then converted into estimates of quantities of oil stranding using the oil loadings calculated from the Joint Response Center (JRC) data (Sommerville et al. 1998) for the heavily oiled beaches (38-55 tonnes/km) and extrapolating from these values to the oil loadings for moderate (0.38-0.54 tonnes/km) and lightly oiled (0.0038-0.0054 tonnes / km) beaches using the relative oil loadings between heavy, moderate and lightly oiled beaches from the literature (ITOPF, 1983).

The estimates for the initial volume of oil stranding (based on CCW survey 23 February - 9 March) were for 98 km of heavily oiled shoreline (3,724 - 5,390 tonnes of oil), 34 km of moderately oiled shoreline (13-18 tonnes oil), and 66 km of lightly oiled shoreline (0.2-0.4 tonnes oil). This provides the best estimate of the volume of oil stranding on the south Wales coastline as 5-7% (3,750 - 5,400 tonnes of oil, Sommerville et al. 1998).

Oil recovered from the shoreline - Range 1-3%: Of the 3,750 - 5,400 tonnes of oil which initially stranded on the shoreline a total of 1,000 - 2,400 tonnes was recovered. The removal of the bulk, free oil from the shoreline was virtually complete by the middle of March some 4 weeks after the grounding of the *Sea Empress*. The volume of oil recovered represents 1-3 % of the total oil spilt and 19-64% of the oil stranding on the shoreline. The oil recovered from the shoreline was composed of:

- Liquid waste 600 - 1500 tonnes
- Solid waste 380 - 880 tonnes

Dispersed oil - Range 46-59%: Fluorometry measurements at sea showed that dispersion was significant in determining the fate of the spilt oil (Lunel et al. 1995; Lunel et al. 1997). However, the rapid dilution of the dispersed oil together with the large volumes over which the oil is distributed means that it is not possible to accurately quantify the dispersed oil budget. Subtracting the volume evaporated, the volume recovered at sea, and the volume stranded on the shoreline from the total budget gives a value of 46-59% of the oil having dispersed through a combination of natural and enhanced dispersion.

Role of the Dispersant Response in Determining the Oil Mass Balance

Response operations have only a secondary level of influence on the fate of an oil spill. This is illustrated by the fact that the oil recovery operation at sea and the recovery operation from the shoreline together accounted for less than 5 % of the total oil spilt. However, if response methods are used to reinforce the naturally occurring fate processes then they can be used to minimise the impact of a spill. In the *Sea Empress* the natural dispersion process was enhanced through the use of dispersants.

Summary of the Dispersant Operation at Sea

The bulk of the 72,000 tonnes of Forties Blend crude oil was released in pulses over a 4 day period from 20:00 17 February to 14:00 21 February. During this period some 442 tonnes of approved dispersant were used. The tactics for applying dispersant is for the remote sensing planes to direct the spray aircraft to the areas of thickest oil and for the spray aircraft to repeatedly pass over the region until the surface oil has been dispersed. A notable feature of the spray response was the highly effective targeting achieved by this technique. This operation allowed the DC3 aircraft to target effectively ribbons of oil as narrow as 10-20 m.

Monitoring the Dispersant Operation

Under the right light conditions, an effective application of dispersant to fresh oil can provide visual evidence of the enhanced rate of dispersion in the form of a plume of dispersed oil droplets in the water column. Under ideal conditions this can be seen by aerial surveillance. However, it has been shown under controlled field experiments that the absence of this visible plume of oil is not evidence that the dispersant is not effective. As reported elsewhere (Lunel 1994; Lunel et al. 1995) and incorporated into the IMO/UNEP guidelines on oil spill dispersant application (IMO, 1995), field experiments have shown that enhanced oil concentrations can occur in the water column following dispersant use, without the appearance of plumes.

The *Sea Empress* spill was the first major spill where boat-mounted monitoring was coordinated with aerial dispersant application in order to provide real time information on the effectiveness of dispersants (Lunel et al.; 1995, Lunel et al. 1996). This monitoring was important in providing evidence to support the aerial surveillance observations that the dispersant operation was indeed being effective.

During natural dispersion maximum concentrations of total hydrocarbons under the fresh crude oil were around 5 ppm in the top 1 m of the water column and typically less than 1 ppm at a depth of 4 m, indicating a relatively low transfer of oil into the water column. The levels measured at the incident were consistent with dispersed oil concentrations measured in field trials with Forties Blend crude oil (Lunel et al. 1995; Lunel & Davies 1996) during which natural dispersion of 6 3 % of the crude oil occurred in the first 30 minutes after release. The distribution of dispersed oil was also very patchy, resulting from individual waves taking droplets of oil into the water column. Once the oil had emulsified and moved to the south the high viscosity of the surface emulsion meant that the rate of natural dispersion became insignificant.

Following dispersant use, maximum oil concentrations were around 10 ppm, with dispersed oil extending down to 4 m, indicating a significantly increased transfer of oil from the surface into the water column. The concentration and distribution of dispersed oil was consistent with controlled field trials with Forties Blend crude oil which showed that over the first 30 minutes after treatment 22 6 % of the surface oil was dispersed (Lunel et al. 1995; Lunel & Davies 1996). The use of dispersants on the patches of emulsion to the south reduced the viscosity of the emulsion and resulted in dispersed oil concentrations of 2 ppm or more throughout the top 4 m of the water column (Figure 2). The levels measured at the *Sea Empress* were much higher than the dispersed oil concentrations under the untreated experimental control slicks which persisted on the sea surface (Lunel & Lewis 1993; Walker et al. 1995; Walker & Lunel 1995).

Effectiveness of the Dispersant Operation

Intensive monitoring allowed an estimate to be made of the split between natural and enhanced dispersion by comparing the concentrations of dispersed oil at the incident with those in controlled field trials (Lunel & Lewis 1993; Walker et al. 1995; Walker & Lunel 1995; Lunel et al. 1995; Lunel & Davies 1996). In those field trials relatively small volumes of oil (20 tonnes) were shown to persist for 5 days or more under similar conditions weather conditions so that there is little doubt that dispersants played a major role in reducing the persistence of the surface slick.

Figure 2. Oil Concentrations measured at two depths illustrating the increased transfer of oil into the water column following the use of dispersants.

Since dispersants enhance the rate of a process that will take place even in the absence of dispersants it is necessary to measure the <u>increase</u> in the amount of oil dispersing. To do this monitoring teams need to compare the amount dispersing under oil that has been treated with dispersant to that under oil which has not been treated. In a real incident it is not possible to leave an area untreated in case it impacts on sensitive resources. However, under the controlled conditions of a field trial it is possible to monitor a slick of Forties Blend crude oil which had been treated with dispersant alongside a slick which was left to disperse naturally. Previous trials under similar wind conditions (14-20 knots) to those experienced at the *Sea Empress* gave the following results for the <u>first 30 minutes</u> after treatment with dispersant (Lunel et al. 1995; Lunel & Davies 1996):

Total dispersion following dispersant application: 22 (6%)
Natural dispersion in a control experiment: 6% (3%)
Enhanced dispersion: 16% (9 %)

The oil concentrations measured at the *Sea Empress* were consistent with the concentrations measured during these sea trials. Although the rates of natural and chemically enhanced dispersion are greatest in the first 30 minutes after release, both processes proceed at a slower rate over a period of hours and days. It is reasonable to assume that the ratio between natural and enhanced dispersion should hold since the dispersant was shown to break the emulsion and result in enhanced dispersion over a period of several hours. The dispersant is gradually lost from the oil over time to become less effective but over the same time period any untreated oil would rapidly emulsify resulting in an similar reduction in the rate of the natural dispersion process.

In the overall mass balance it was estimated that 46-59 % of the oil dispersed. This represents the total dispersion following treatment with dispersant over a timescale of days rather than 30 minutes. Since the measured dispersed oil concentrations at the *Sea Empress* were consistent with those in the field trials, the best estimate of the split between natural and enhanced dispersion comes from extrapolating from the quantitative data collected during the first 30 minutes of the dispersion process. This implies that the total dispersion of 46-59 % is composed of:

Natural dispersion: 7-21 %
Enhanced dispersion: 24-52 %

The range of 7-21% dispersion due to the natural dispersion process alone is consistent with earlier field trial experience. It is also consistent with the predictions for the natural dispersion of Forties Blend crude oil using the field validated mathematical model OSIS which was used during the response to the *Sea Empress* incident (Lunel et al. 1995).

On the basis of these estimates, the dispersant operation increased the amount of oil dispersed by at least 17,000 tonnes, with a mean value of 27,000 tonnes. Since 446 tonnes of dispersant were used, each tonne of dispersant resulted in an extra 60 tonnes of oil being dispersed (with a range of 38-82 tonnes per tonne of dispersant).

The estimate that each tonne of dispersant dispersed 60 tonnes of oil reflects a higher ratio than the 1 : 20 ratio which is typically used in oil spill response and planning. However, the 1 : 20 ratio has been in the literature since the 1970's and is used in laboratory testing of dispersants to ensure there is an excess of dispersant to produce a successful dispersion. In the absence of data from real spill incidents this has been adopted as the working basis for planning an oil spill response. The results from the monitoring at the *Sea Empress* has shown that a more favourable ratio between the volume of dispersant applied and the volume of oil dispersed is possible. This has been confirmed with laboratory testing and field work recently carried out on Forties Blend which indicates that the weathered oil can be effectively dispersed at ratios of 1:200 and 1:400 (Lewis & Lunel, *in preparation*).

This high level of effectiveness recorded at the *Sea Empress* is a reflection of a number of factors:

Optimal wind speeds for enhancing the rate of natural dispersion (15-30 knots).
Forties Blend crude oil has been shown to be dispersible both in laboratory and field tests.
The pulsed release over a 4 day period meant that response could be targeted to relatively fresh crude oil for much of the dispersant operation.
Accurate targeting of the surface oil by the spray aircraft with the help of the remote sensing aircraft and surface monitoring teams.

The use of dispersants to enhance the natural dispersion process will not always be the most appropriate action to an oil spill, nor will it always be as efficient as it was at the *Sea Empress* incident. However, for this incident the value of having a dispersant operation in place as a first response in the UK National Contingency Plan was clearly demonstrated.

Summary of Oil Budget

The oil budget was clearly not fixed for the entire duration of the spill as it is a time dependant variable. Three time frames are considered:

- Pre response: The first few hours of the spill where the process of evaporation dominates.

- Post response at sea: At the end of February 1996, two weeks after the *Sea Empress* went aground, only sheens remained at sea and the response at sea had been scaled down.

- Post primary shoreline response: By the middle of March 1996 the majority of the bulk oil had been removed from the beaches.

A summary of the mass balance at these four times is presented in Figure 3. Table 2 gives the changes in oil budget for the first month following the spill.

Figure 3. Mass balance budgets for the crude oil

Table 2 Changes in the oil budget (%) during the first month following the spill

	Pre response (first few hours)	Post response at sea	Post primary shoreline response
Evaporation	35 - 45	35 - 45	35 - 45
Sea surface	51 -63	<1	
Naturally Dispersed	2 - 4	7 - 21	7 - 21
Chemically Dispersed		24 - 52	24 - 52
Recovered at sea	1 - 2	1 - 2	
Stranded on shoreline		5 - 7	2 - 6
Recovered from shoreline		1 - 3	

Mass Balance for the Heavy Fuel Oil

Since the volume of Heavy Fuel Oil (HFO) spilt at the *Sea Empress* was less than 1% of the total oil spilt there is relatively little information documenting its fate compared to the fate of the Forties Blend crude oil. It is believed that the 230 tonnes of HFO released at the mouth of the Haven between 15-22 February (which was mixed in with the Forties Blend crude oil at an average of 0.3% of the volume) would have formed a small component of the crude oil mass balance. In addition, 250 tonnes of HFO was released inside the Haven on 22 February in the absence of Forties Blend crude oil. It is estimated, on the basis of previous experience of spills involving HFO, that 90-95% stranded on the shoreline of Milford Haven (largely the beaches on the southern side of the Haven) where a significant proportion remained a year after stranding.

Oil Budget Compared to Other Spills

The aim of this section is to illustrate a range of possible oil budgets for oil spills by comparing the mass balance from the *Sea Empress* with two recent spills which represent two extremes for the fate of crude oil spills

Table 3. The crude oil mass balance for the *Sea Empress*, the *Braer* and the *Exxon Valdez* spills after the first stage response at sea and on the shoreline.

Oil Fate	*Exxon Valdez* 1989 (%)	*Braer* 1993 (%)	*Sea Empress* 1996 (%)
Recovered at sea	4-8	0	1-2
Recovered from the shoreline	7-15	0	1-3
Evaporated, diluted and	20-30	20-25	35-45
Dispersed, diluted and degraded	20-25	75-80	46-59
Stranded on shoreline	22-51	0	5-7

The difficulties of access in Alaska meant that the role of at sea response in influencing the oil fate was fairly limited. Thus, somewhere between a quarter and a half of the oil spilt stranded on the shoreline and resulted in a significant environmental impact (Wolfe et al. 1993, Galt 1991, Miller 1990, Maki 1991).

At the *Braer* spill, the fate of the oil was determined entirely by natural process with the entire crude oil cargo evaporating and dispersing and no oil stranding on the shoreline. The studies following the *Braer* spill concluded that overall there was no significant impact on the Shetlands environment (ESGOSS, 1994).

Although the weather conditions at the *Sea Empress* were similar to those at the *Exxon Valdez* (significantly less severe than at the *Braer* incident), Table 3 shows that the crude oil mass balance was in fact closer to that observed at the *Braer* incident than that for the *Exxon Valdez*. In contrast to the *Exxon Valdez* where a significant proportion of the oil stranded on the shoreline and resulted in a significant environmental impact, at both the *Braer* and the *Sea Empress* evaporation and dispersion prevented most of the oil coming ashore and minimised the associated environmental impacts. The mechanisms by which the hydrocarbon input to the atmosphere and the marine environment are degraded are discussed in the following sections.

Fate of Oil on the Sea Surface

The oil was released from the *Sea Empress* in pulses over 3-4 hour periods at each low water. At each low water oil was forced out of the damaged tanker. The Table below shows estimates of the times of the main oil releases from the *Sea Empress* which coincided with times for low tide. The bulk of the 72,000 tonnes of Forties Blend crude oil was released over the 4 day period from 20:00 17 February to 18:00 21 February. It is clearly very difficult to provide accurate estimates of the volumes of oil released, therefore, these figures should only be used for indicative purposes.

Despite the fact that around 40% of the volume of the oil (which contained the most toxic compounds) evaporated over the first few hours of each pulsed release, the oil remaining on the sea surface still posed a significant pollution threat. As a result of water becoming physically incorporated into the crude oil, the volume of pollutant on the sea surface increased to 3-4 times its original volume. Therefore, even though evaporation removes 40% of the oil, the remaining 60% can be emulsified up to a volume double that originally spilt. The persistence of the remaining oil depends on both the wind conditions and the tendency of the oil to form water-in-oil emulsions. Samples of the surface oil showed that under the 15-30 knot winds the Forties Blend crude oil was forming viscous emulsions (3,000-13,000 cP @ 10s-1) within 6-12 hours of being released from the *Sea Empress* and would therefore potentially persist at sea for days to weeks.

It is essential for a response operation aimed at reducing the volume of oil on the sea surface to predict and track the movement and properties of the surface oil. In response to the grounding of the *Sea Empress* at the mouth of Milford Haven, MPCU activated the UK National Contingency Plan and immediately deployed surveillance aircraft to fly over the vessel. Predictions of where the major

Table 4 Estimate of the main releases of crude oil from the *Sea Empress*.

Date (February 1996)	Time (GMT)	Estimate of oil released (tonnes)	Wind speed (knots)	Wind direction
15	20:00 - 22:00	2,000	16	290
16			16	270
17	20:00 - 23:00	5,000	26	250
18	10:00 - 13:00	2,000	31	290
18	21:00 - 24:00	5,000	28	20
19	10:00 - 13:00	8,000	28	15
19	22:00 - 01:00	20,000	19	10
20	10:00 - 13:00	15,000	26	30
21	00:00 - 02:00	10,000	21	30
21	11:00 - 14:00	5,000	13	350
TOTAL		72,000		

areas of oil contamination were to move and the likely weathering state of the oil were provided by the oil spill model OSIS. The initial prediction was that with the westerly winds the oil would be driven ashore between the mouth of the Haven and Linney Head . This prediction was confirmed by remote sensing over-flights at 03:45 and 07:00 on 16 February which showed that the oil had come ashore at Linney Head and Angle Bay.

A distribution of surface oil close to the coastline was typical while the westerly winds persisted. Had the wind remained from the west during the main period when oil was released, the short time between release and stranding of the oil and the close proximity of the surface oil to the shore would have meant that little response at sea would have been possible. The bulk of the emulsified oil would have been stranded on the shoreline in the vicinity of Milford Haven. However, on the evening of the 18 February, when the wind veered to Northerlies most of the oil spilt was driven out into open water to the south where response to the oil was possible. From the morning of the 23rd February the winds backed to south westerlies and the remaining surface oil was pushed onto the beaches of Carmarthen Bay.

To summarise, the fact that the wind was from the north during the main period where oil was released from the *Sea Empress* was critical in driving the oil out to sea and allowing time to mount a response at sea. Unfortunately, the switch in wind direction to south-westerly from the morning of 23 February meant that most of the oil remaining out at sea at this stage was driven onto the beaches in the western half of Carmarthen Bay. It is estimated that 70% of the emulsion stranding on the shoreline occurred between Tenby and Pendine.

Fate of Oil in the Water Column

Initial Concentrations of Dispersed Oil and Dilution Over Time in Offshore Waters
Through the action of waves and the turbulence of the surface waters oil is dispersed into the water as small oil droplets typically of a diameter between 1-70 m. As described earlier, the initial monitoring of oil concentrations in the water column was carried out with the purpose of determining the efficiency of the dispersant operation at enhancing the rate of the natural dispersion process (Lunel et al. 1995; Lunel et al. 1997). However, it is also important to measure the rate and extent of dilution of the dispersed oil concentrations following natural and enhanced dispersion (Lunel et al. 1995; Lunel et al. 1997). Three organisations have been involved in the monitoring of the dilution of the dispersed oil concentrations, the National Environmental Technology Centre of AEA Technology (NETCEN), The Centre for Environment Fisheries & Aquaculture Science (CEFAS, formerly MAFF Fisheries Laboratory) and the Environment Agency (EA). The fact that there was consistency between the results of these independent organisations gives a high level of confidence in the results obtained.

The hazard posed by a pollution event is a combination of the toxicity arising from the concentration of the pollutant and the length of exposure to the elevated concentrations. The potential for environmental damage is in the possible generation of oil concentrations in the water column which:

are acutely toxic
cause long-term tainting of commercially important fish and shellfish

A literature survey carried out by SEEEC (SEEEC project P4) found that total hydrocarbon concentrations in the range from 0.001 to 0.010 ppm is considered as the benchmark for most areas, with concentrations of higher than 0.003 ppm only reported in inshore waters. Within Milford Haven concentrations were found to vary between 0.005-0.053 ppm in the jetty area and Pembroke river, which compares to areas such as Southampton Water where concentrations in the range 0.09-1.9 ppm have been measured.

There is much debate on the threshold of oil concentration where toxic effects are likely to be observed. The two major issues being firstly, that different components of the oil have very different toxic effects (the light aromatic compounds such as benzene and xylenes having the greatest effect), secondly, different species and life stages have a wide range of tolerances to dispersed oil. The available acute (short-timescale) toxicological data support the conclusion that, at water column concentrations of dispersed oil at or below 10 ppm total hydrocarbons for 2-4 hour exposure duration, adverse ecological effects are not expected (SEA 1995).

During the dispersant operation at the *Sea Empress* dispersed oil concentrations only locally exceeded 10 ppm for short periods of time (Figure 2). Dispersant was not applied to enhance the dispersion process inside the Haven because the rate of dilution of the dispersed oil would have been significantly slower than is the case out at sea. Total hydrocarbon concentrations were at 1 ppm or less in the zone where dispersants were not applied and greater than 1 ppm (to a depth of 5 m) in the zone of chemical dispersion. It is clear that the dispersant operation enhanced the oil concentrations measured in the water column. However, these elevated concentrations did not approach the threshold level of 10 ppm oil concentrations maintained for a period of 2-4 hours. Therefore, in terms of acute (immediate) toxic effect, the dispersed oil concentrations generated by the initial natural dispersion and the dispersant operation were below the threshold limits.

In addition, the dispersed oil concentrations diluted rapidly over a period of days and weeks (Lunel et al. 1995; Lunel et al. 1997): rapid dilution to concentrations less than 1 ppm 2-3 days was measured after the end of the dispersant operation. By the end of March concentrations had diluted to less than 0.1 ppm over most of the affected area with a few local "hot-spots" up to 0.5 ppm. By June 1996 oil concentrations in the water column had returned to background levels (0.001-0.010 ppm) for the area.

Composition of the Dispersed Oil and Degradation Over Time

The toxicity of oil dispersed into the water column depends of the composition of the oil. The lighter components of the oil evaporate within the first few hours after the crude oil is spilt. The most acutely toxic components to the marine environment (the benzene, toluene, ethylbenzene and xylenes - BTEX fraction) are lost from the oil on the sea surface almost immediately. Dispersant application was prohibited within the first km of the coast and this allowed the BTEX fraction to evaporate prior to chemical dispersion. By contrast, the natural dispersion of the oil as soon as it was released from the tanker did introduce toxic BTEX components into the water column in the immediate vicinity of the grounding site at St Anne's Head.

Once in the water column as dispersed droplets of oil, biodegradation by naturally occurring marine bacteria also has a significant effect on the composition of the oil. The straight chain hydrocarbons (n-alkanes and paraffins) and the lower molecular weight aromatics (e.g. naphthalenes and phenanthrenes) which remain in the oil after evaporation are biodegraded over a period of weeks to months. The by-products of this biodegradation process are carbon dioxide and water and the remaining non-biodegradable components (approximately 5% of the Forties Blend crude oil and around 40% in the case of Heavy Fuel Oil).

By the time the dispersed oil had reached the near-shore waters in Carmarthen Bay it was biodegraded relative to the oil that was stranded on the shoreline (Lunel et al. 1996; Lee et al. 1997a, 1997b). Comparing the oil composition on the shoreline at Amroth and in the near shore waters at Amroth showed that the low molecular weight hydrocarbons have been lost preferentially relative to the high molecular weight compounds. In addition, the ratio between the biodegradable compounds and the non-biodegradable markers (C17/pristane and C18 /phytane) was lower in the oil samples from near shore waters, a clear indication that biodegradation has taken place.

Laboratory work simulating marine conditions of dispersed oil in offshore locations has also shown an enhanced rate of biodegradation of oil when dispersants are used to stimulate the natural dispersion process (Swannell et al. 1997). This indicates that the critical step in the degradation of oil is the formation of dispersed oil droplets in the water column whether this is by natural or chemically enhanced dispersion. This suggests that the observed increase in the rate of oil degradation after dispersants are used is a result of the increase in the surface area available for colonisation by marine bacteria when the fraction of oil dispersed is enhanced by the use of dispersants. Thus, the dispersed oil is not only diluted over time but also biodegraded in the water column so that by June 1996 oil concentrations in the water had returned to background levels.

Fate of Oil in Sediments

Dispersed oil in the water column is buoyant and will have a tendency to rise back to the surface in the absence of the mixing processes which keep the small 1-70 m droplets suspended in the water column. Dispersed oil will not sink unless it becomes associated with suspended sediment. In most spills association of dispersed oil with sediment is not a major transport pathway for the oil. However, the severe storm conditions at the *Braer* oil spill in January 1993 meant that the resuspended sediment load in the coastal waters off Shetland was particularly high at the time of the spill. The post spill monitoring found two major areas where oil contaminated fine sediments had settled out into sedimentary basins. The sampling indicated that up to 30% of the oil spilt ended up in these deep water sediment sinks.

With that experience in mind a considerable effort was spent by SEEEC in assessing the potential areas where oiled sediment might have accumulated. The first stage was to identify potential sites for sedimentation through both modelling and a review of the characteristics of the sea bed in the region to identify areas of high mud content where sediment associated oil might have accumulated. The areas identified by both modelling and a literature review of potential sediment transport paths were:

Inner and outer Carmarthen Bay
15 km south of St. Govan's Head

Additional areas identified by the literature review were:

Inner St. Bride's Bay
Inner Cardigan Bay
Wexford Harbour, Bideford, and Newport Bay
Celtic Deep

Since the residence time of oil in sediments is on the timescale of months to years the presence of oil in the sediment cannot necessarily be linked to the *Sea Empress* spill. The background concentrations in the sediments in these coastal waters varies between approximately 10-100 ppm depending on sediment type (the fine silt sediments having the higher background values). An extensive field survey of the sedimentary regions which included the areas listed above (except Wexford Harbour, Bideford, and Newport Bay) was then carried out by CEFAS (formerly MAFF). Overall, the survey did not reveal any significant accumulations of oil in the sediment (Figure 4). The survey carried out in February 1996 covered an area of 1500 square kilometres and the range in sediment total hydrocarbon concentrations was 0.5-183 ppm with an average of 40 ppm. The concentrations were largely within the range of concentrations typically found in the area. While some of the samples showed a clear signature from the Forties Blend cargo, for example West Angle

Bay, for many of the samples analysed the oil was not derived from the *Sea Empress* spill, for example St Bride's Bay and Swansea Bay.

Figure 4. Oil concentrations measured by CEFAS in sediment samples affected by the *Sea Empress* spill

In order to provide a comprehensive survey of potential sites for oil sedimentation, SEEEC requested CEFAS to widen its survey area to cover nearly 9000 square kilometres in a survey carried out in May to June 1996. This surveyed showed an even lower average total hydrocarbon concentration (22 ppm) in the sediments sampled. Therefore, beyond reasonable doubt, unlike at the *Braer* incident, there was no significant deposit of oiled sediment material.

While the survey confirmed that there was no large sink of oil to the sediments it did reveal one localised area of very high total hydrocarbon concentrations (with the highest concentration measured being 2,670 ppm) in the near shore sediments of Skrinkle Haven. It was also clear from the gas chromatogram that the oil was Forties Blend crude oil. It is thought that this localised area of high concentrations resulted from the difficult access to Skrinkle Haven which meant that clean up teams could not remove the emulsion that initially came ashore before it became buried by sand. Later re-working of this buried oil by the action of the sea could explain the localised high concentrations.

Conclusions

When oil is spilt at sea there will be effects on the environment. At the *Sea Empress* spill, as at any other major oil spill, these environmental effects have been observed. However, the environmental impact could have been much greater considering both the volume of oil spilt, twice the volume spilt at the *Exxon Valdez*, and the sensitivity of one of Britain's most important marine and coastal habitats. The fact that the impact was not as great as first feared is a result of generally favourable environmental conditions (for example, blowing the oil offshore to allow response at sea) and a successful response that was aimed at working with these natural fate processes rather than against them.

The aim of response at sea is to minimise the volume of oil stranding on the shoreline while at the same time ensuring there is no significant increase in the effects on the marine environment. Enhancing the dispersion of oil into the water may be an appropriate strategy if predictions and monitoring show that sensitive resources are threatened by an oil spill despite a combination of mechanical recovery at sea and the natural processes of evaporation and dispersion. Following the *Braer* incident the strategy of the use of dispersants in the UK was reviewed by the Ministry of Fisheries and Food (MAFF 1996, Lunel *et al.* 1994). This review concluded that under the sea conditions typical of those found in UK coastal waters it was appropriate for the UK to maintain dispersants as the primary method of response to oil spills.

As a result of the grounding of the *Sea Empress*, 72,000 tonnes of Forties Blend oil was released into the environment making this incident among the 20 largest oil spills of all time. With 35-45% evaporating and 7-21% dispersing naturally the potential was for 24,000-41,000 tonnes of oil to come ashore. Since Forties Blend oil rapidly emulsifies to produce a 70% water-in-oil emulsion this could have translated into 80,000-140,000 tonnes of emulsion stranding on the South Wales coastline.

The net environmental benefit of the response was therefore:

- A highly effective dispersant response resulted in enhanced dispersion accounting for 24-52% of the total oil spilt.
- The favourable wind speed and direction, the oil type, the release characteristics and the accurate application of dispersant combined to provide a very efficient dispersant response with each tonne of dispersant resulting in the dispersion of 38 to 82 tonnes of oil.
- The dispersed oil did not result in a long-term contamination of the commercial fisheries in the area.
- Enhancing the natural dispersion process does not appear to have resulted in a measurable increase in the environmental effects of the dispersed oil.
- The dispersed oil did not result in a significant accumulation of oil from the *Sea Empress* in sediments.
- Reducing the volume of oil on the sea surface acted to minimise the impacts on sea birds and sea mammals.
- In the absence of a response at sea 80,000-140,000 tonnes of emulsion could have stranded on the shoreline. This was reduced to 11,000-16,000 tonnes through the response at sea

(Sommerville et al. 1998). This minimised the impact to the intertidal zone and enabled the efficient shoreline response to recover and remove the emulsion before it could remobilise and oil other areas.

The *Sea Empress* is the oil spill where monitoring teams were mobilised at the same time as the response to the spill. As a result, the oil budget and the potential sources of oil contamination have been more fully characterised than for any previous spill. The benefits derived from the monitoring carried out at the *Sea Empress* spill means that monitoring the natural fate of the oil and the effects of response actions on the fate of the oil should be essential parts of local and national oil spill contingency plans.

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Biographical Sketch of the Author. Dr Tim Lunel has been the Principal Consultant with the Marine and Freshwater Department, National Environmental Technology Centre in the U.K since 1994, where he is the leader of a team specialising in oil and chemical pollution at sea. He received his PhD in Oceanography from Cambridge University in 1990 and worked with the Warren Spring Laboratory from 1990 until 1994. His oil spill experience includes: *Sea Empress* (1996); Pionersk (1994); and *Braer* (1993). His earlier work included: studies of oil dispersion; a review dispersant use in the UK; and most recently he served as leader of a consortium of research laboratories from France (CEDRE), Norway (IKU), USA (Exxon and Battelle) and Canada (Environment Canada) to develop an internationally accepted laboratory test of dispersant efficiency. In addition, Dr. Lunel received his MBA from the London Business School in 1995.

The AEA '97 North Sea Field Trials on Oil Weathering and Aerial Application of Dispersants

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Abstract
This paper describes the AEA Technology 1997 (AEA'97) field trial that investigated the 'weathering' of crude oils and the effectiveness of oil spill dispersants on emulsified crude oils and a residual fuel oil. Four experimental oil slicks, two of 50m^3 (approximately 300 barrels) of Forties Blend crude oil, one of 30m^3 (approximately 200 barrels) of Alaska North Slope crude oil and one of 20m^3 (approximately 130 barrels) of IFO-180 fuel oil were released onto the sea surface. Surface sampling, sub-surface oil concentration monitoring and airborne remote sensing were used to study the changes in oil properties and behaviour caused by oil weathering.

After two days at sea, each of the two Forties Blend crude oil slicks were treated with two different oil spill dispersants, Corexit 9500 and Dasic Slickgone NS. The dispersants were sprayed from a DC-3 aircraft. Surface sampling, sub-surface oil concentration monitoring and airborne remote sensing were used to study the effects of dispersant application. The single slick of Alaska North Slope crude oil was allowed to weather for 55 hours and was then sprayed with Corexit 9500 oil spill dispersant from a DC-3 aircraft. The same techniques were used to study oil weathering and the effect of dispersant application. The IFO-180 fuel oil slick was sprayed three times with dispersant; after four hours, 23 hours and 25 hours on the sea surface.

Both of the emulsified crude oils were rapidly dispersed after spraying with Corexit 9500 and Dasic Slickgone NS dispersants. The IFO-180 fuel oil was partially dispersed by spraying with only 600 litres of Corexit 9500 after it had been on the sea for 4 hours. However, operational problems prevented further application of dispersant. When further dispersant application was possible the following day, it was only slightly effective due to a significant increase in viscosity caused by evaporation and emulsification. Subsequent treatment with much more dispersant did not produce any appreciable further effect.

Introduction
The primary purpose of the majority of experiments conducted during the AEA Technology 1997 field trial was to answer the two major questions that remain regarding dispersant effectiveness:

1. The degree to which multiple applications of oil spill dispersants can break and subsequently disperse the relatively high viscosity emulsions formed by crude oils that have weathered on the sea surface for several days.

2. The degree to which residual fuel oils can be chemically dispersed.

The AEA'97 field trial was planned to consist of a series of four major experiments. Three of these experiments were designed to determine the period of time during which dispersant use is a viable response option to spills of oils of different characteristics. The fourth experiment was concerned with the calibration of thermal Infra-Red (IR) remote sensing and is not reported in this paper.

Two crude oils (Forties Blend crude oil and Alaska North Slope crude oil) and a residual fuel oil (Intermediate Fuel Oil, IFO-180) were used in the weathering and aerial application of dispersant experiments. The two crude oils that were used were selected to represent a range of weathering behaviour. Both crude oils had been spilled in large volumes at actual oil spill incidents; Alaska North Slope crude oil was spilled at the *Exxon Valdez* incident and 72,000 tonnes of Forties blend crude oil was spilled at the *Sea Empress* incident (Harris, 1997).

Forties Blend crude oil from the UK sector of the North Sea is a paraffinic crude oil and is known to form a relatively low viscosity, low stability emulsion when it weathers on the sea surface. Alaska North Slope crude oil has a higher asphaltene content and is capable of forming a higher viscosity, higher stability emulsion. IFO-180 marine residual fuel oil was also used, being representative of the fuel oil used in many ships.

Both of the crude oils were to be allowed to 'weather' (principally lose the most volatile components by evaporation and incorporate water to form emulsions) to a point that was thought to be approaching the limit of when dispersants are fully effective. Dispersant was then to be sprayed from DC-3 aircraft and the effects monitored by a variety of techniques.

The Field Trial Experiments

The field trial experiments were carried out during the 17th to 23rd of September 1997 in a specially designated area of the North Sea off of the eastern coast of the UK. The area was chosen after consultation with the relevant UK authorities and environmental groups within the UK to ensure that the oil spill would present a minimal risk to the environment. The discharge of oil required a licence from the UK Ministry of Agriculture, Fisheries and Food (MAFF). The area is far from fishing grounds, away from sensitive coasts and there is a very low amount of sea bird activity in September.

Weather and Sea Conditions

The weather during the field trial period was very mild, with a high pressure area producing settled weather for nearly two weeks. A meteorological buoy was deployed to record the relevant weather and sea state data. The temperatures were atypically high for the time of year; air temperatures of 14ºC to 17ºC and a sea temperature of 18ºC. The wind was generally from the north-east with average wind speeds ranging from a light breeze of 4 to 6 m/s (approximately 8 to 12 knots), gusting to 8 - 9 m/s (16 - 18 knots). The sea state was calm with large wavelets and occasional breaking waves on most occasions and fairly frequent 'white horses' when the wind speed increased.

Personnel and Equipment.
Conducting a major sea trial requires a considerable amount of personnel and equipment. Fourteen scientific personnel from AEA Technology, together with scientists and observers from Alaska Department of Environmental Conservation (ADEC), Exxon, International Tanker Owners Pollution Federation (ITOPF), Marine Pollution Control Unit (MPCU), SINTEF Miljø (Norway) and Steptech Ltd were involved with the operations from the ships.There were several scientific staff involved with air operations, in addition to the flight crews of the numerous aircraft.

Ships and Boats
Two large vessels and several smaller boats were required to conduct the sea trial.

<u>*MV Seaspring.*</u> *MV Seaspring* was chartered by MPCU from Briggs Marine. *MV Seaspring* is a specialised oil pollution vessel with a wide variety of oil spill response equipment including booms and skimmers. *Seaspring* was the major research ship on this sea trial and provided accommodation for the majority of the scientific personnel and observers.

<u>*MV Onrust*</u>. *MV Onrust* was chartered by MPCU from Smit International. She is a 39 metre long crane / support and salvage vessel with a crew of six and accommodation for a further six. The deck space was large enough to house both the lab/storage container and *Black Tern*.

<u>*Black Tern*</u>. *Black Tern* is a 12-metre steel and GRP landing craft built by Rotork in 1974. She is powered by two 90 hp OMC outboard engines and has a maximum speed of 20 knots She is normally crewed by three people. The UVF (Ultra-Violet Fluorescence) and PDPA (Phase Doppler Particle Analysis) monitoring and logging equipment were installed in the cabin. A 6 metre sample pole, holding the pumps for the fluorometers and the laser head for the PDPA, was positioned at about the mid point on the starboard side, outside the rail and secured fore and aft by wire and rope strops respectively.

<u>Sampling Boats</u>. Two 5 metre Zodiac RB6 inflatable boats, with 25 and 35 hp outboard engines, were used for taking samples of oil and emulsion from the sea surface. Both boats operate with a crew of two or three.

Aircraft
Several aircraft were used during this sea trial. All of the aircraft operated out of Norwich airport for this sea trial.

<u>Air Atlantique Cessna 404</u>. The Air Atlantique Cessna 404, call sign Atlantic 404, is on long-term charter to MPCU. Its role is to act as a surveillance and remote sensing aircraft. The aircraft is equipped with a thermal Infra-Red (IR) imaging camera and an ultra-violet (UV) camera (the images being recorded on an S-VHS video recorder) and Side Looking Airborne Radar (SLAR). It also has a vertically mounted video and can be used for photography and oblique video recording.

The Cessna 404 is also used to guide the dispersant spraying aircraft. As the dispersant spraying DC-3 aircraft operates at very low altitude, typically 15 to 30 feet during dispersant spraying, it is not possible to see the oil that is to be sprayed from the flight deck before it has been passed over. The Cessna 404 is flown above and behind the spray aircraft. The pilot of, or an observer in, the Cessna can instruct the DC-3 crew on the best line of approach to the spilled oil and then issue “spray on” and “spray off” instructions.

Air Atlantique Cessna 402. The Air Atlantique Cessna 402 is on long-term charter to the UK Environment Agency (EA) for remote sensing duties. The aircraft is equipped with a thermal IR camera, a UV camera and a CASI (Compact Airborne Spectral Image) analyser. The images were recorded in a digital format for subsequent analysis.

Dispersant Spraying Aircraft. Two DC-3 aircraft, operated by Air Atlantique and under long-term charter to MPCU, were used in this sea trial.

Each aircraft contains five tanks with a capacity of approximately one tonne of dispersant per tank. Each aircraft is therefore capable of carrying nearly 5 tonnes of dispersant. The dispersant is sprayed out through a short spray bar located on the underside of the aircraft near the rear of the fuselage, but ahead of the tail. The dispersant is passed to the spray bar by a small propeller-driven pump.

For the purposes of this sea trial, half of the spray holes on the spray bar of the DC-3 had been blanked off with tape so that the spray system delivered only 11 litres/second, which is approximately half of the normal flow rate. This was done to produce a lower dispersant treatment rate on the oil, so that the emulsion-breaking effect of the dispersants could be studied by surface sampling .

Other Aircraft. Other surveillance aircraft equipped with remote sensing systems attended the field trial for various purposes. These included aircraft operated by the Belgian and Dutch authorities plus other UK aircraft.

Methods Used on Sea Trial

The techniques used on the sea trial included the following.

Surface Sampling

Samples of oil and emulsified oil were generally taken from the thickest patches of emulsion in the slicks. The sampling location was determined by visual observation from small inflatable boats and the locations were subsequently correlated with thermal IR images that were being obtained by the surveillance aircraft.

A sample was scooped from the sea surface with a specially designed plastic bucket. The sample of emulsified oil was immediately transferred into a 500 ml PTFE separating funnel and left to settle for 2 minutes to allow the ‘free’ water (sea water that had inevitably been obtained with the sample, but not water that had been entrained to form emulsified oil) to separate. The free water was drained off and the funnel was gently rotated, end-over-end, ten times to produce a thoroughly mixed sample.

A 20 ml vial was filled with the sample for subsequent evaporative loss determination by gas chromatography (GC). A 100 ml plastic bottle was also filled with the sample, labelled and taken back, as quickly as possible to the laboratory container on board one of the research vessels.

The following properties of the recovered samples were then measured.

Viscosity of Oil and Emulsified Oil. The viscosity of the surface samples of weathered oil and emulsion taken from the sea was measured using the Haake VT550 viscometer in the laboratory container. The procedure involved a ramped shear rate according to the method developed by McDonagh and Hokstad, 1993. All viscosity results in this paper are those obtained at a shear rate of $10s^{-1}$.

Water Content of Emulsion. The water content of the emulsified oil was determined in the laboratory on board MV Onrust by ‘breaking’ 50 mls of the emulsion - causing the emulsion to rapidly separate into its constituent components of oil and water - by the addition of 0.2 mls of Alcopol O (a 60% wt. solution of sodium *bis*2-ethylhexyl sulphosuccinate) and heating to 50°C. The ‘broken’ emulsion was poured into a measuring cylinder and the relative volumes of oil and water were noted and the percentage of water in the original emulsion was calculated. The water contents of sub-samples of emulsified oil were subsequently measured in the laboratory by the use of the Dean and Stark method (IP 74/82, ASTM D95-81 and IP 358/82, ASTM D4006-81) and the Karl Fisher method.

Evaporative Loss. The amount of evaporative loss was estimated by comparison of the GC (gas chromatogram) of the sample obtained at sea with calibration samples obtained by distillation. The GC apparatus used was a Pye Unicam PU4500 Gas Chromatograph with a flame ionisation detector (FID), and Dexsil PP stationary phase.

Slick Thickness Measurement. The thickness of the emulsified oil slicks were measured at various locations by two methods; pad sampling and the “Plexiglas tube” technique.

Pad sampling is a technique often used in sea trials and has been described in detail in references such as Lambert et al., 1994. Pad sampling was achieved by placing 30 cm square pads of 3M polypropylene sorbent on the sea surface and removing them after 30 seconds. The pads absorbed the oil. The pads were then placed inside sealed Kilner jars. After the sea trial, the pads were photographed to allow an estimate of oil coverage to be made. The oil was extracted from the pads with chloroform, dried over sodium sulphate, and the amount of oil was measured by spectrophotometry at 580 nm and comparison with calibration standards of artificially weathered oil.

The “Plexiglas tube” method involved the use of an apparatus consisting of a tube with a hinged flap operated by a lever . The flap was opened, the tube inserted through the oil slick and the flap was closed. The entire apparatus was then removed from the slick and taken into the sampling boat. Visual inspection through the transparent side of the tube allowed the oil thickness to be measured.

Sub-surface Oil Concentration Measurement

UVF (Ultra-Violet Fluorescence) was used to measure the dispersed oil concentration at depths of 0.5, 1, 2, 3, 4 and 5 metres. UVF is a technique that has been used for many years at experimental oil spills (Brandvik et al., 1994 and Lunel, 1995) more recently, at actual oil spill incidents. Six Turner AU10 fluorometers were used with the 'short oil' filter set, excitation frequency of 254 nm and emission frequency of 360 nm. Water from the appropriate depth was pumped up a tube attached to a vertical pole deployed from a small boat into a fluorometer. The fluorescence signal output was recorded on a data logger as the boat made transects across the slick. Samples of the water containing the dispersed oil were taken and retained for calibration purposes. The oil was solvent-extracted from these water samples and the amount of oil was calibrated against spectrophotometric standards produced from artificially weathered oil.

Thermal Infra-Red (IR) Remote Sensing

Thermal Infra-Red (IR) imaging from surveillance aircraft is a technique that is routinely used at oil spill incidents (Goodman, 1994). A camera detects the thermal IR (8 to 14 micron) radiation emitted from a surface. The camera detects the equivalent black body temperature of a surface and this is displayed on a screen, after suitable amplification, as a black and white image. The IR signal detects the small differences in temperature of the surface of the oil slick, which can be indicative of slick thickness.

The Forties Blend Crude Oil Experiment

There were two releases each of approximately 50 m^3 of Forties blend crude oil and these were designated as the Charlie and Sierra slicks.

The main points of the Forties blend crude oil experiment were:

1. The release of 49,625 litres of Forties blend crude oil to form the Charlie slick took place between 16:20 and 16:55 on Wednesday 17th September.

2. The Sierra release of 49,345 litres of Forties blend crude oil took place one hour later, between 17:20 and 18:05 on the same day.

3. Several surface samples were taken from the Charlie slick, but none from the Sierra slick, before darkness fell on Wednesday. Several UVF transects of the Charlie slick were made during this time.

4. Another ten surface samples were taken from Charlie slick before it was sprayed with Corexit 9500 on Friday 19th September in a period from 12:25 until 13:23, almost 44 hours after the oil had been released.

5. Four surface samples were taken from the Sierra slick before it was sprayed with Dasic Slickgone NS on Friday 19th September in a period between 16:05 and 17:01, 46 hours after the oil had been released

Weather Conditions During Forties Blend Crude Oil Experiment

During the 44 hours that the Charlie slick was at sea the average wind speed was generally 3 to 4 m/s for the first 24 hours, rising to 6 m/s and finally 8 m/s just prior to dispersant spraying between 12:30 and 13:30 on 19th September. As the Sierra slick was at sea for approximately the same time, the conditions were the same, except that at the time of dispersant spraying (16:00 to 17:00 on 19th September) the wind speed had risen.

Properties and Distribution of Oil Prior to Spraying

Sub-Surface Oil Concentrations During and After Forties Blend Crude Oil Release. Dispersed Forties Blend crude oil was detected at all measured depths, the maximum concentration was 1.8 ppm at 0.5 metre, and at 5 metres the dispersed oil concentration was high at 1.3 ppm. These elevated concentrations of oil are common after the initial release of the oil, due to the turbulence caused by the release of the oil forcing it into the water column.

Spreading of Forties Blend Crude Oil (Charlie and Sierra Slicks). Each of the 50 tonnes of Forties blend crude oil in each slick was discharged in approximately 35 minutes. Four minutes before the end of the oil release, the thermal IR image indicated that the area of oil in the Charlie slick was approximately 23,000 m^2. Eight minutes after the end of the discharge time, the Charlie slick was approximately 400 meters long by 300 metres wide, but not all of this area was covered with oil. The oil covered area was estimated to be approximately 50,000 m^2.

The oil-covered area in the Sierra slick was of a similar size, around 50,000 m^2, although with a higher coverage of oil in the total slick area because the Sierra slick was more compact. Even in this very short period of 35 minutes it is likely that the Forties blend crude oil had lost approximately 15% to 25% of its total volume by evaporation. The volume of oil remaining in each slick would therefore have been approximately 40 m^3 by the end of the release. The average slick thickness would have therefore been approximately 0.8 mm. Two pad samples were taken in the thicker areas of the Charlie slick at this time; the slick thicknesses were measured as 1.43 mm and 2.08 mm.

During the time at sea evaporation would proceed until most of the more volatile components had been lost. The volume lost by evaporation was calculated by analysing individual samples. Some oil volume would also have been lost from the slick by natural dispersion. It is not possible to measure the rate or extent of natural dispersion directly, although UVF transects that measure dispersed oil concentration give a good relative indication of the degree of natural dispersion. The rate of natural dispersion will be greater in rougher seas and will be resisted as the viscosity of the oil increases due to oil weathering. Previous work with Forties crude oil had indicated that this size of oil slick would lose oil by natural dispersion at approximately 0.5 % of its volume per hour in the earliest stages of weathering.

After 15 hours of weathering, the volume of the slick would have decreased to approximately 27m^3. This takes into account 37% due to evaporative loss and an estimated 10% due to natural dispersion. There is also a small amount of emulsion formed and therefore 3% water content is also included in the equation. The total area of the slick was 381,614 m^2 and if it is assumed that the thickness of the slick is constant throughout, the thickness would be 70 microns. Several pad samples were taken in the thickest parts of the Charlie slick and were between one millimetre and one-third of a millimetre thick.

Evaporation of Forties Blend Crude Oil. The loss by evaporation from samples of Forties blend crude oil recovered from the Charlie and Sierra slicks was estimated by the gas chromatography (GC) method which had been calibrated against simulated evaporation samples that had been obtained by distillation. The results, expressed as evaporative loss are shown in Figure 1. All of the samples except one were recovered from the Charlie slick.

The zero time on the graph is at the end of the release time, 35 minutes since the start of release. The first sample was taken from a region of the slick that had been on the water for some time. There was a very rapid loss of the most volatile components - 25 % volume had been lost from the oil that was first released, by the time that the last of the oil was released, a period of only 35 minutes. Subsequent evaporation was slower and an estimated 40% of volume would have evaporated before the slick was sprayed with Corexit 9500, 44 hours after release.

Emulsification of Forties Blend Crude Oil. The water content of the emulsion formed from the residue of Forties blend crude oil that remained in the Charlie and Sierra slicks after the evaporative loss of the volatile components gradually increased with time and is shown in Figure 2.

The virtual absence of breaking waves, caused by an average wind speed below 5 m/s, caused water incorporation to be slow and the volume of water in the emulsion to be below 15% volume for at least the first 30 hours at sea. After this period, the wind speed increased to an average of 6 m/s. Although the difference in wind speed between 4 and 6 m/s (approximately 8 and 12 knots) may seem slight, it is important because this is the threshold of significant breaking wave action.

Viscosity Measurements of Weathered Forties Blend Crude Oil. The viscosity of the emulsified Forties Blend crude oil that remained in the Charlie and Sierra slicks after evaporation increased with time and is shown in Figure 3.

The viscosity increase from 8 cP (‘fresh’ Forties Blend crude oil) to approximately 1,500 cP over the first 24 hours was due almost entirely to the evaporative loss of volatile components because the water content of the emulsion was only 10% volume by this time. Such a low water content in an emulsion contributes very little to the continuous phase (oil) viscosity. The subsequent viscosity increase to nearly 4,000 cP, which occurred overnight, was almost entirely due to the incorporation of approximately 50% volume of water in the emulsion, as very little additional evaporative loss occurred during this time.

Corexit 9500 Dispersant Spraying of Charlie Slick of Weathered Forties Blend Crude Oil
The Charlie slick had been at sea for 44 hours before dispersant spraying was carried out. The spray aircraft carried out a total of 11 spray runs onto the Charlie slick, applying a total of 2250 litres of Corexit 9500.

Figs. 1,2,3

Distribution of Weathered Forties Blend Crude Oil in Charlie Slick prior to Spraying. The Charlie slick had been on the sea surface for 43.5 hours before spraying commenced at 12:25 on the afternoon of Friday 19th September. Both the video and thermal IR images taken shortly before spraying started showed that the emulsion had been driven into three distinct wind rows 5-10m wide and that the slick had now broken into ribbons. These ribbons measured up to 1150 metres in length by 5 to 10 metres wide and were spread out over a very large area. Prior to spraying, the total area of the Charlie slick visible in a thermal IR image was estimated to be approximately 100,000m^2. From the same thermal IR images the thick oil appeared to be in two main windrows, with an area of approximately 8,500 m^2.

Most of the emulsified oil was concentrated in the windrows and it is estimated that approximately 26m^3 of emulsified oil was contained within an area of 8,500 m^2, giving an average emulsion thickness of 3 mm. Sampling by the Plexiglas tube method at various locations in the windrows showed that the emulsion thickness was up to 3 to 5 mm thick.

The Dispersant Spraying Operation of Charlie Slick. The spraying system of the DC-3 aircraft had been adapted for these trials to spray dispersant at a lower rate than would normally be the case in actual oil spill response operations. Half of the holes in the spray bar had been blocked off to produce a spray rate of 10 litres per second of Corexit 9500.

The swath width of the Corexit 9500 spray from the DC-3 was narrow, depositing the majority of dispersant on the sea as a strip approximately 7.5 to 9 metres wide. The wind speed was 7 to 8 m/s (14 to 16 knots) and the air speed of the aircraft was approximately 100 knots (50 m/s). Dispersant spraying was always carried out as directly into the wind as possible, consistent with obtaining good coverage of the windrows. The ground speed, the speed at which the spray aircraft was moving over the slick, was therefore approximately 85 knots (~ 43 m/s).The amount of Corexit 9500 applied onto the oil/emulsion (or sea surface) was therefore approximately 25 to 30 ml of dispersant per square metre, equivalent to 27 to 32 US gallons per acre, during a single spray pass. The spray aircraft applied a total of 2250 litres of Corexit 9500 onto the Charlie slick.

Initially, the windrows were each sprayed twice, giving a treatment rate that was approximately 60 ml/m^2 (equivalent 64 US gallons per acre). After the surface sampling and UVF monitoring, the spray aircraft returned and another two spray runs were made on each of the windrows. The emulsified oil in this windrow had therefore been sprayed four times with a total of nearly 800 litres of Corexit 9500. The area of the windrows sprayed with 800 litres of Corexit 9500 was approximately 8,000 m^2 at an average of 100 ml/m^2 (equivalent to 108 US gallons per acre).

Effects of Dispersant Spraying on Weathered Forties Blend Crude Oil in Charlie Slick. After the first two spray runs on the left windrow, the visual effect of Corexit 9500 application was near-instantaneous. The emulsified oil on the surface immediately turned to an orange-brown colour from the original dark brown colour of the untreated emulsion.

The thermal IR images taken just after the completion of the first spray run appeared to indicate that the oil was dispersing very rapidly indeed; the dark areas of thick oil that were evident before spraying were not evident immediately after spraying. However, 4 minutes later some of the darker areas of thick oil had reappeared. The apparent disappearance and then reappearance of the oil is thought to be caused by a temporary masking effect for which there are two possible explanations; one is that the dispersant was cold and masked the IR signal from the oil, or the second possibility is that the warm surface of the oil was temporarily disrupted by the dispersant. However, this effect was short-lived. Fifteen minutes after the last spray treatment, a thermal IR image revealed that the darker areas of thick oil were permanently removed from the image. Thermal IR images taken 4.5 hours after the end of spraying, showed that only a thin oil sheen, with an estimated area of 49,000m^2, remained on the sea surface.

The sample boats moved into the dispersant-treated areas shortly after spraying. Even after the first two spray runs on any particular slick area, the surface emulsion had already largely dispersed making surface sampling very difficult. The surface samples that were collected showed that before treatment the emulsion contained 45-55% water and had reached a viscosity of 3,500-3,900 cP. After dispersant treatment, the water content of the emulsion samples which could be recovered ranged from 20-50% volume with viscosities of 2,800-3,100 cP. Definite signs of emulsion breaking were difficult to find because the areas of emulsion that had been sprayed dispersed very rapidly. Under the microscope it could be seen that the larger droplets had dropped out of the emulsion and only the small droplets remained.

A total of 10 UVF transects across the Charlie slick were conducted. Figure 4 shows the dispersed oil concentration for each of the 6 depths at 12:11, approximately 15 minutes before spraying commenced. The maximum oil concentration at 0.5 metre was 0.5 ppm and 0.2 ppm at one metre depth. From two to five metres depth, the oil concentration was less than 0.05 ppm.

Dispersant spraying began at 12:25 and finished at 13:23. A fluorometry transect was undertaken during spraying at 13:05, (Figure 5), after six spray runs had been completed. This transect was taken across the width of the slick and shows the dispersed oil concentration over a distance of 1600 metres. Dispersed oil was detected at all measured depths. The maximum concentration at 0.5 metre was 6 ppm and 3 ppm at one metre depth. Oil concentration reached a maximum of 1 ppm at a depth of five metres. Figures 6 shows oil concentration with depth over distance at 13:44 which was 30 minutes after dispersant spraying was completed. Dispersed oil was detected to depths of five metres in all the transects, to a maximum concentration of 2 ppm at five metres.

Dasic Slickgone NS Treatment of Sierra Slick of Forties Blend Crude Oil.
The Sierra slick had been on the sea surface for 46 hours before the spraying operation commenced.

<u>Distribution of Oil in Sierra Slick Prior to Spraying</u>. The change in physical properties of the weathered Forties blend crude oil in the Sierra slick were almost identical to that of the same oil in the Charlie slick. A thermal IR image of the Sierra slick was taken after 46 hours on the sea surface. This showed that the bulk of the oil was in two fairly large patches which were joined together by

Figure 4. UVF transect of Forties Charlie slick at 12:11- before dispersant spraying

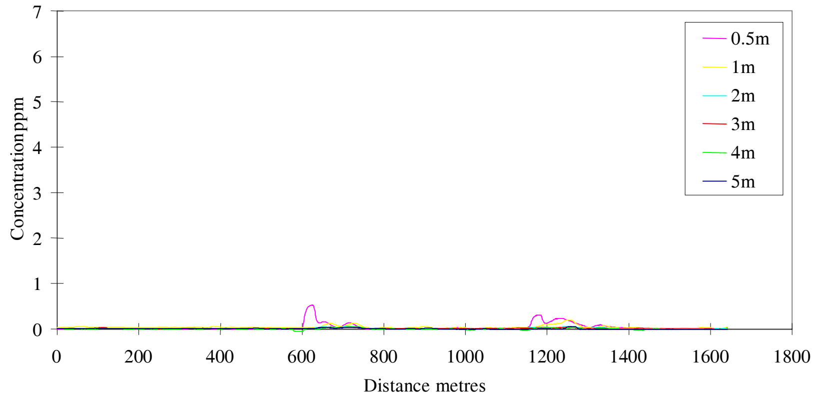


Figure 5. UVF transect of Forties Charlie slick at 13:05 - during dispersant spraying

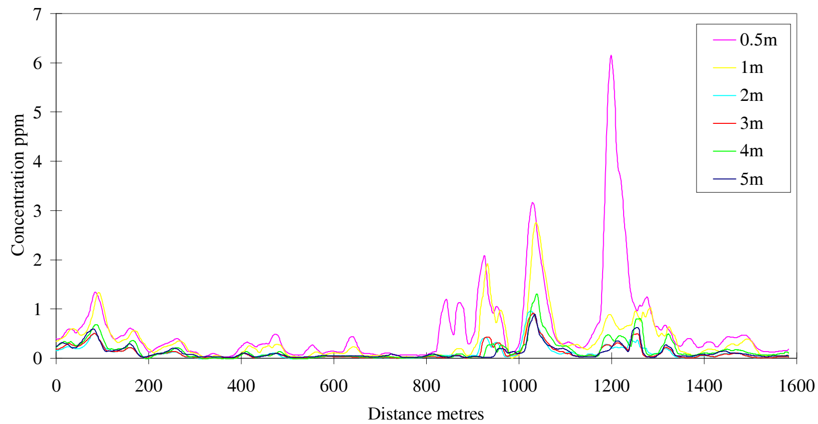
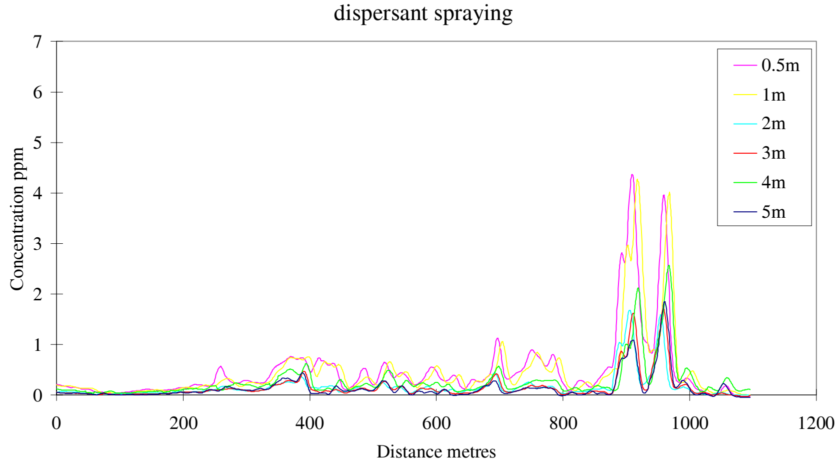


Figure 6. UVF transect of Forties Charlie slick at 13:44 - after dispersant spraying



a narrow ribbon of oil. The remaining emulsion, had been driven into windrows 4 to 14 metres wide which were contained within the largest patch of oil.

The Dispersant Spraying Operation. The second DC-3 spray plane had been loaded with 4500 litres of Dasic Slickgone NS. As when spraying the Corexit 9500 onto the Charlie slick, the DC-3 spray aircraft was flown at an altitude of 15 to 30 feet above the sea at a speed of approximately 100 knots. The low altitude is needed to reduce wind-drift of the dispersant and ensure that the thicker patches of oil are accurately sprayed, without excessive loss of dispersant to thinner areas of sheen or open water. At such low altitude, it is not possible for the flight crew to see the oil that needs to be sprayed before they have passed over it. The DC-3 was guided towards the thicker oil patches of oil by the Cessna 404 and given instructions to start and stop spraying from this aircraft.The spray aircraft carried out a total of 10 spray runs onto the Sierra slick, applying a total of 2,700 litres of Dasic Slickgone NS.

Effects of Dasic Slickgone NS Spraying. The immediate colour change of the emulsion formed by the weathered Forties blend crude oil observed on spraying with Corexit 9500 was not observed in the case of the treatment with Slickgone NS. A thermal IR image taken at 18:08, one hour after the termination of spraying, showed that the area of oil detectable by thermal IR was much reduced. The areas of thin oil that remained had an estimated area of 54,000 m^2 compared to the area of approximately 133,000 m^2 it had occupied prior to spraying. By 07:31 on the morning of Saturday 20th September, the estimated area of broken oil sheen remaining on the sea surface had reduced to about 11,000 m^2. A subsequent surveillance flight at 14:30 confirmed that only broken sheen remained.

By 17:06 when around 2.7 tonnes of Dasic Slickgone NS had been applied, the surface emulsion had been partially broken and the viscosity and water content dropped to 3,000 cP and 30% volume, respectively, for any emulsion remaining on the surface.

Sub-surface Oil Concentrations after Dispersant Treatment. Figure 7 shows dispersed oil concentrations at 15:28, 30 minutes before the Dasic Slickgone NS spraying operation began on the Sierra slick. Below 1 metre the oil concentration was less than 0.25 ppm. This is comparable to the dispersed oil concentrations measured in the Forties Charlie slick, 15 minutes before dispersant spraying (Figure 4).

Dispersant spraying of the Sierra slick began at 16:05 and finished at 17:01. The slick was monitored during dispersant spraying, and for 20 minutes after spraying had finished. Figures 8 shows a UVF transect made during initial dispersant spraying at 16:16. It shows an increase in dispersed oil concentrations to between 0.7 and 1.8 ppm over the half to five metre depth range. Figure 9 shows a transect across the slick 10 minutes after dispersant spraying was completed at 17:12. There is dispersed oil at all depths and the dispersed oil concentration at 5 metres was approximately 0.5 ppm.

Figure 7. UVF transect of Forties Sierra slick at 15:28 - before dispersant spraying

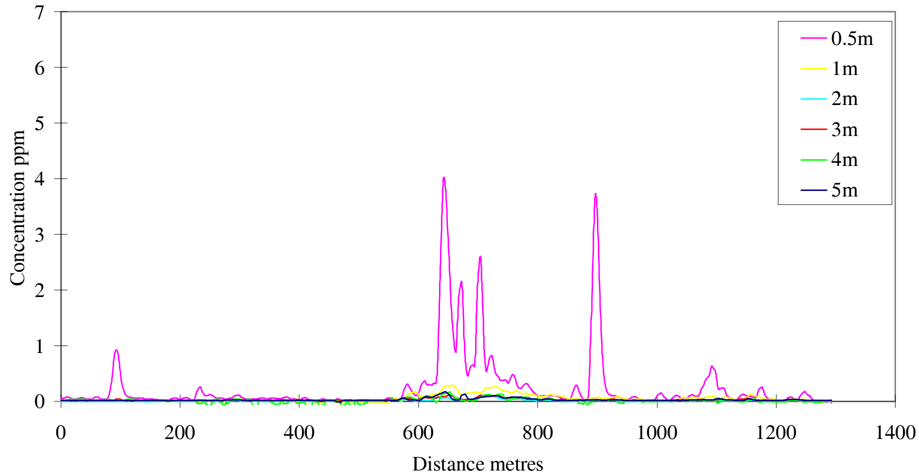


Figure 8. UVF transect of Forties Sierra slick at 16:16 - During dispersant spraying

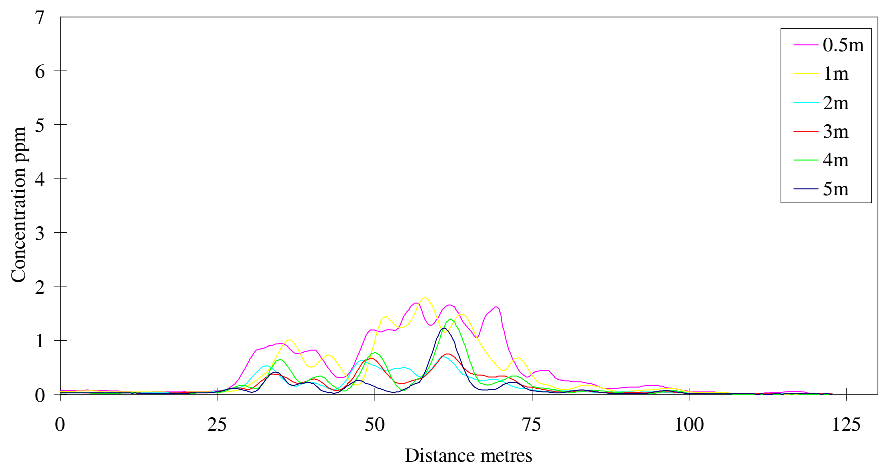
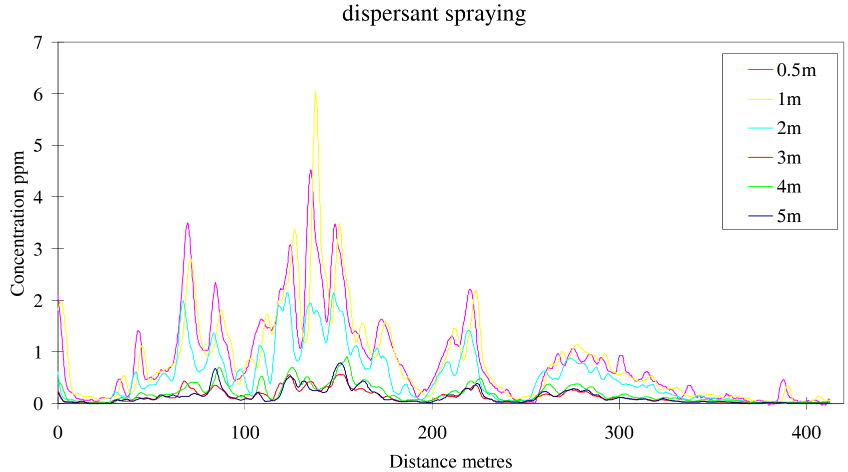


Figure 9. UVF transect of Forties Sierra slick at 17:12 - After dispersant spraying



The Alaskan North Slope Crude Oil Experiment

There was a single release of approximately 30 tonnes of Alaska North Slope crude oil and this was designated as the Alpha slick.

The main points of the Alaska North Slope crude oil experiment were:

1. The release of Alaska North Slope crude oil started at 08:40 on Saturday 20th September. Discharge stopped at 09:02 when 33,190 litres (7,300 Imp. gallons on the ship's gauge, equivalent to 8,767 US gallons and 29.30 tonnes) had been released.

2. Surface samples were taken for analysis during the 9 hours following release on Saturday 20th. Three surface samples were taken the next day, Sunday 21st, and samples were taken before the Alpha slick was sprayed with Corexit 9500 on Monday 22nd after approximately 54 hours on the sea surface.

3. The Alpha slick was first sprayed with Corexit 9500 at 15:53 on Monday 22nd September, approximately 55 hours after it had been released. Four spray runs, delivering 400 litres of dispersant, were conducted between 15:53 and 16:01. Another 600 litres of Corexit 9500 was sprayed between 16:28 and 16:41 on the same day.

Weather Conditions during the Alaskan North Slope Crude Oil Experiment

During the time that the Alpha slick was at sea, the average wind speed was rising from 3 m/s to 5 m/s (6 to 10 knots), with gusts to 7 or 8 m/s (14 to 16 knots) during the first 24 hours. During daylight on the 21st the average wind speed was 5 m/s (10 knots) with gusts up to 15 knots. At the time of dispersant spraying the average wind speed was 6 m/s (12 knots) with a maximum wind speed of 17 knots. The sea temperature was 18ºC throughout the trial period while the air temperature was 15º$\pm$0.5ºC while the Alpha slick was on the sea surface.

Distribution and Properties of the Alaska North slope Crude Oil Slicks

<u>Spreading of Alaska North Slope Crude Oil (Alpha slick)</u>. The release of Alaska North Slope crude oil initially formed a circular slick as Seaspring gently circled while discharging the oil. As the ship circled and the area of oil expanded as it spread out, the ship inadvertently entered the slick and then passed through it. The Alpha slick was split into two distinct areas by the passage of the ship. On completion of the release, the Alpha slick was approximately 320 metres long by up to 270 metres wide and covered an area of about 58,000m^2.

After 3.5 hours on the sea surface the Alpha slick had spread out to a maximum of approximately 400 metres long by 340 metres. However, not all of this area was oil covered. Thick areas of oil which appeared as black patches were clearly visible in the IR image. These thick areas of oil were embedded within a much larger area, approximately 63,000 m^2, which was detected by thermal IR. Further IR images taken once the oil had been on the sea surface for 8-10 hours revealed that the slick had spread out to approximately 800 metres long by 400 metres. However, once again not all of this area was oil covered. The oil was estimated to cover a surface area of about 120,000 m^2. By this time, it is likely that the Alaska North Slope would have lost about 30 % of its volume by

evaporation and a further 3.5 m^3 by natural dispersion, giving approximately 18m^3 of oil remaining in the Alpha slick. After 9 hours on the sea surface the mean water content of the emulsion that had been formed was approximately 44 % volume producing a total emulsion volume of 25 m^3.

A thermal IR image obtained at 14:19 on the afternoon of Sunday 21st September, 29 hours after oil release, showed that the Alpha slick was now much more spread out than before and measured approximately 1,500 metres in length by up to 470 metres. Due to the "lace-like" structure of the slick, only about 20% of this area was actually oil covered, giving a total surface area of approximately 136,000 m^2.

<u>Evaporation of Alaska North Slope Crude Oil</u>. The loss by evaporation from samples of Alaskan North Slope crude oil recovered from the Alpha slick was estimated by the gas chromatography (GC) method , calibrated against simulated evaporation samples that had been obtained by distillation. The results, expressed as evaporative loss are shown in Figure 10.

<u>Emulsification of Alaskan North Slope Crude Oil</u>. The water content of the emulsion formed from the residue of Alaska North Slope crude oil that remained in the Alpha slick after the evaporative loss of the volatile components gradually increased with time and is shown in Figure 11. The water content rose for the first ten hours to approximately 40 % volume, but then decreased overnight to 25 to 35 % for samples taken before spraying.

<u>Viscosity Measurements of Weathered Alaska North Slope Crude Oil</u>. The viscosity of the emulsified Alaska North Slope crude oil that remained in the Alpha slick after evaporation increased with time and is shown in Figure 12. The viscosity rose slowly to 15,000 cP although individual samples exhibited a wide range of values.

Corexit 9500 Spraying of Alpha Slick of Weathered Alaska North Slope Crude Oil
During the afternoon of Monday 22nd September, almost exactly 55 hours after the Alaska North Slope crude oil had been released onto the sea surface, a DC-3 aircraft sprayed the Alpha slick with Corexit 9500 dispersant. The spray equipment configuration (pump setting and spray bar) were identical to that used when spraying the Charlie and Sierra slicks and a very similar operational technique was used.

<u>Distribution of Oil in Alpha Slick Prior to Spraying</u>. The thermal IR image taken shortly before spraying commenced showed that the main body of the slick was now spread out over an area about 1000 metres long by 250 metres. A few smaller patches of oil had broken away from the main slick. The actual surface area covered by the oil was estimated to be 75,000m^2.

Assuming that the Alaska North Slope had by now lost approximately 40% of its volume by evaporation and a further 6 m^3 due to natural dispersion, the volume of oil remaining would have been about 12 m^3. However, after 55 hours the mean water content was approximately 35% water in the emulsion giving a total of 16 m^3 of emulsion. From the video image, the thick oil appeared

Figure 1. Evaporative Loss of Forties Slicks

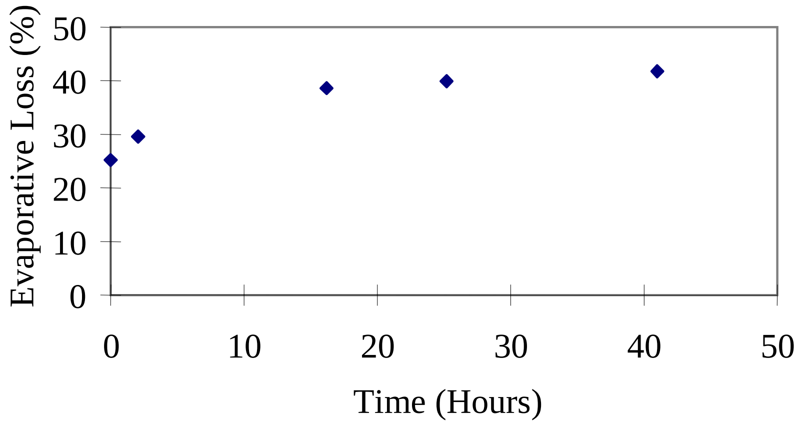


Figure 2. Water content of Forties Slicks

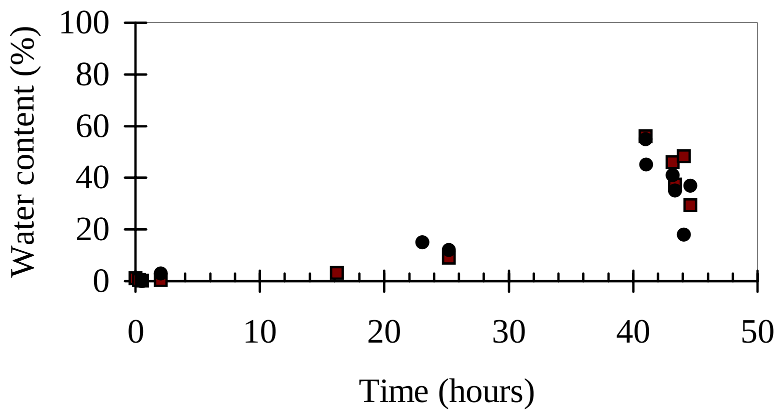
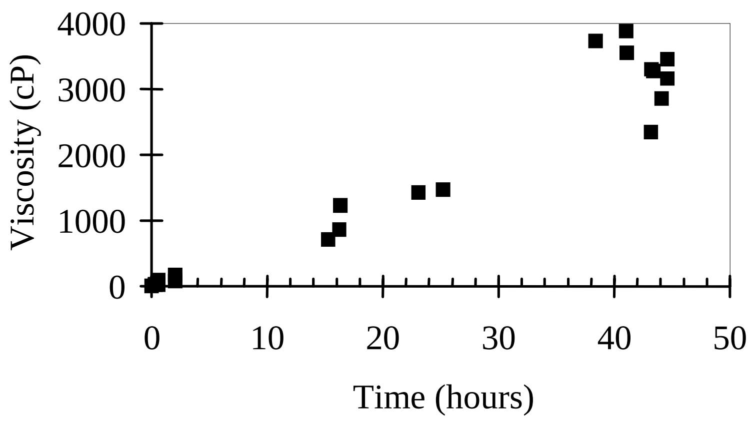


Figure 3. Viscosity of Forties Slicks



to be in three main lines, with the windrows estimated to be up to 570 metres long by 9 metres wide. Assuming that 90% of the oil was in the thick areas, this meant that about 14m^3 of emulsified oil was contained within an area of 15,000m^2 giving an average emulsion thickness of 1 mm in the windrows immediately prior to spraying.

The Dispersant Spraying Operation. The Alpha slick was sprayed with Corexit 9500 on the afternoon of Monday 22nd September. Dispersant spraying was conducted in two phases. The initial four sprays (see Table 1) applied between 400 and 500 litres of Corexit 9500 and it was estimated that 90% of the thick oil area had been sprayed.

Table 1 First spraying operation

	Spray Time (seconds)	Spray Distance (metres)	Approximate Area (metres^2)	Corexit 9500 sprayed (litres)	Comments
Spray run 1	12	530	4400	120	On target
Spray run 2	8	350	3000	80	Missed
Spray run 3	15	650	5600	150	On target
Spray run 4	12	530	4500	120	On target

Surface samples were taken and UVF transects were made after this first spraying operation and the spray aircraft loitered nearby as this was done. Thirty minutes after the first spraying operation, a second spraying operation was conducted. The areas of thicker emulsified oil had spread out after the first spraying operation and the aircraft conducted another five spray runs (see Table 2).

Table 2 Second spraying operation

	Spray Time (seconds)	Spray Distance (metres)	Approximate Area (metres^2)	Corexit 9500 sprayed (litres)	Comments
Spray run 5	14	620	5100	140	On target
Spray run 6	10	440	3600	100	On target
Spray run 7	12	530	4400	120	On target
Spray run 8	12	530	4400	120	On target
Spray run 9	11	480	4000	110	On target

Nearly 22,000 m^2 of emulsified oil was sprayed with approximately 600 litres of Corexit 9500.

Effects of Dispersant Spraying. After the first four spray runs between 15:52 and 16:01, a total of 400 litres of Corexit 9500 had been applied.

An IR image taken at 16:04 indicated that the surface emulsion had already broken. A further 6 spray runs were made between 16:28 - 16:41 during which a further 600 litres of dispersant was applied bringing the total to 1 tonne. The IR image taken at 17:14 showed that the slick now covered an area of approximately 55,000 m^2 compared to the 75,000m^2 it had occupied prior to spraying and appeared to be breaking up.

Subsequent IR images taken at lower altitude confirmed that the slick was breaking up and showed no evidence of any remaining patches of thick emulsion. A further reconnaissance flight the next day confirmed that the remaining oil had dispersed overnight.

Sub-surface Oil Concentrations. A UVF transect made before spraying of the Alpha slick is shown in Figure 13. The dispersed oil concentration is very low at all depths.

Dispersant spraying was carried out in two batches, the first at 15:52 to 16:00 and the second at 16:28 to 16:38. After the first batch of dispersant was applied to the slick, a number of transects were carried out. Figure 14 shows a transect made at 16:14. Dispersed oil concentration increased to 7 ppm at one metre depth and 1.1 ppm at 5 metres depths. These results show that the emulsified Alaska North Slope crude oil was beginning to be rapidly dispersed after the first batch of nearly 400 litres dispersant was applied.

UVF monitoring continued for an hour after the second batch of dispersant was applied. Figure 15 shows the transects at 17:10, 30 minutes after the end of spraying. Dispersed oil concentrations in these transects are less than detected in the previous transect as the dispersed oil is diluted away by currents. At 5 metres, maximum dispersed oil concentration is about 0.6 ppm, nearly half of the previous levels detected. At 1 metre, dispersed oil is less than 2 ppm, slightly less than detected previously.

The IFO-180 Fuel Oil Experiment

The main points of the IFO-180 fuel oil experiment were:

1. 4,400 gallons, equivalent to 20,000 litres (and 5,284 US gallons) of IFO-180 was released onto the sea surface between 10:09 and 10:30 on Sunday 21st September.

2. It was planned that the slick was going to be left to weather for 2 hours before spraying with Corexit 9500 dispersant. Under the prevailing calm wind conditions there was only a slow increase in emulsion viscosity. After 1-2 hours the viscosity was only 2,500 cP at 15°C with less than 5% volume water content. It was therefore decided to delay dispersant spraying until at least 4 hours after release.

Figure 13. UVF transect of ANS slick at 15:30 GMT - Before dispersant spraying

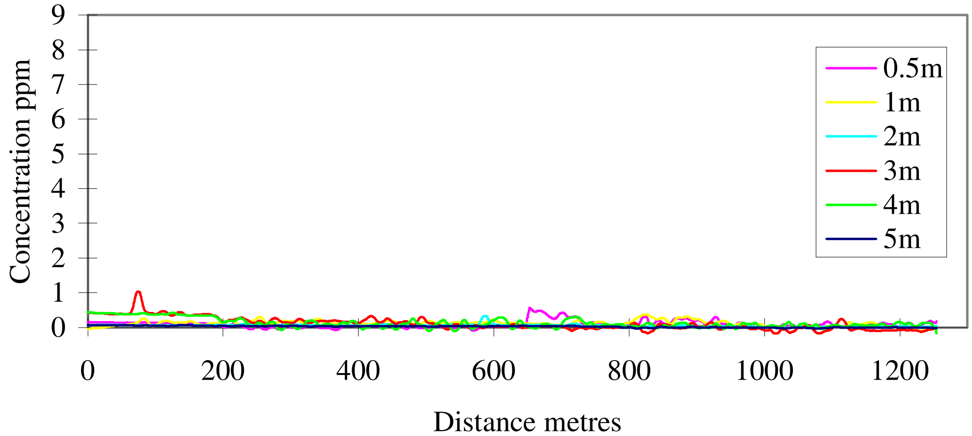


Figure 14. UVF transect of ANS slick at16:14 - During dispersant spraying

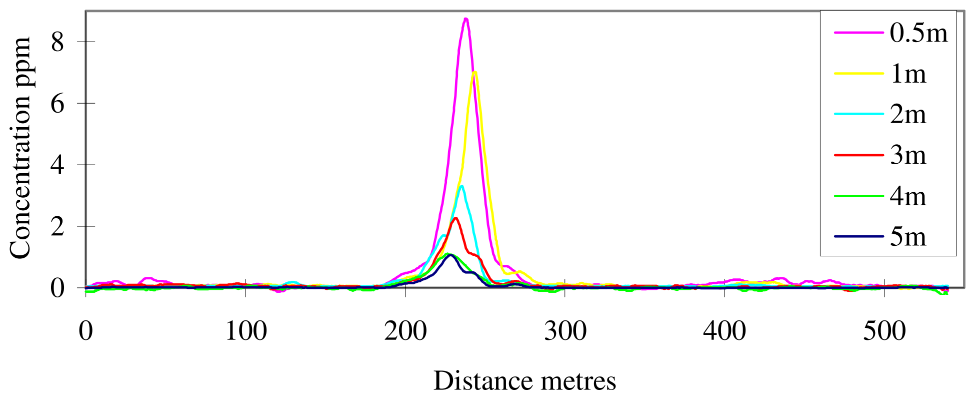
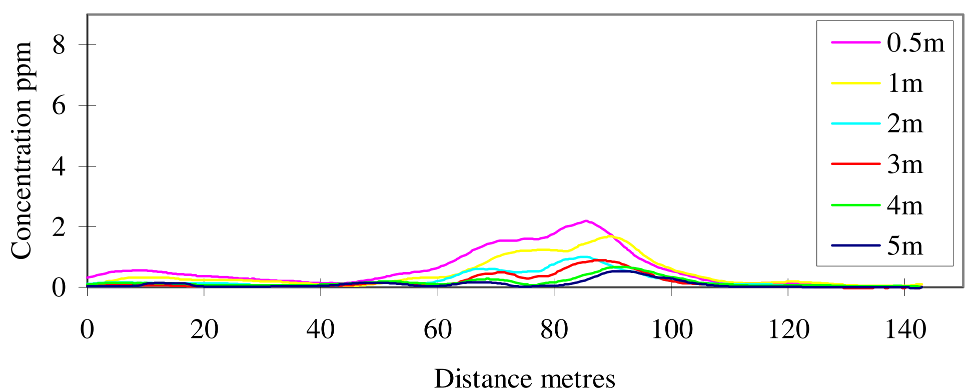


Figure 15. UVF transect of ANS slick at 17:10 - After dispersant spraying



3. By 14:00 the viscosity of the IFO-180 emulsion was nearing the target range and three spray runs with Corexit 9500 began at 14:55, four and a half hours after the end of release. A further 3 spray runs were completed between 15:10 and 15:17 by which time a total of 900 litres of Corexit 9500 had been used. 600 litres of this was judged to have been on target. Analysis of the surface samples showed that there was a drop in emulsion water content and viscosity following dispersant treatment. However, one hour after the spraying the emulsion water content and viscosity started to rise again. It was decided that a second application of Corexit 9500 was necessary.

4. Unfortunately, the DC-3 spray aircraft had lost pressure in one of its tyres when it landed at Norwich airport and was not immediately available for spraying.

5. The aircraft fault was rectified overnight and a second spraying with Corexit 9500 was carried out the next morning, Monday 22nd September.

6. The viscosity of the IFO-180 fuel oil emulsion was measured to be between 7,700-10,400 cP just prior to dispersant spraying between 09:12 and 09:24 on Monday morning. Monitoring indicted that the emulsion was breaking and there was a rise in dispersed oil concentrations. Between 09:35 and 09:51 a further 360 litres of Corexit 9500 was applied. Between 11:17-11:33 a further 1 tonne of Corexit 9500 was applied bringing the total to 2 tonnes for the 22nd September experiment.

Distribution and Properties of the IFO-180 Fuel Oil

Sub-surface Oil Concentrations during and after Oil Release. The IFO-180 fuel oil was released on 21st September at 10:09, and the release finished at 10:30. The slick was monitored for 1 hour 20 minutes immediately following the release and before any treatment. The maximum oil concentrations measured at 0.5 metre depth were 3.8 ppm and 1.5 ppm at 1 metre depth, but less than 0.3 ppm at two to five metres depth, ten minutes after release.

Spreading of IFO-180 Fuel Oil (Hotel Slick). The 20,000 litres of IFO-180 fuel oil in the Hotel slick was discharged in approximately 21 minutes and the rate was therefore approximately 1,000 litres per minute. A fairly compact slick was produced during the release. The relatively high viscosity of the IFO-180 meant that the Hotel slick spread slowly and patches were up to 4 to 7 mm thick for the first 30 minutes after release. At the end of the release, the Hotel slick measured approximately 275 metres by 170 metres and had an estimated surface area of 22,000 m^2.

Weathering of IFO-180 Fuel Oil. The IFO-180 residual fuel oil used in this trial consisted of 92% volume of a heavy residue (equivalent to IFO-380 residual fuel oil, with a viscosity at 50ºC of 380 cP) diluted, or ‘cut-back’, to the specification viscosity with 8% by volume of marine diesel fuel oil. It had not been intended to let the IFO-180 residual fuel oil remain on the sea surface for as long as occurred on the trial. The plan was to let the oil emulsify for two hours and then disperse it with Corexit 9500. It had therefore been considered that evaporation would not be a significant factor in the weathering of this oil.

However, two factors resulted in the IFO-180 fuel oil being on the sea surface for longer than originally intended:

1. The very calm sea conditions resulted in a slow rate of emulsification and the oil was intentionally left for approximately four hours before being sprayed with Corexit 9500. It was then intended that it should be sprayed again after an interval of $2^1/_2$ hours.

2. The partial deflation of the spray plane's tyre on landing meant that the Hotel slick could not be sprayed with dispersant for a second time until it had been on the sea surface for approximately 23 hours.

During this prolonged period on the sea surface there were significant changes in the properties of the IFO-180 fuel oil.

Evaporation of IFO-180 Fuel Oil. The IFO-180 fuel oil consisted of a blend of 92% volume heavy residue and 8% volume marine diesel oil. The maximum evaporative loss for this fuel oil would therefore be expected to be 8% volume and it appears that the oil lost almost this volume overnight.

Emulsification of IFO-180 Fuel Oil. Emulsification only occurs in the areas of thick oil in a slick. Sheen cannot emulsify because it is too thin and there is no room for the water droplets within the body of the oil. The IFO-180 fuel oil incorporated water at a slow rate (Figure 16).

After two hours there was less than 10% water volume in the emulsion. After 4 hours on the sea surface the water content had risen to 25% to 35 % volume, with the exact value depending on where the sample was taken from within the area of thick oil in the slick. It appears that the edges of the thickest patches of oil were incorporating water more rapidly than the centres of these patches.

The water content remained low as the slick weathered throughout the night only reaching 15% to 20% volume by Monday morning. It is probable that a small quantity of Corexit 9500 remained in the undispersed oil and that this suppressed emulsification.

Viscosity Measurements o the IFO-180 Fuel Oil. The viscosity of the IFO-180 fuel oil that was released onto the sea was just over 3,000 cP (measured at 15ºC and $10s^{-1}$). The viscosity values are shown in Figure 17.

The viscosity only increased to 5,000 cP over the first three hours as a small amount of the marine diesel diluent evaporated and a small amount of water was incorporated to form an emulsion. The viscosity of the emulsified IFO-180 fuel oil had risen to approximately 6,000 to 8,000 cP after four hours at sea, before it was sprayed for the first time with Corexit 9500.

After the first dispersant spraying the viscosity dropped and emulsification was suppressed overnight. The subsequent increase in viscosity was slow. On Monday morning the water content started to increase and this was accompanied by an increase in viscosity from 10,000 cP to 23,000 cP.

Figs. 16, 17

There was wide variation in the viscosities of samples recovered from different areas of the Hotel slick. Samples taken from the center of the thickest patches of emulsion had viscosities of around 7,500 cP, while samples taken from the outside edges of the thickest patches of emulsion had values up to 23,000 cP. This was probably due to varying exposure to wave action, dependent on location.

Corexit 9500 Spraying of IFO-180 Fuel Oil

The Hotel slick, which originally contained 20,000 litres of IFO-180 fuel oil, was sprayed with Corexit 9500 on three occasions:

1. On the afternoon of Sunday 21st September between 14:50 and 15:15, approximately 4 hours after release.

2. On the morning of Monday 22nd September, between 09:12 and 09:50, approximately 23 hours after release.

3. Later the same morning (Monday 22nd September) between 11:15 and 11:32, approximately 25 hours after release.

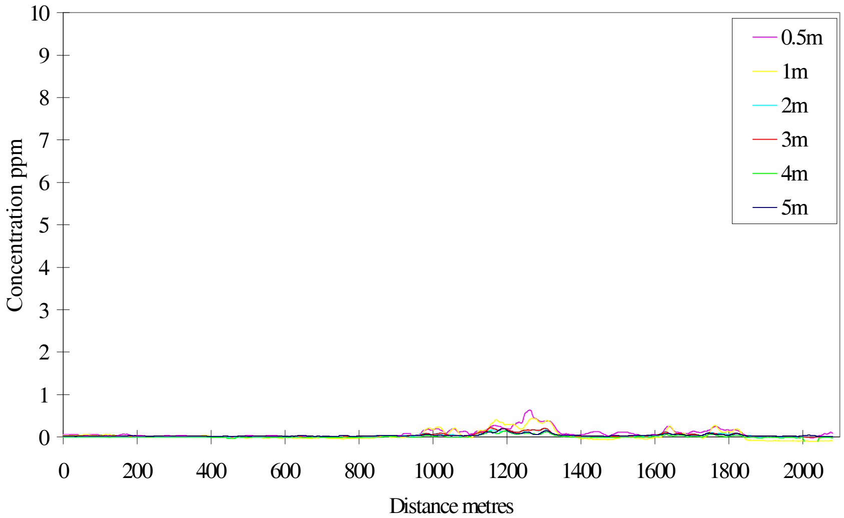
<u>The First Dispersant Spraying Operation (Sunday Afternoon)</u>. Six spray passes, applying a total 900 litres of Corexit 9500, were made between 14:50 and 15:15 on Sunday 21st September, approximately 4 hours after release. Of the total of nearly 900 litres of Corexit 9500 applied, only 600 litres was judged to be on target on the thick oil area.

Observation from the sampling boats did not reveal any change in the colour of the emulsified oil, or a plume of dispersed oil, in the Hotel slick when it was treated with Corexit 9500 on any of the three spraying occasions, although larger patches of emulsion did seem to be breaking up slowly into smaller patches after the first spraying.

Just prior to the first spraying with Corexit 9500, the viscosity of samples of emulsified IFO-180 fuel oil taken from the Hotel slick ranged from 6,000 to 8,000 cP with a range of water contents of from 25% to 35 % volume. A few minutes after completion of the first three spray runs of the first spraying operation, the viscosity of a sample taken from the sprayed area of the Hotel sick was 4,000 cP and the water content was only 5% volume. A sample taken 15 minutes after the last of the spray runs had a viscosity of 3,500 cP with a water content of 3% volume. At this very low volume, the water content would not make any contribution to emulsion viscosity and the value represents the viscosity of the IFO-180 residue that remained after the evaporative loss of some of the marine diesel diluent.

The dispersed oil concentrations at each of the depths immediately before dispersant spraying are shown in Figure 18, at 14:40. The concentration of the dispersed oil is less than 1 ppm, progressively decreasing with depth to 0.7 ppm at 0.5 metres to 0.2 ppm at 5 metres. These concentrations are less than those measured immediately after release about 4 hours earlier, indicating a very low level of natural dispersion.

Figure 18. UVF transect of IFO-180 on 21/09/97 at 14:40 - Before dispersant spraying HFO



The dispersed oil levels were monitored during spraying. Figure 19 is a transect showing the dispersed oil concentration half way through the first dispersant spraying operation, at 14:56. Oil is detected at significantly higher levels at all depths in comparison to the oil concentrations measured before dispersant treatment. At 1 metre maximum oil concentration is 8 ppm, and at 5 metres the dispersed oil concentration is 1 ppm. This indicates that the IFO-180 fuel oil was beginning to disperse into the water column.

Initially it was felt by the surface monitoring team that even the low dosage rate of dispersant had been successful and therefore subsequent addition of dispersant was delayed in order to determine whether complete dispersion would occur. However, over a period of 30 minutes to an hour it became clear that the dispersion was only partial. Visual observation from the sampling boats indicated that a significant quantity of emulsified fuel oil remained on the sea surface after this first spraying. A thermal IR image taken at 15:53 also showed that a significant volume of oil remained on the sea surface, with patches of thick emulsion still clearly visible. It was decided to carry out a second application of dispersant, but the technical problems with the DC-3 aircraft (deflated tyre) prevented the spraying from being undertaken before it got dark.

<u>The Second Dispersant Spraying Operation (Early Monday Morning)</u>. Eight spray passes, delivering a total of 1000 litres of Corexit 9500, were made between 09:12 and 09:50 on Monday 22nd September, approximately 23 hours after release. A total of 1000 litres of Corexit 9500 had been applied in this spraying session with 730 litres being judged on target.

There was no visual effect caused by the dispersant. UVF transects taken during the second spraying operation detected only a very small increase in dispersed oil concentration. Figures 20 shows the transect carried out at 11:53.

Dispersed oil concentration at 0.5 metres depth reached a maximum of 3.5 ppm, but remained fairly consistent at the 0.5 to 1.5 ppm at lower depths. These concentrations suggest that some of the IFO-180 fuel oil was dispersing, but only slowly.

Extensive patches of emulsified oil remained after the second dispersant spraying. Samples with viscosities of less than 30,000 cP were not recovered from the Hotel slick after it had been sprayed for the second time. Some of the emulsion appeared to have been broken with subsequent dispersion of the oil. However, the emulsion samples with the highest viscosity were taken from the slick after the second dispersant treatment with Corexit 9500. Samples of emulsion with viscosities of 34,000 and 43,000 cP were found in areas that had been treated with Corexit 9500.

This appears to indicate that emulsion which had a viscosity less than approximately 20,000 cP to 30,000 cP had been dispersed, but emulsion that had a higher viscosity than this range was not dispersed, even by repeated spraying with Corexit 9500.

Figure 19. UVF transect of IFO-180 on 21/09/97 at 15:56 - After dispersant spraying

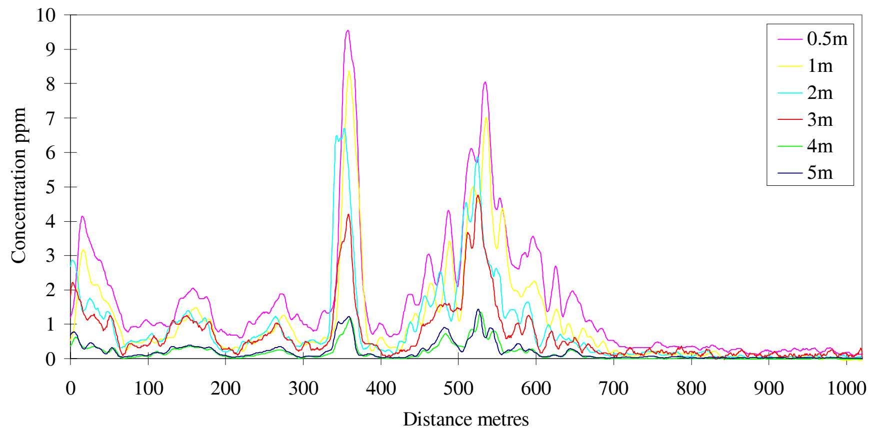
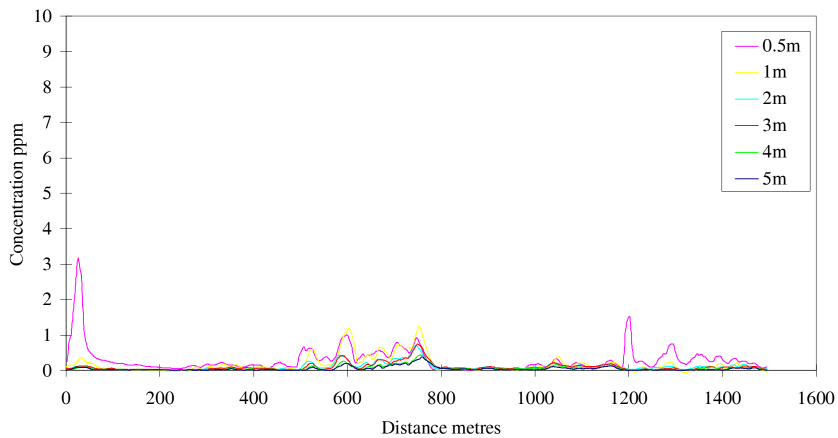


Figure 20. UVF transect of IFO-180 slick on 22/09/97 at 11:53 - During dispersant spraying



Third Dispersant Spraying Operation (Late Monday Morning). Surveillance flights carried out later on Monday found emulsified oil in the Hotel slick. It was decided to spray the slick with dispersant.

Six spray passes were made between 11:15 and 11:32 on Monday 22nd September, approximately 25 hours after release. Two areas of the slick were being targeted in each spray pass. Approximately 1000 litres of Corexit 9500 was applied, with 800 litres being judged on target. The ship was driven through the Hotel slick in an attempt to aid dispersion, but some of the emulsified IFO-180 fuel oil remained as small broken patches on the sea surface.

Summary and Conclusions

These field experiments have estimated the effectiveness of aerially applied dispersants on weathered crude oils and a fuel oil. The experiments were conducted in relatively calm sea conditions which limited the rate of oil weathering, but provided only moderate wave energy for chemically enhanced dispersion.

The specific findings from these field trials are:

(i) Corexit 9500 and Dasic Slickgone NS rapidly and totally dispersed Forties blend crude oil that had been weathered on the sea for approximately 45 hours. The emulsified Forties oil had a viscosity of 4,000 cP to 4,500 cP with a water content of 50% volume.

(ii) Aerially applied Corexit 9500 totally dispersed Alaska North Slope crude oil that had been weathered for 55 hours. The rate of dispersion appeared to be slightly slower than that observed for the weathered Forties oil but the Alaska North Slope oil was also totally dispersed. The emulsified Alaska Noth Slope crude oil had a viscosity in the range of 15,000 cP to 20,000 cP with a water content of 30 ± 5% volume.

(iii) The application of only 600 litres of Corexit 9500 slowly, but only partially, dispersed IFO-180 fuel oil that had been weathered for 4.5 hours. Further application of dispersant was not possible because of technical problems with the spray plane. The emulsified IFO-180 fuel oil had a viscosity of 5,000 cP to 8,000 cP and a water content of 20 to 30% volume before spraying and the viscosity and water content dropped as the dispersant broke the emulsion and some of the oil was dispersed.

(iv) Corexit 9500 had a limited dispersing effect on IFO-180 fuel oil that had been allowed to weather for 23 hours, even when the dispersant was used in much greater quantities than in the previous experiment. On the basis of samples collected it seems that the emulsified IFO-180 fuel oil which had a viscosity of 8,000 cP to 12,000 cP (with a water content of 20 to 30% volume was) dispersed, but emulsified IFO-180 fuel oil with a viscosity above 20,000 cP to 30,000 cP was not dispersed to any degree.

It can therefore be concluded that emulsion viscosity (expressed as the viscosity at a shear rate of $10s^{-1}$) is a only an approximate guide to dispersibility by the addition of dispersants. It is evident that higher viscosity emulsions are generally more difficult to disperse than lower viscosity emulsions, and that the chemically enhanced dispersion of high viscosity emulsions is generally slower than that of lower viscosity emulsions, but it is not possible to determine whether an emulsified oil is dispersible from considering only the viscosity of the emulsion.

The results presented in this paper show that it was possible to totally disperse an emulsified crude oil residue with an emulsion viscosity of 20,000 cP. Using a low dose rate of Corexit 9500 it was possible to partially disperse an emulsified fuel oil with a maximum emulsion viscosity of approximately 12,000 to 20,000 cP. When the emulsified fuel oil viscosity had reached 20,000 cP, the emulsion could not be dispersed to any significant degree, even when a much higher dose rate of dispersant was used.

The viscosity of the oil residue that constitutes one phase of the emulsified oil is obviously an important determinant of dispersant performance. Two emulsions may have the same viscosity, but for different reasons; a high viscosity oil residue with a low water content will produce an emulsion of similar viscosity as that of a low viscosity oil residue with a much higher water content. The emulsion formed from the lower viscosity oil residue will be more dispersible than that formed from the higher viscosity oil residue because the action of some dispersants is to ‘break’ the emulsion (convert it back to its constituent phases of oil residue and water) before the oil is dispersed. The viscosity of the oil residue that remains after evaporation of the more volatile components is of greater importance to chemically enhanced dispersion than the emulsion viscosity.

The effectiveness of an oil spill dispersant in breaking an emulsion is therefore another important factor in controlling chemically enhanced dispersion. The emulsion breaking capability of a dispersant will be resisted by the stability of the emulsion to chemical breaking. Emulsions of different crude oils have different stabilities. The emulsion formed from the residue of Forties Blend crude oil that is left after substantial evaporative loss is not very stable to breaking by dispersants. The emulsion formed by weathered Alaska North Slope crude oil is more stable, but was still broken by Corexit 9500 and the oil residue was dispersed.

Predicting the effectiveness of dispersants needs to take into account more than the viscosity of the emulsion that is formed by oil weathering. It is not possible to derive an emulsion viscosity value, or an oil residue viscosity value, that will reliably indicate the limits of dispersants (in general, or for a specific dispersant) on all oils. The stability of an emulsion to breaking by a dispersant is an important factor that cannot be predicted from a consideration of chemical composition of an oil. At present, the most reliable predictions of the effectiveness of dispersants can only be made on the basis of specific dispersant testing in the laboratory using artificially weathered oils. Assumptions of dispersant effectiveness made on the basis of a general limiting emulsion viscosity that is applicable to all oil types cannot be justified.

Acknowledgements

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The efforts of all the ship and aircraft crews, scientists and observers (NETCEN staff and others) and other people that participated in this field trial, or helped to make it possible in other ways, are gratefully acknowledged.

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Biographical Sketch of Senior Author. Alun Lewis, a graduate of the Royal Institute of Chemistry, London, joined the BP Research Centre in 1967. Having totally failed to appreciate the significance of the *Torrey Canyon* oil spill (which had happened the same year) on his future work, he concentrated on analytical procedures that are used by the oil industry. This involved working with crude oils and all liquid petroleum products from gasoline to bitumen. This preoccupied him for much of the late 60s and early 70s. Moving on to product development projects, he specialised in oil/surfactant interactions in products as diverse as cattle food grown on oil, bitumen emulsions for highways and lubricating greases. In 1979 he joined the BP team that were developing oil spill dispersants that were to be used in Arctic areas. This topic led him to be interested in oil weathering and the fate and effects of spilled oil. During the early 80s he helped develop the Enersperse range of oil spill dispersants and participated in field trials in the North Sea (UK and Norwegian sectors) and in the Beaufort Sea. In 1986, BP terminated its research on oil spills. After working on a range of other topics, such as marine lubricants for sulphur oxide emission reduction and the combustion of Orimulsion, he left BP at the end of 1992.

After a short spell at the now defunct Warren Spring Laboratory in 1993, Alun joined SINTEF in Trondheim , Norway to work on oil spill topics. He participated in the 1994, 1995 and 1996 field trials with an interest in remote sensing from aircraft and the helicopter application of dispersants. In June 1997 he left SINTEF and joined AEA Technology at Culham in Oxfordshire.

Dispersant Experience in Norway:
Dispersant Effectiveness, Monitoring and Fate of Dispersed Oil

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Daling, P.S., PJ. Brandvik, and M. Reed. 1998. Dispersant Experience in Norway: Dispersant Effectiveness, Monitoring and Fate of Dispersed Oil. In Trudel, B.K.(ed.). Proceedings of the Conference, "Dispersant Use in Alaska: A Technical Update", Anchorage, Alaska, March 18 & 19, 1998, Prince William Sound Oil Spill Recovery Institute, Cordova, Alaska.

Abstract
In Norway, mechanical recovery has traditionally been the preferred response technique for the past two decades. More recently, the Norwegian Pollution Control Authority (SFT) has opened the door to the consideration of dispersant use in certain oil spill situations. The responsibility for planning and decision for use / non-use of dispersants lies with the oil industry / enterprise itself; their decisions are subject to review and approval by the Pollution Authority. This is in accordance with the "Principle of Internal Control" on which the Authorities focus their regulations. The new regulations for use of dispersants in Norway will require well-documented contingency plans both at refineries, oil terminals and offshore installations. The background for the change in the attitude for use of dispersants in Norway is a result of the recent years progress in scientific documentation of dispersant use.

This paper gives an overview of methodology developed and recent research findings at SINTEF from oil weathering studies and dispersant performance testing in the laboratory and in meso-scale flume basin tests. Additionally, a summary of the Norwegian dispersant field trials program in the North Sea (1994, 1995 and 1996) are given, where the main objectives have been to optimize the efficiency of dispersant treatment operations in Norwegian waters, in order to form a basis for building up an operational and effective dispersant response for specific Norwegian locations (oil terminals, refineries and off-shore oil fields).

Examples from a dispersant contingency plan for a coastal oil terminal in Norway are presented as a case study. Here the "Oil Spill Contingency and Response" (OSCAR) model system was a key tool in quantifying the effectiveness of various response countermeasures and in Net Environmental Analysis (NEBA) of oil spill scenarios. OSCAR was also used in development of a "dispersant-effectiveness map system" of the geographical area around the terminal as support for a rapid decision-making and response action under various environmental conditions.

Introduction

The behavior of spilled crude oils and refined oil products depends on the prevailing conditions (e.g. temperature, sea-state, currents) and on the chemical composition of the oil. Large variations in crude oil properties cause them to behave differently when spilled at sea. The Gullfaks crude spilled at the "Braer" incident in the Shetlands has a low content of waxes and asphaltenes, which are important compounds for stabilizing water-in-oil *(w/o)* emulsions formed on the sea surface. This, combined with violent weather conditions, resulted in consequences that were much less severe than might have been expected (Harris, 1995). Almost all of the 84,000 tons of the spilled Gullfaks crude oil was naturally dispersed. During the recent "Sea Empress" spill, a significant amount of the surface oil was converted into *w/o-emulsion* (Lunel et aI., 1996). In the "Amoco Cadiz" and the "Metula" spills, persistent "chocolate mousse" has contaminated the shorelines for years after the initial spill (Gundlach et al. 1995, Baker et aI., 1993). Prior knowledge of the likely behavior and weathering of a spilled crude oil, pre-spill analyses of the feasibility and effectiveness of different response strategies for the actual oil under various environmental conditions should therefore be an essential part of any oil spill contingency planning. It is necessary to predict the total amount of damage that various oil spill scenarios would cause before estimating how much of this damage would be prevented by the proposed response. Such a pre-spill analysis has been formalized as the NEBA process *("Net Environmental Benefit Analysis"* of a combat operation (e.g. Baker, 1995 and 1997).

Norwegian oil production sites have, in recent years, been sited both further north and to more coastal areas. This means shorter oil drifting time to sensitive areas. Furthermore, the increasing variation in types of crude oils coming into production and a large number of petroleum products which are transported under different environmental conditions along the Norwegian coastline calls for more effective and t1exible oil spill contingency plans. It is generally accepted that no single technique will be capable of dealing with every oil spill scenario. In Norway, mechanical recovery has traditionally been the preferred response technique for the past two decades, however, the recent years, the situation has been changing. Pronouncements from the Norwegian Pollution Control Authority (SFT) state that the response alternative chosen should be the one that minimizes the environmental damage that would be caused by the oil spill - in line with the NEBA philosophy. The Norwegian Pollution Authority has therefore opened the door for considering use of dispersant in certain oil spill situations. This must been seen as a result of the recent years progress taking place in the research and scientific documentation of:

- Dispersibility and "window of opportunity" for effective use of dispersants for different oil types under various spill conditions
- Development of less toxic dispersants formulations
- Dispersant performance testing ensure that dispersant products coming in contingency stock "match" to the oil type in order to obtain optimal effectiveness
- Improved dispersant application technology and operational response strategy

In Norway, the responsible party takes the lead in responding to the spill. This is in accordance with the "principle of internal control" that the pollution authorities focus their *"New regulations for Use of Dispersants in Norway"* on (SFT, 1998). The Norwegian Pollution Control Authority requires well documented contingency plans at refineries, oil terminals and offshore installations. The OSCAR (Oil Spill Contingency and Response) model system (Aamo ~~et al.~~ 1997a and b, Reed et al., 1995 and 1997) is now extensively used in such contingency planning for pre-spill scenario analysis and to quantify the fate, weathering, potential environmental consequences and the feasibility and effectiveness of various combat methods (including use of dispersants). Quick response decision-making procedures are imperative to minimize the overall environmental impact of a spill.

This paper gives an overview of methodology development and recent research findings at SINTEF on oil weathering studies and dispersant performance testing in the laboratory and in meso-scale flume basin tests. Additionally, the paper summarize the Norwegian dispersant field trials program in the North Sea (1994, 1995 and 1996). Here the main objectives were to optimize the efficiency of dispersant treatment operations, in order to form a basis for building up an operational and effective dispersant response for specific Norwegian locations (oil terminals, refineries and offshore oil fields). Examples in use of OSCAR in connection with dispersant contingency planning for a coastal oil terminal in Norway are presented as a case study.

SINTEF Methodology for Characterizing an Oil's Weathering Properties and Chemical Dispersibility

Small-scale Weathering

A small-scale laboratory procedure to characterize the weathering properties of different oils has been developed and standardized at SINTEF (Strøm-Kristiansen, et al., 1993, Daling et al. 1997). To isolate influence of different weathering processes (i.e. evaporative loss, photo-oxidation and water-in-oil emulsification), topped oil residues and water-in-oil emulsions (altogether 16 weathered samples) are prepared in a "step-wise" way from the fresh oil as schematically shown in Figure 2.1. These weathered samples represent various stages (weathering times) at sea. The samples are characterized to determine the changes in physico-chemical and emulsifying properties as well as the chemical dispersibility (Daling et al., 1990). The experimental data created from this laboratory investigation (see Table 2.1) form a basic input for predicting the weathering behavior of the different oils at sea by use of the SINTEF Oil Weathering Model (SINTEF-OWM, see chapter 3).

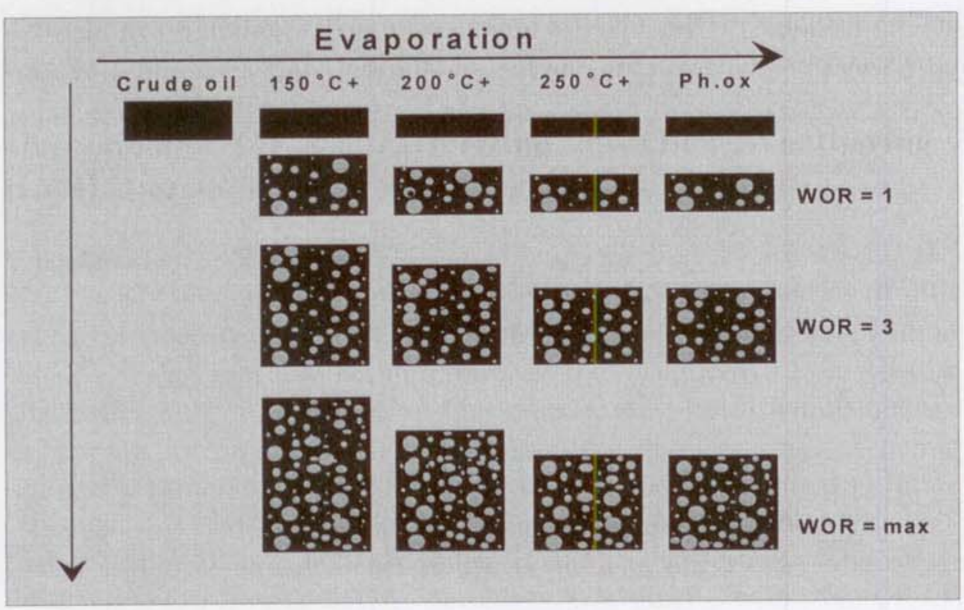

Figure 2.1 Flow chart for "stepwise" weathering (evaporation, photo-oxidation and water-in-oil emulsification) of a crude oil. The four water-free samples are evaporation residues. The evaporation is performed either by distillation or photo-oxidation. Emulsions with three different water contents (water-to-oil ratios, WOR) are also prepared.

Table 2.1. Example of experimental data generated from laboratory weathering investigation of Troll crude oil and used as input to the SINTEF Oil Weathering Model(SINTEF-OWM)

Oil type:	**Troll North Sea Crude**						
Data Source:	IKU Petroleum Research, SINTEF						
Product:	Crude						
Location:	North sea						
Year:	1995						
Description:	Troll crude, distillation data from Statoil.						
Lab weathering data:		Oil topping (vapor temp.)				**TBP-curve:**	
PROPERTY	Fresh Crude	150^0C+ residue	200^0C+ residue	250^0C+ residue		Temp. (°C)	Volume (%)
						65.0	1.43
Boiling (liquid) temp. (°C)	-	210	255	300		90.0	3.04
Volume topped (%)	0	8	15	24		150.0	9.57
Residue (wt.%)	100	93	87	78		180.0	13.83
Specific gravity (g/l)	0.893	0.903	0.909	0.919		240.0	24.49
Pourpoint (°C)	-39	-15	-9	3		320.0	45.71
Flashpoint (°C)	3	50	80	119		375.0	57.21
Viscosity at 13°C(cP)	27	49	83	200		420.0	63.59
Viscosity of 50% emulsion (cP)	-	343	593	1300		525.0	83.78
Viscosity of 75% emulsion (cP)	-	1815	2673	4790		565.0	87
Viscosity of max water (cP)	-	-	-	-			
Max. water content (%)	-	75	75	75			
Halftime for water uptake (hrs)	-	0.09	0.07	0.13			
Stability ratio	-	0.78	1	1			
Chemical dispersibility (viscosity ranges, cP at shear $10s^{-1}$):							
Dispersible	< 3000 cP						
Reduced dispersibility	3000 – 7000						
Poorly/slowly dispersible	> 7000						

Laboratory testing of an oil's chemical dispersibility

Weathering causes an increase in the viscosity of the oil, raises its pour point and can form water-oil-emulsions of very different stability (e.g. Lewis et al., 1995a). All of these processes will tend to make an oil less dispersible when the viscosity of the oil or emulsion approaches a limiting value. The precise value of this limiting viscosity depends on the type of crude, the prevailing conditions and on the type of dispersant used (e.g. Fiocco and Lessard, 1997). As an approach in finding dispersibility to the specific oils, SINTEF has chosen to use the relatively energetic MNS test to represent the most energetic conditions and the lower energetic IFP test to represent calmer conditions (Daling et al., 1990, Lewis et al., 1995b). Schematics of the two methods are given in figure 2.2).

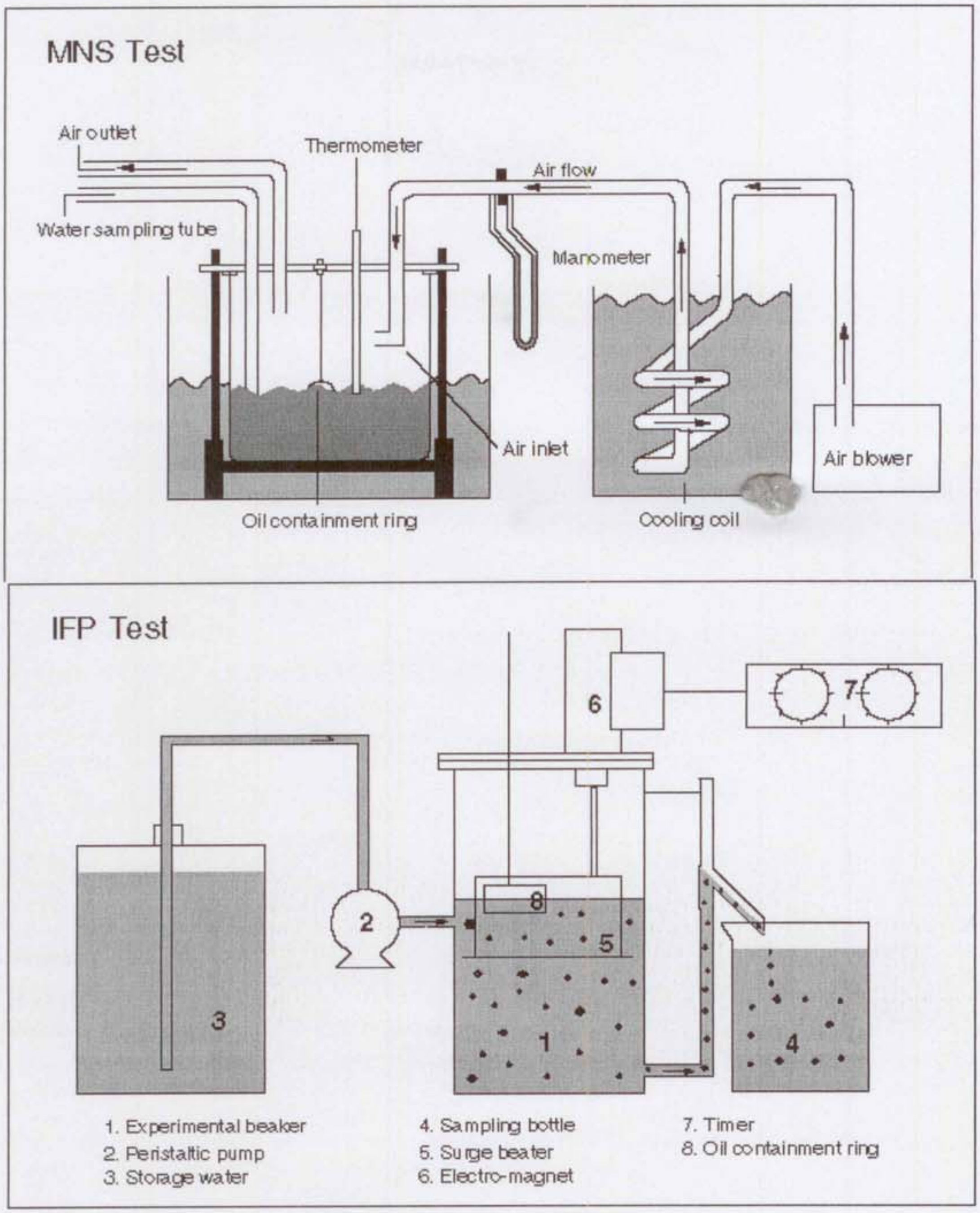

Figure 2.2 Laboratory apparatus for effectiveness testing of dispersants.

Several dispersants, selected to represent the range of products that could be used to treat the spill, are then tested in both methods against all the 16 distillation residues and emulsions prepared in Figure 2.1. The dispersant effectiveness results are plotted as a function of the viscosities of the oils / residues and water-in-oil emulsions, measured at shear rates 100 and $10s^{-1}$, respectively. An example of such plots ("trend curves") is given in Figure 2.3. Table 2.2 lists the criteria chosen for an oil's chemical dispersibility. From this extensive laboratory dispersibility testing, the "dispersibility properties" (given in viscosity ranges) are defined for each specific oil and used in the SINTEF-OWM to estimate the "time window" for appropriate use of dispersants for different oils spilled under various environmental situations (see chapter 3). Table 2.3 gives examples of the great variation in "dispersibility properties" (given in viscosity areas) for the different oils tested. These dispersibility results are based on the best dispersant product tested for each oil. The table shows also the effect of using the optimal dispersant product for the specific oil (e.g. by using Corexit 9500 instead of 9527 on Alaska North Slope).

Experience from the 1994 field trials with application of dispersants on weathered/emulsified Sture blend crude (Lewis et al., 1995d) and the recent UK AEA-97 trials (Lewis et al. 1998) both indicate that the laboratory-derived dispersibility values are in fairly good agreement with the field observations. The laboratory test methods produce data that represents, however, only a "snapshot" of the dynamic and time-dependent dispersion process which often takes place at sea. This means that highly weathered emulsions showing low dispersibility in the laboratory tests, may have a slow but enhanced "natural" dispersion that take place, over a longer period (many hours or even 1-2 days after treatment) in the field (Lichtenthaler and Daling, 1985, Lewis et al. 1995c and 1995d). This phenomenon is not sufficiently reflected in the present laboratory procedures for defining the criteria for dispersibility at sea. There is, however, a potential in improving the test procedures in order to better reflect the more "long-term" effects of dispersants treatment. SINTEF will therefore focus the research on improving test methodology procedures. This will enable us to create more representative empirical dispersibility data that can be used as input to weathering models to improve the prediction quality of the "operational time window" for use of dispersants under various spill situations. This will increase the reliability of oil weathering models as operational tools for use in contingency planning and during combat operations.

Table 2.2 Criteria for chemical dispersibility of an oil tested on different weathered samples.

Chemical dispersible	if the effectiveness is higher than 50% with the IFP-test and 70-80% with the MNS-test.
Reduced dispersibility	where the IFP-values drops below 50% to the viscosity where the MNS shows 5% effectiveness.
Poorly / slowly dispersible	if the MNS-value is showing less than 5% effectiveness.

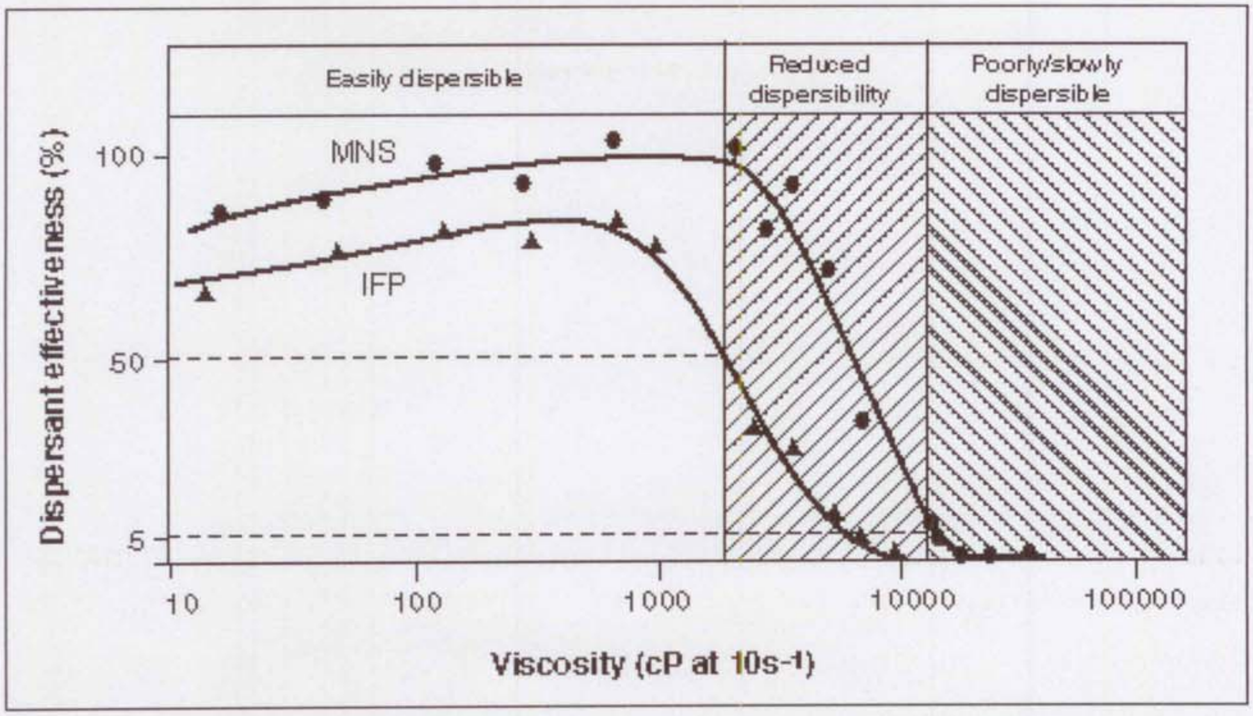

Figure 2.3 Example of dispersants effectiveness data ("trend curves") obtained with the MNS and IFP laboratory tests used in defining the chemical dispersibility of an oil.

Table 2.3 "Dispersant properties" (given in viscosity areas) for some crude oils tested.

	Viscosity (cP, measured at shear rate 10 s^{-1})		
Crude oils	**Dispersible**	**Reduced Dispersibility**	**Poorly / slowly Dispersible**
Alaskan North Slope with Corexit 9527	< 1,000	1,000 to 10,000	> 10,000
Alaskan North Slope with Corexit 9500	< 4,000	4,000 to 20,000	> 20,000
Balder (Norwegian)	< 6,000	6,000 to 20,000	> 20,000
Bonny Light	< 500	500 to 2,000	> 2,000
BCF-17 (Venezuela)	< 10,000	10,000 to 26,000	> 26,000
Grane (Norwegian)	< 12,000	12,000 to 30,000	> 30,000
Oseberg-Etive (Norwegian)	< 4,000	4,000 to 6,000	> 6,000
Sture blend (Norwegian)	< 2,000	2,000 to 9,000	> 9,000
Troll (Norwegian)	< 3,000	3,000 to 7,000	> 7,000

Meso-scale flume basin for oil weathering and in-situ dispersant effectiveness studies

When studying weathering effects and chemical dispersibility of different oils, it is important that the oils are exposed to weathering under as realistic conditions as possible. At SINTEF, a meso-scale flume basin has been carefully designed to simulate the weathering processes (i.e., evaporative loss, photo-oxidation, natural dispersion, emulsification, dissolution etc.) which simultaneously take place at sea. This elliptical flume is 9 m in circumference, 0.5 m wide and has a water depth of 0.4 m giving a volume of approximately 1.75 m^3 of sea water circulating in the flume (see schematics in figure 2.4). An adjustable wave generator supplies wave energy. Two fans placed in a wind tunnel can create various wind velocities. Water currents is generated by water pumps at the basin bottom (Singsaas et al. 1993). A large number of experiments have been carried out in the flume basin under different environmental (i.e., tropical, North Sea, and arctic) conditions by varying parameters like oil type, temperature, wave-energy, salinity etc.

The flume basin has demonstrated to provide reliable conditions for studying the weathering properties of different oil types and for testing the performance of dispersants. The flume basin has therefore become an important supplement to the small-scale ("stepwise") weathering procedure to give data input to the SINTEF-OWM used for predicting oils' behavior at sea and in realistic laboratory dispersant performance studies. Correlations between experiments in the SINTEF flume and ground-truth data from field experiments are discussed by Strøm-Kristiansen et al., (1997).

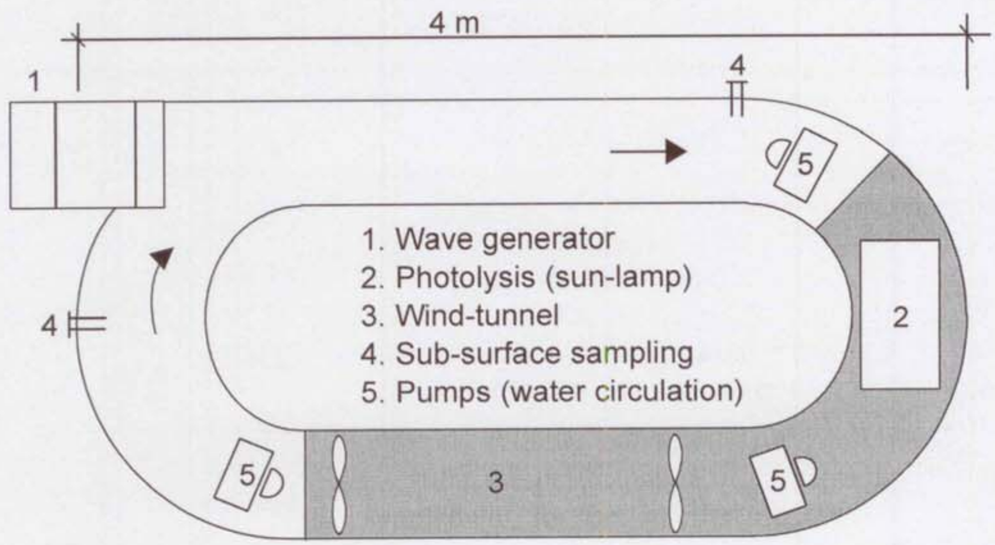

Figure 2.4 SINTEF's meso-scale flume basin for oil weathering and in-situ dispersant testing

The figures 2.5 and 2.6 show examples from data generated from a 3 days weathering study in the SINTEF meso-scale flume with the Troll crude. The weathering study was followed by 2 series of low dosage dispersant treatment of the w/o-emulsion with Corexit 9500. The 1st series of dispersant treatment (dispersant-to-oil ratio of e.g. 1 : 75, means a dispersant-to emulsion ratio of about 1 : 200) led to dispersion of about the half of the emulsion available on the surface into the water column (see fig 2.5). The emulsion remaining on the surface got a drastic reduction in water-content and viscosity (see fig. 2.6). This emulsion-breaking properties of certain dispersant concentrates at low dosage treatment has been documented also in field (Lewis et al., 1995c).

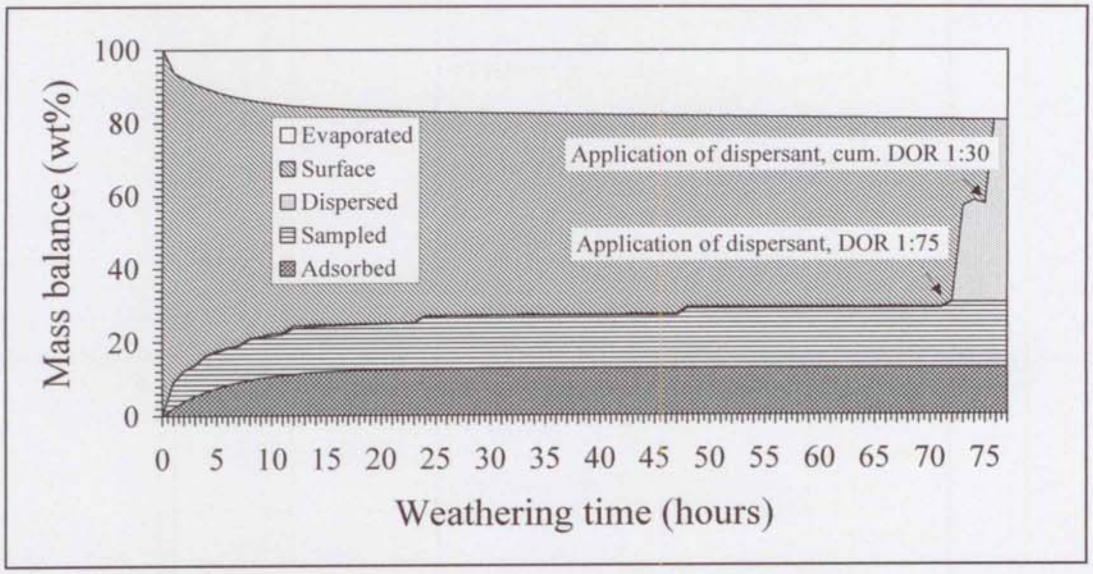

Figure 2.5 Mass balance of Troll crude oil during 3 days weathering followed by 2 series of low dosage treatment on the w/o-emulsion with Corexit 9500

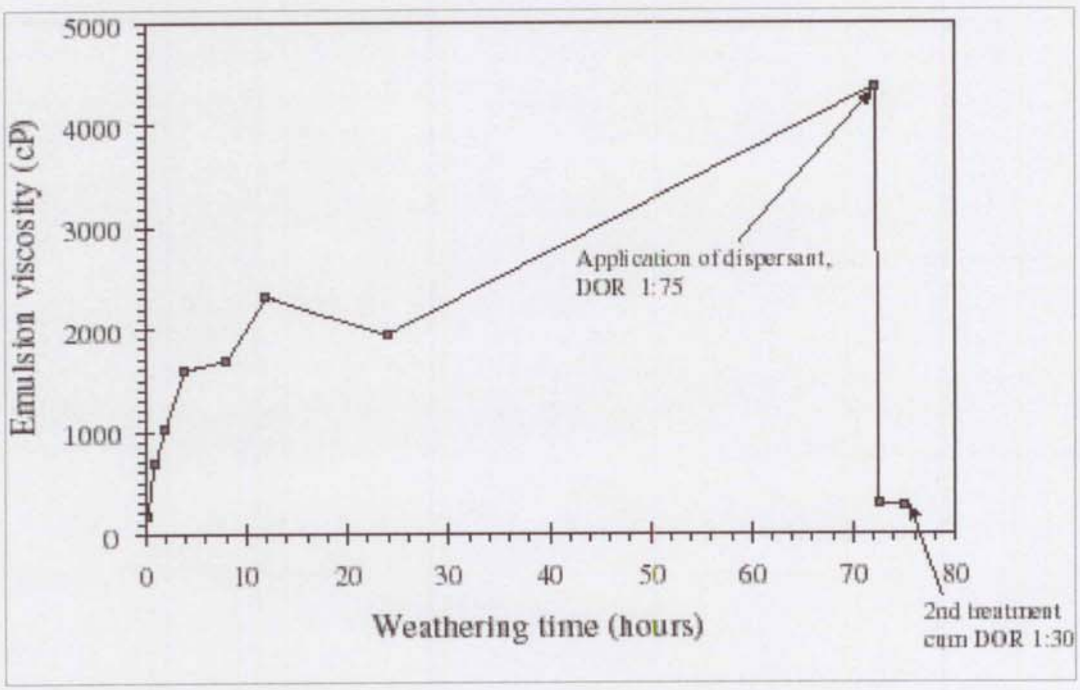

Figure 2.6 Development in w/o-emulsions (measured at shear rate $10s^{-1}$) of Troll crude oil during 3 days weathering, and the effect of low dosage treatment on the w/o-emulsion with Corexit 9500.

SINTEF-OWM for predicting oils' properties and estimating "time-window" for effectiveness use of dispersants at sea.

The SINTEF-OWM – an empirical oil weathering model approach

Different approaches to predict changes in oil properties due to weathering have been developed by the industry during the last decades (e.g. ITOPF, 1987). In many cases, these models are based on a set of "mixing rules", where various physical oil properties are derived on the basis of composition change caused by evaporation of the lighter oil components. Algorithms based on such simple "mixing rules" may be relevant for prediction of some properties, such as density, but are less relevant for other properties, such as viscosity, pour-point and w/o-emulsification properties (Johansen, 1991). As a consequence, an empirical model approach has been used in the development of the SINTEF-OWM (Daling et al., 1990, Aamo et al., 1993). The SINTEF-OWM (see schematic diagram in figure 3.1) calculates the changes in oil properties due to weathering under user-specified environmental conditions (release conditions, film thickness, sea state and temperatures) and is based on the empirical data from the previously described standardized laboratory weathering methodology. The current version of SINTEF-OWM runs under Microsoft Windows NT on a personal computer. Figure 3.2 gives an example of an output sheet from the SINTEF-OWM, showing predicted viscosity values for the Troll crude at 2, 5, 10 and 15 m/s constant wind conditions. The predictions are very comparable with measured viscosity values with the same crude weathered in the meso-scale flume basin (simulating wind conditions corresponding to 5-10 m/s wind) and in the field (where the wind speed varied between 5 to 8 m/s during the experiment, NOFO 1995 trial).

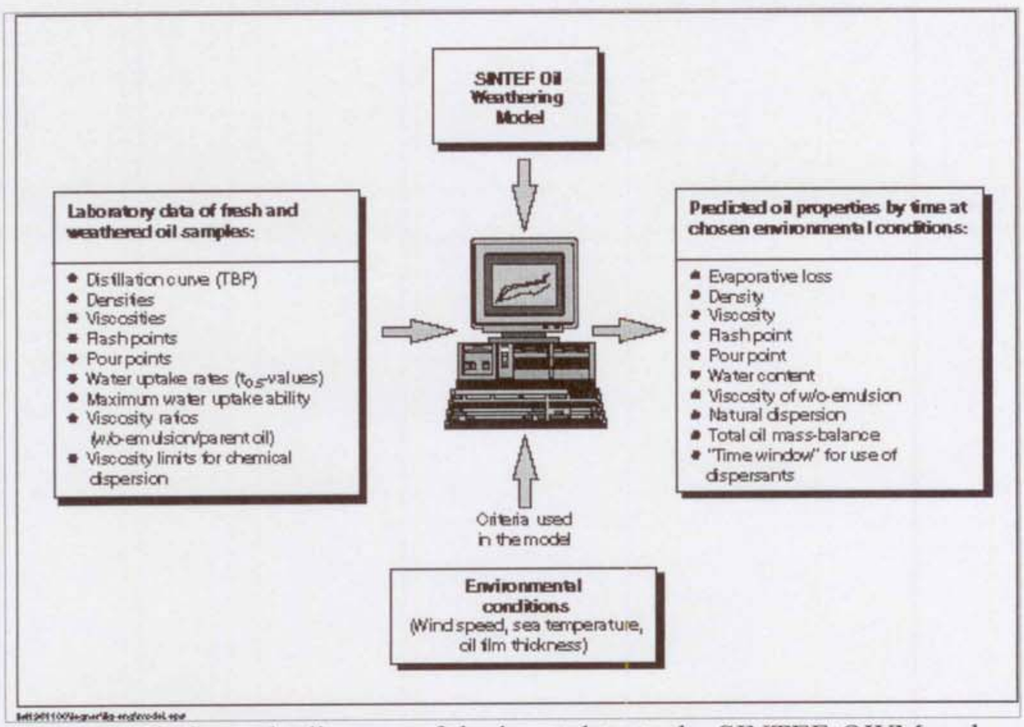

Figure 3.1Schematic diagram of the input data to the SINTEF-OWM and the predicted output oil properties.

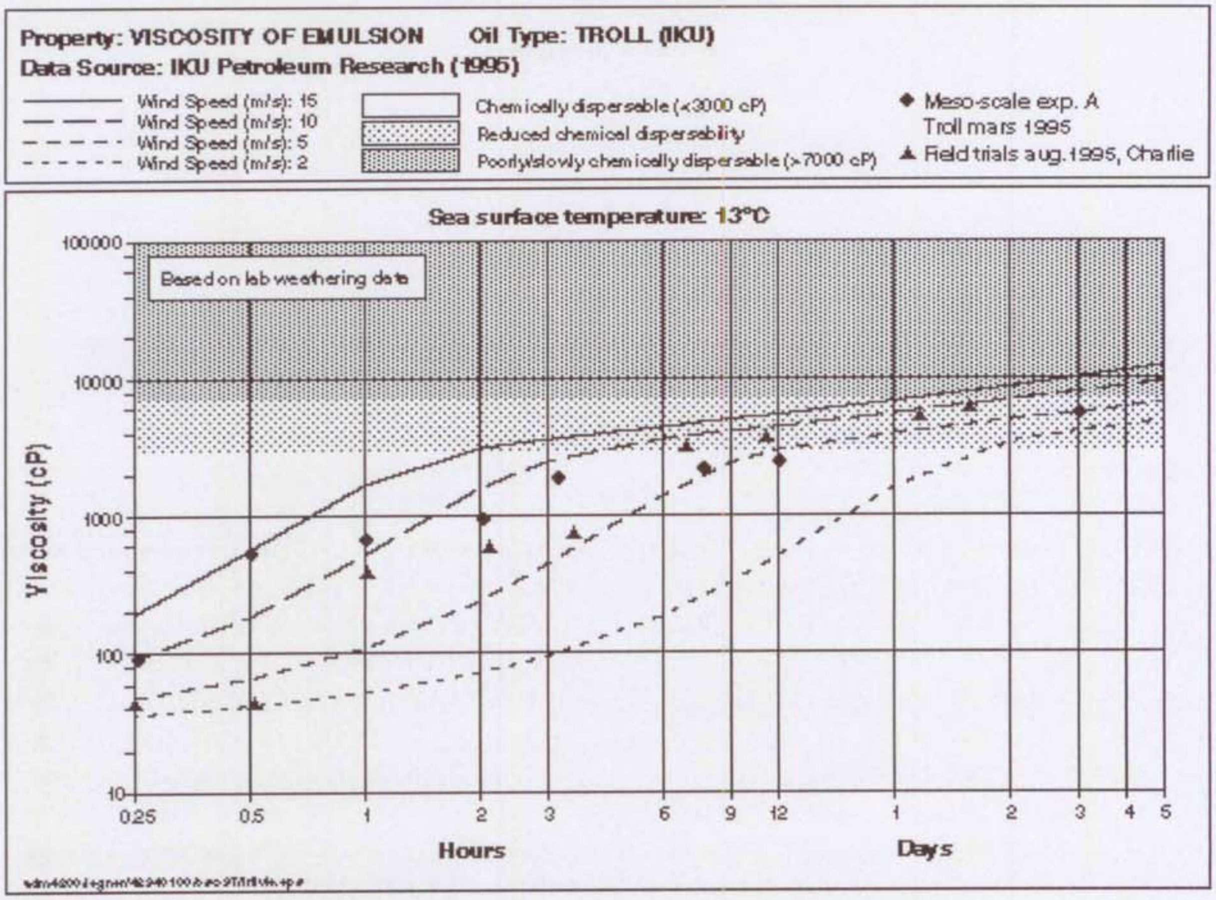

Figure 3.2 Example from a prediction sheet from the SINTEF-OWM showing viscosity development at 4 user-specified wind speeds compared to measured values obtained in the meso-scale flume basin and in the field (NOFO-1995 trial).

Time window for dispersant use

By combining the predictions of the increase in emulsion viscosity from the weathering modeling with the results of the chemical dispersibility study (Table 2.3), the viscosity prediction chart (figure 3.2) can, for each specific oil, be divided into the three "dispersibility areas". This make it possible to give an estimate of the "time-window" for effective use of dispersant under the chosen sea conditions.

Several crude oils recently coming into production in Norway have shown to be crudes with very high wax content. For some waxy crudes, high pour-point may limit the dispersant performance. Experience with such oils on the sea surface are that the oil may remain as a liquid, and emulsify as long as the sea temperature is less than 10 to 15°C below the pour point of the oil. In winter temperature these oils may, however, rapidly solidify on the surface and may be very difficult to deal with both with mechanical and chemical countermeasures. Dispersant effectiveness studies have also shown that oils are chemically dispersible up to 10 to 15°C below their pour point (Daling and Brandvik, 1991). Table 3.1 lists the pour point criteria chosen for predicting the chemical dispersibility of the weathered oils.

These criteria have been used in pour point prediction charts to estimate the time window for use of dispersants with respect to an oil's increase in pour point under chosen conditions (Lewis et al., 1995b).

Table 3.1 Pour point criteria for the predictions.

Pour point	Dispersibility
<5°C higher than sea temperature	Dispersible
5 to 15°C above sea temperature	Reduced dispersibility
>15°C above the sea temperature	Poorly / slowly dispersible

Comparison of model predictions with field data from trials in the North Sea

The SINTEF-OWM has been extensively tested and verified towards results from the 1994 and 1995 Norwegian field trials in the North Sea and the 1997 UK/AEA field trials in the southern North Sea. Different crude oils (Sture blend, Troll crude oil and Alaska North Slope) were used in the three series of field trials. The main objectives of the trials were to study the behavior of different crudes spilled under various conditions, and to identify the operational and logistical factors associated with different dispersant application techniques (see chapter 4). At the same time these field trials were carefully designed and planned in order to verify laboratory weathering studies and oil weathering model predictions.

Correlations between oil weathering values predicted by the SINTEF-OWM and ground-truth data obtained in the field are generally good (see examples in figure 3.3. and 3.4) when the model predictions are based on laboratory and meso-scale weathering input data. Further comparisons between field data vs. model predictions are given in Daling et al. (1997 and 1998).

The strength of the SINTEF-OWM lies in the continuous evolution of empirical algorithms based on good data from experimental field trials performed the last 15 years in Norway. New empirical data in future field trials will be used in further refinements of the algorithms in order to improve the accuracy in the predictions under various release and sea conditions (e.g. both calm and breaking wave conditions, underwater and surface releases, arctic and temperate conditions).

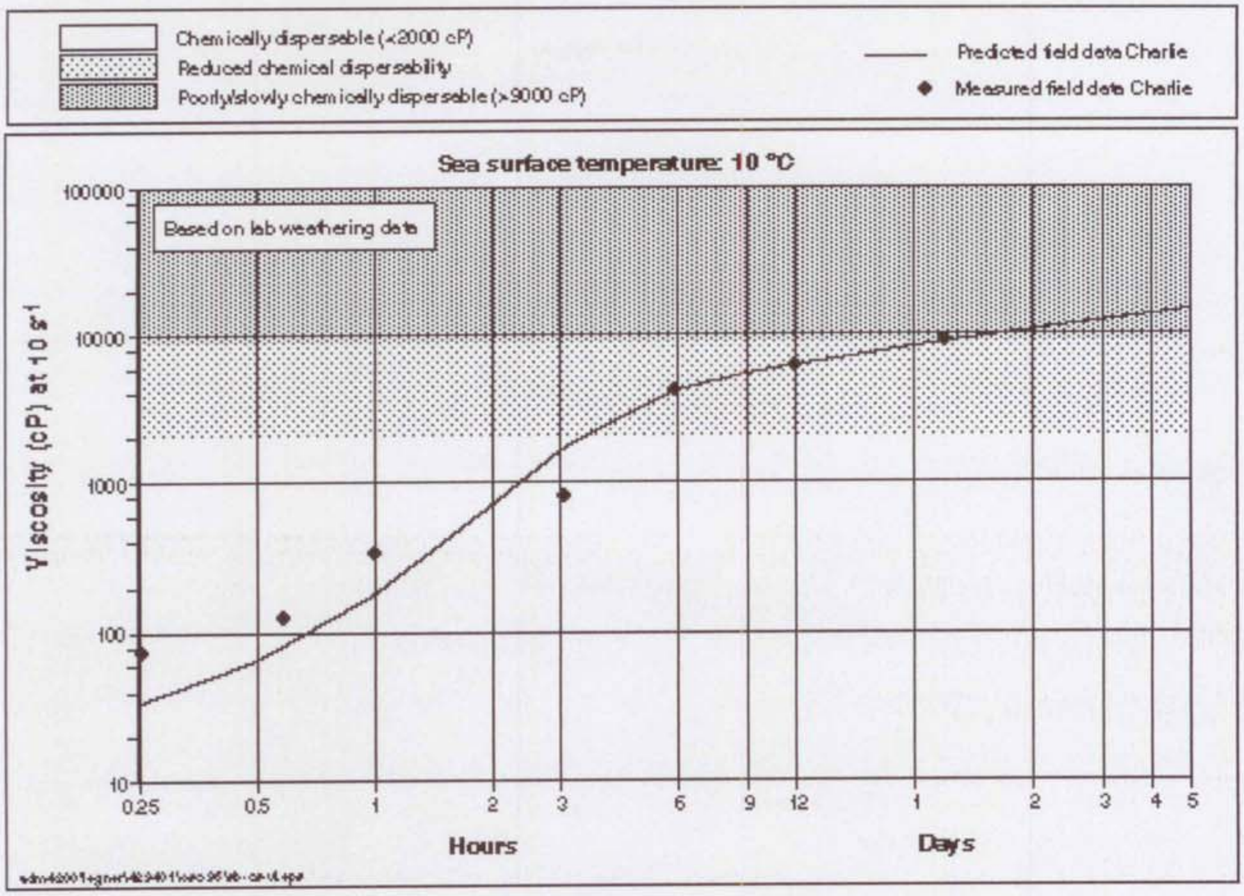

Figure 3.3 Good correlations obtained between predictions from the SINTEF-OWM and measured values of viscosities of w/o-emulsion of Sture Blend crude oil (20 m^3 crude released) obtained in 7-10 m/s wind conditions (Norwegian - NOFO field trial, June 1994).

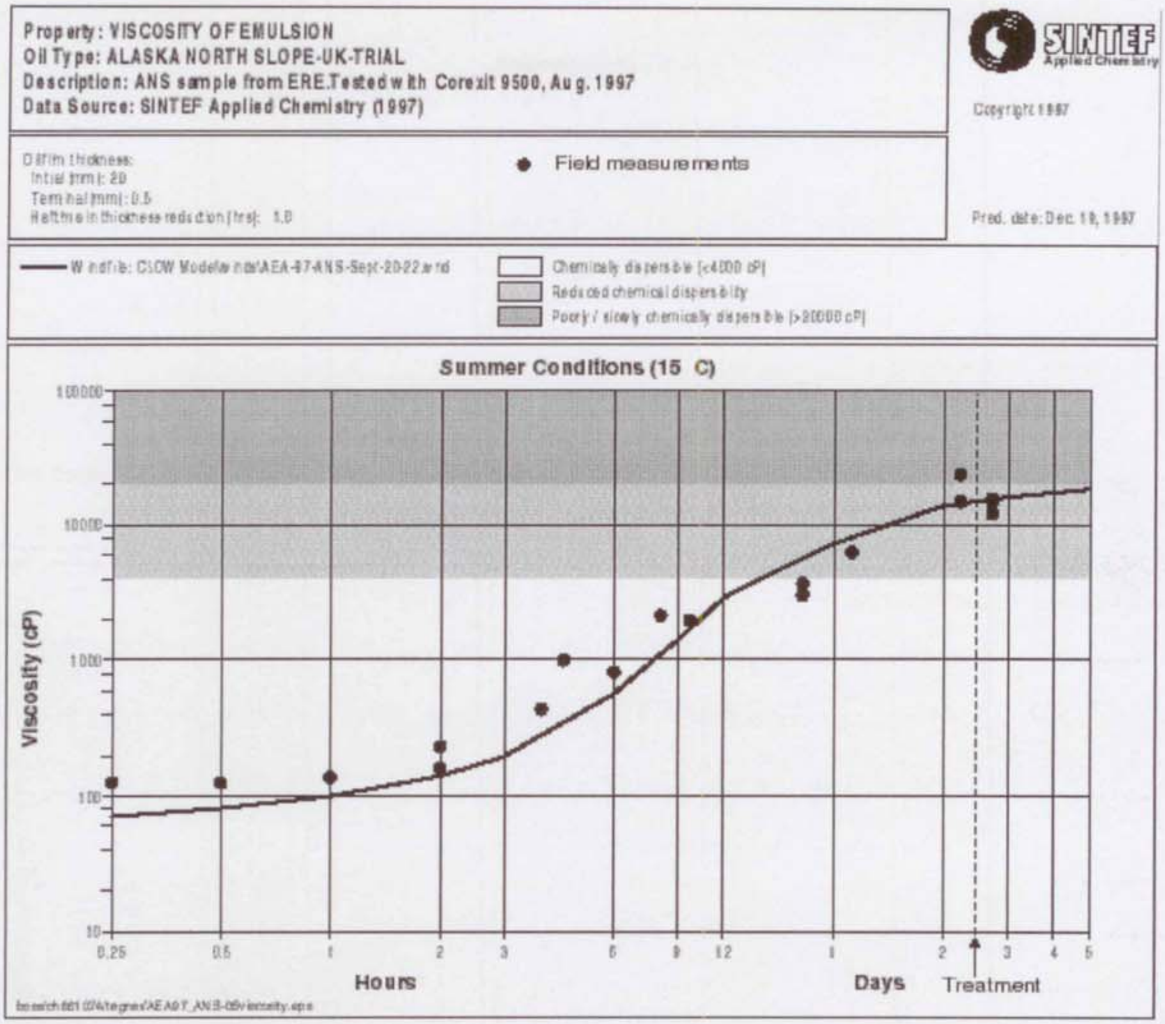

Figure 3.4 Predictions versus measured values for viscosity (at shear10 s^{-1}) of surface emulsion of Alaska North Slope (31 tons crude released) during relative high sea temperatures (15-18°C) and sunny conditions in the UK-AEA trials, Sept. 1997.

Dispersant Field Trials in Norway

This chapter gives the main findings from three series of full-scale field trials performed in the Norwegian sector of the North Sea. The field trials were carried out in June 1994, August 1995 and June 1996. The field trials were performed in close cooperation with the Norwegian Clean Seas Association for Operating Companies (NOFO), Norwegian oil companies, the Norwegian Pollution Control Authority (SFT) and SINTEF. The main objectives of the trials were to study the behavior of different crudes spilled under various conditions, and to identify the operational and logistical factors associated with different dispersant application techniques. These experiments have all been performed in the same area on the Norwegian continental shelf, see Figure 4.1.

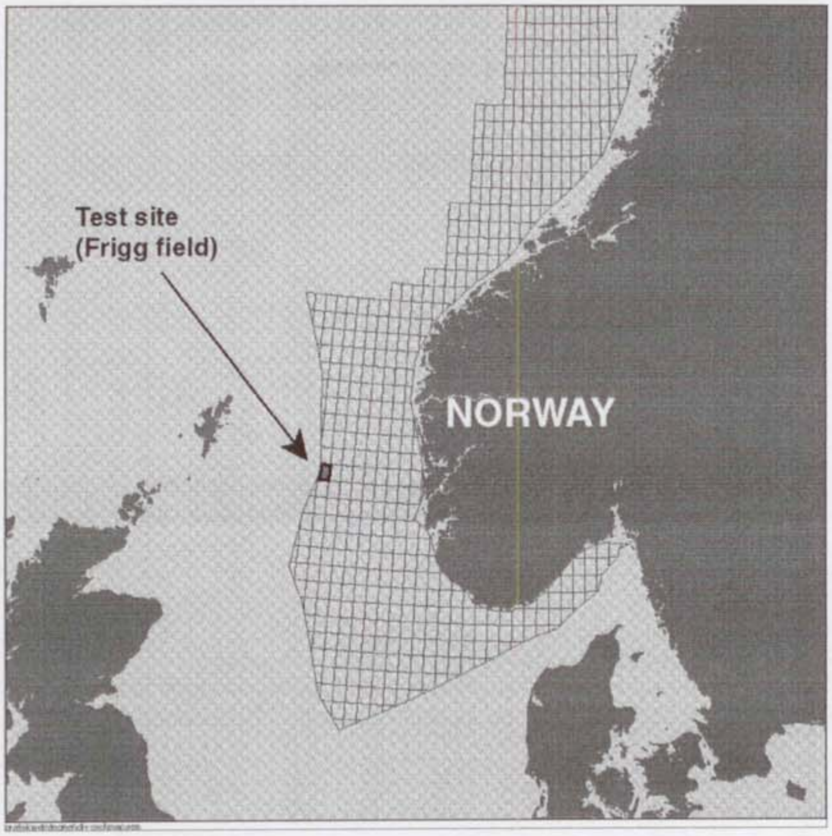

Figure 4.1 Map showing the location of the spill site and surrounding areas.

The 1994 Field Trials

The main objectives with this field trial were to perform operational testing of a Helicopter bucket for dispersant application and to verify laboratory studies of oil weathering (evaporation, natural dispersion and emulsification). Two oil slicks (2 x 20 m^3 of Sture Blend crude) were released and one slick (Tango slick) was treated with dispersant (Corexit 9500) after 3 and 7 hours weathering. The dispersant was applied by a Rototech TC-3 bucket from a Sikorsky S-61N helicopter, see figure 4.2. The objective was to focus the spray operation on the thick (emulsified) parts of the slick, see figure 4.3.

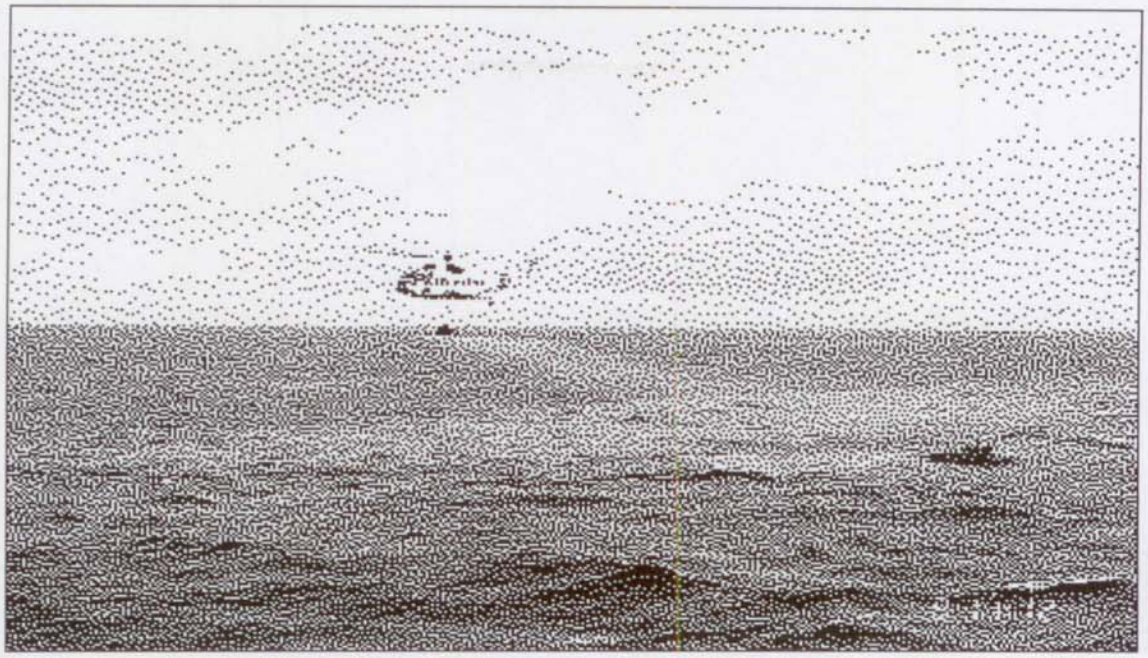

Figure 4.2 Dispersant application by the Rototech TC-3 bucket from a Sikorsky S-61N helicopter.

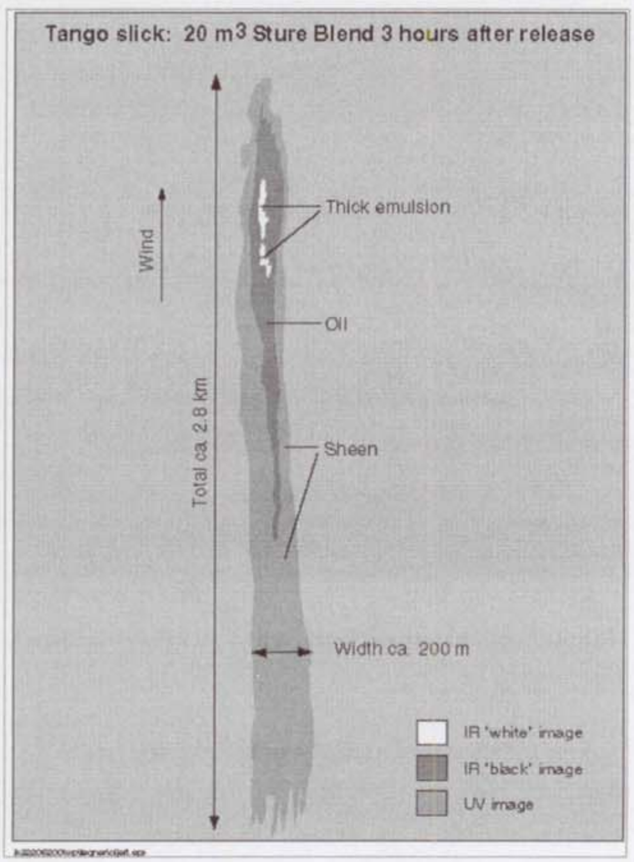

Figure 4.3 Oil distribution within the oil slick after 4 hours weathering and just before dispersant treatment (1994 field trials).

The main conclusions from the 1994 sea trial were:

1. Weathering .The weathering behavior of the released oil was in accordance to conclusions from previous laboratory studies and is used as calibration data for the SINTEF Oil Weathering model.

2. Dispersant application. Not only the thick emulsified parts of the slick were treated (see figure 4.3), but also the thinner "black oil" parts of the slick. This resulted in a very low dosage ratio (1:300 – 1:700) on the thick (2 – 9 mm) surface emulsion. This gave a slow but enhanced dispersion process due to a significant reduction in water content and viscosity of the emulsion after the 1st treatment. Figure 4.4 shows the lifetime of the treated slick (Tango) compared to the reference slick (Charlie). The treated slick was sprayed twice with dispersant and also the reference slick was treated after 28 hours to remove residual surface oil.

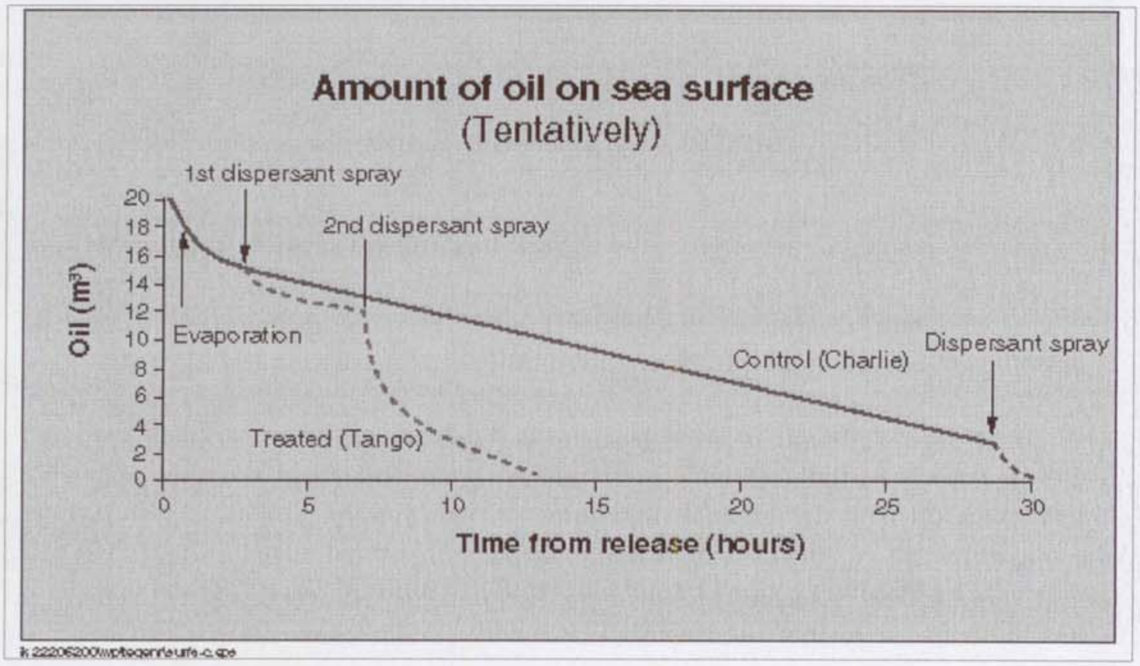

Figure 4.4Lifetime of surface oil slick; slick treated with dispersant (Tango) versus control slick (Charlie), 1994 sea trials.

Further details both concerning operational aspects, monitoring, analytical methods and conclusions from this sea trial are described in several reports e.g. Lewis et al., 1995a and 1995d.

The 1995 Field Trials

The main objectives with this field trial were to perform operational testing of a larger Helicopter bucket (SOKAF 3000, with $3m^3$ loading capacity) for dispersant application and compare it with dispersant application by boat. Three oil slicks (3 x 15 m^3 of Troll crude) were released for dispersant testing. One of the oil slicks was treated by helicopter, the second by boat and the third was left as a reference.

An underwater release of oil was performed to simulate a pipeline leakage. 25 m^3 of crude were released from a depth of 106 meters. The resulting slick was compared with that of a surface release.

Figure 4.5Dispersant application by the French SOKAF 3000 bucket from a Sikorsky S-61N helicopter (1994 field trials).

The dispersant effectiveness of the two different dispersant application techniques was monitored with UV fluorescence (Figure 4.6a) and by comparing with a corresponding reference slick (Figure 4.6c).

The underwater release was performed from a submerged platform trough a 4" opening without using excessive pressure and without gas to simulate oil leakage from an underwater pipeline. The underwater plume and the resulting surface oil slick were extensively monitored, see figure 4.7.

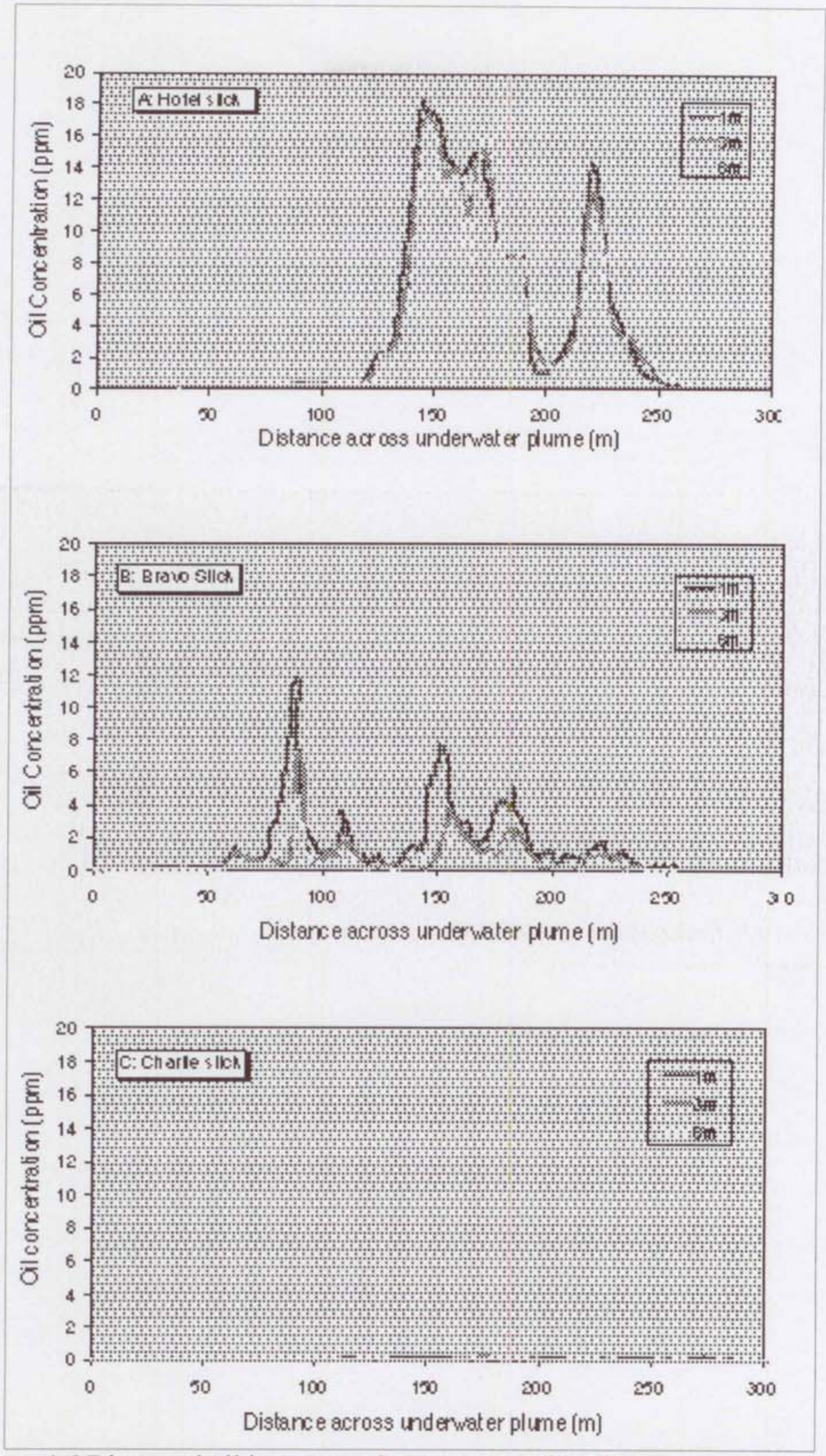

Figure 4.6 Dispersed oil in water column measured by UV fluorescence about 30 min after dispersant treatment. A: Helicopter application, B: Boat application, C: Control slick.

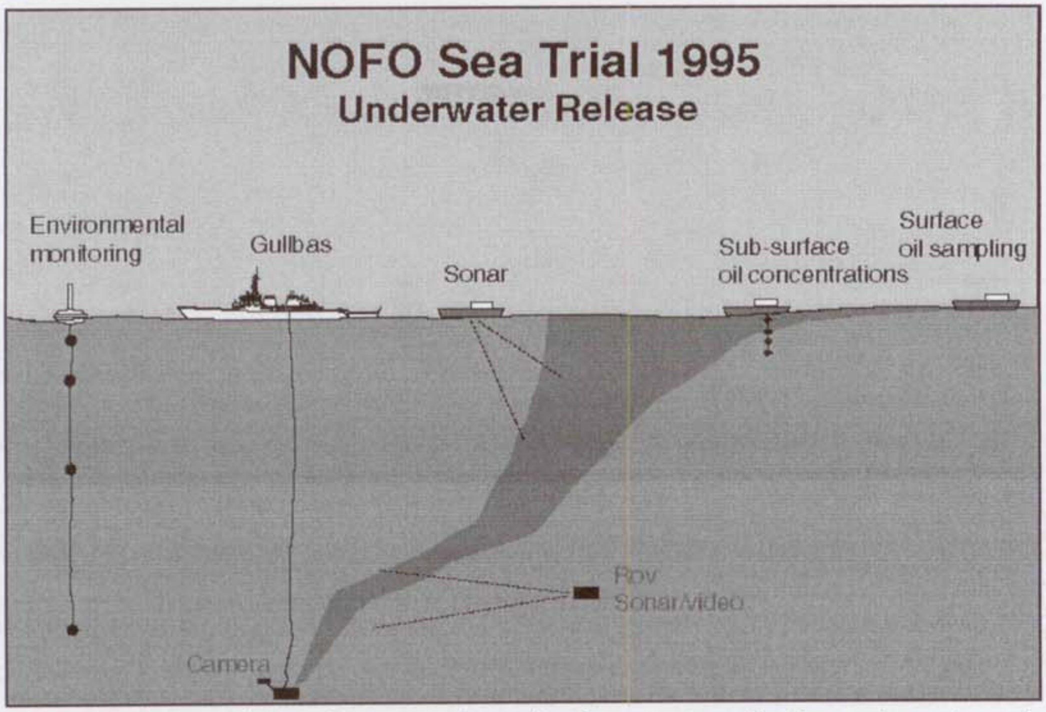

Figure 4.7 Experimental setup and monitoring strategy for the underwater release during the 1995 sea trial.

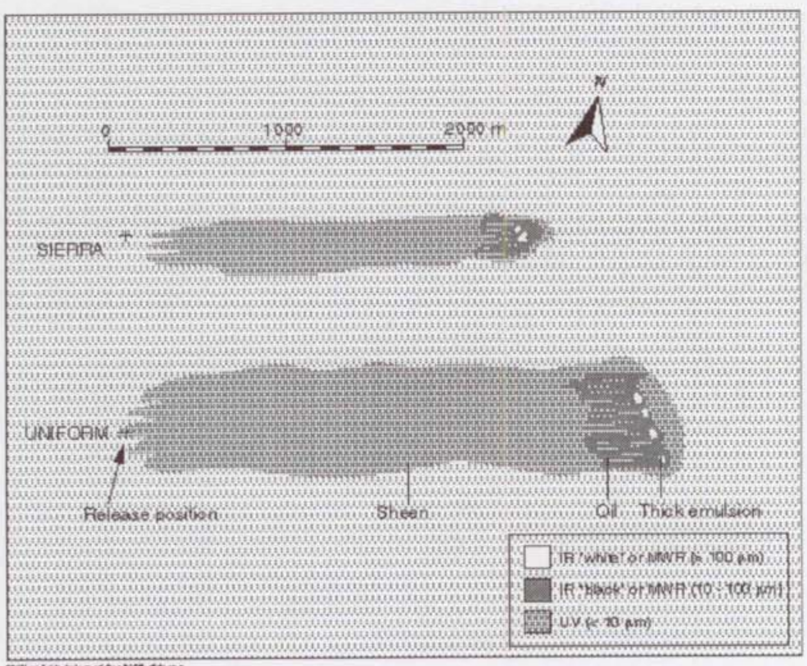

Figure 4.8 The resulting surface oil slick from the simulated underwater pipeline leakage (Uniform) compared to the control slick released at the surface (Sierra).

The main conclusions from the 1995 sea trial were:

1. Dispersant application. The treatment of the thick emulsified oil with the large SOKAF helicopter bucket was very rapid and accurate. High concentrations of dispersed oil were measured (15-20 ppm) 15-30 minutes after treatment, and the surface oil was completely dispersed within 10 minutes after treatment. Application from the vessel took somewhat longer time and the application was less accurate, but the surface oil was completely dispersed 30 minutes after treatment.

2. Underwater release – pipeline leakage. The underwater plume of oil droplets was monitored and the droplets were large (2-5 mm), due to the low energy during the oil release. The surface oil slick formed was only 2-3 times larger than the corresponding control slick (see figure 4.8), due to the short rising time of the large oil droplets.

Further details both concerning operational aspects, monitoring, analytical methods and conclusions from this sea trial are described in several reports e.g. Brandvik et al., 1996.

The 1996 Field Trials

The main objectives with this field trial were to perform operational testing of a newly developed Norwegian Helicopter bucket, called Response 3000D. The bucket has a large capacity (3 m^3), a twin nozzle system and can be refilled offshore directly from a supply vessel (see Figure 4.9). The twin nozzle system makes it possible to apply dispersant with two different dosages 900 and 200 liters/min. The low dosage system has separate nozzles, which create smaller droplets more suitable for thinner oil films (see Figure 4.10). Further details concerning the research and development of this helicopter bucket are described in a separate report, Brandvik et al., 1996. Two crude oil slicks (2 x 15 m^3) were released for the dispersant testing. One of the oil slicks was treated with the new helicopter bucket and the second was left as a reference.

To preferably spray the thick emulsified parts of the oil slick a FLIR camera (Forward looking infrared) was used. The search and rescue helicopters are usually equipped with these cameras to find and rescue personnel in a "man-overboard" situation. The FLIR camera is a very effective tool to locate the thick areas to spray and facilitate the helicopter to do "self assisted" spraying, without further assistance from surveillance aircraft. Figure 4.11 shows the oil slick trough an ordinary video camera compared to the FLIR camera. The thin areas (approx. 1-100 microns) in the oil slick are black, while the thicker emulsified areas (several millimeters) are white.

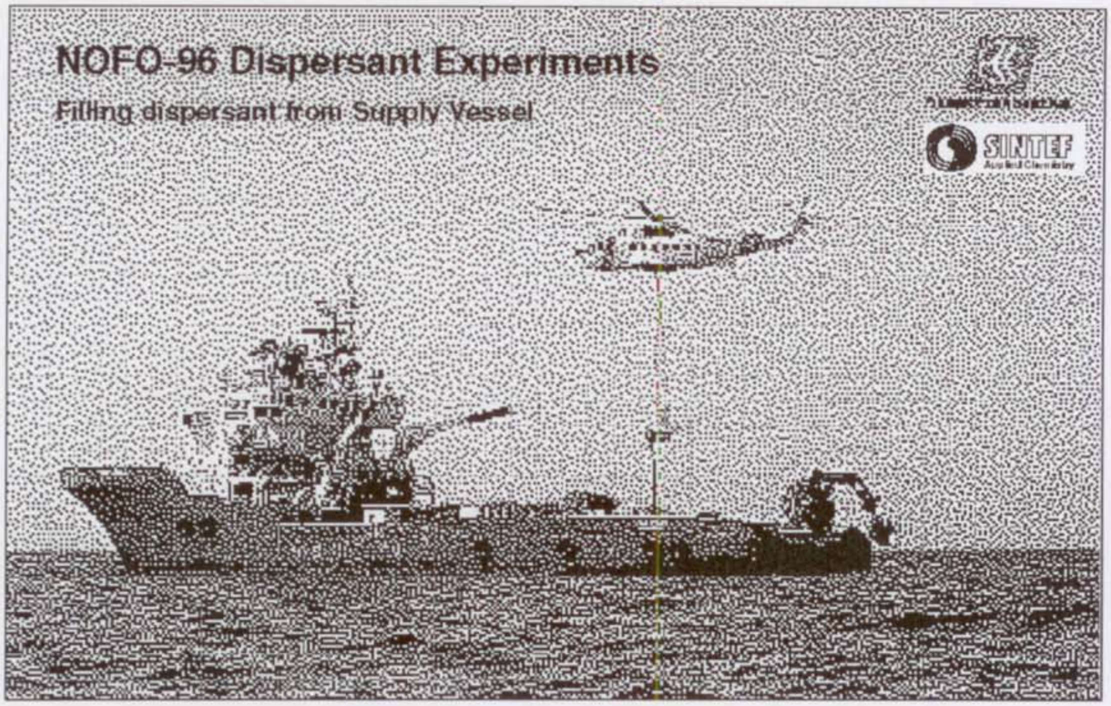

Figure 4.9 On-site refilling of the new Norwegian dispersant bucket (Response 3000D) directly from a supply vessel.

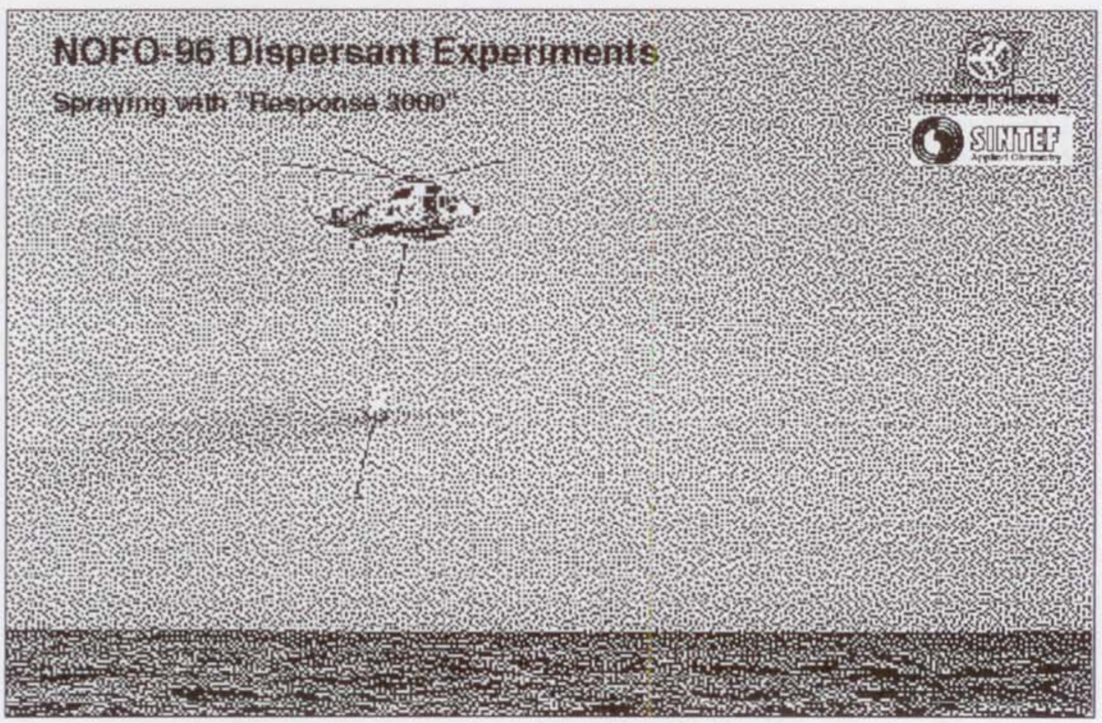

Figure 4.10 Dispersant application by the new Norwegian dispersant bucket using the large dosage system (900 l/min) to treat thick emulsified oil slicks

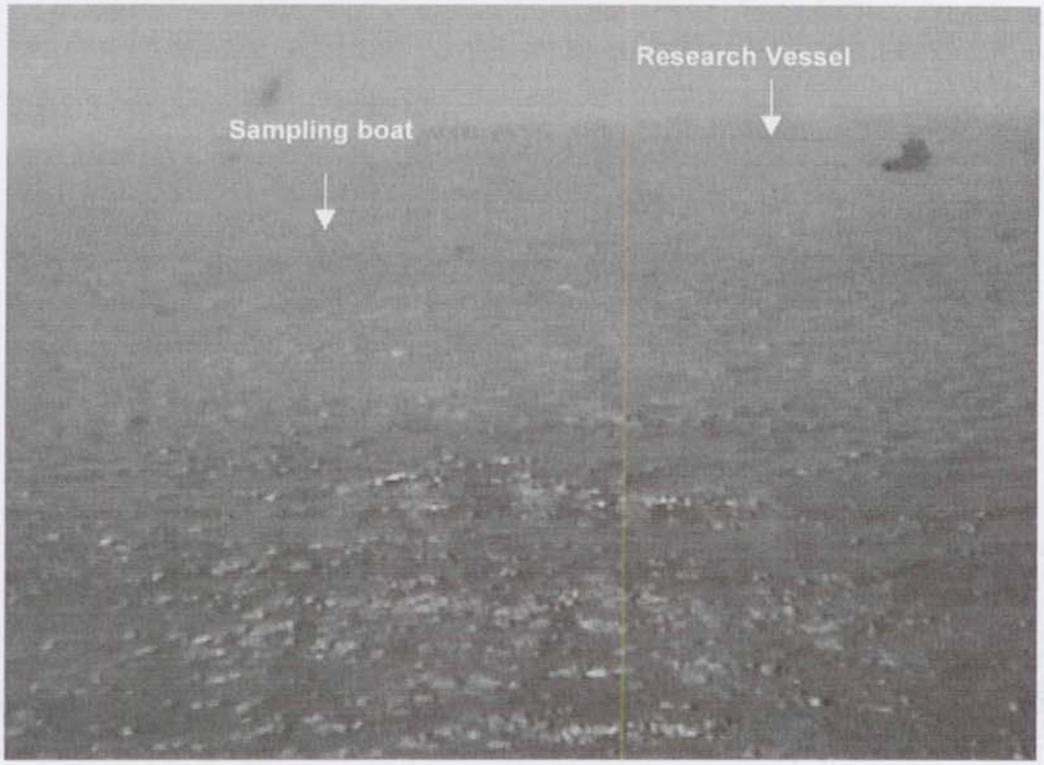

Figure 4.11a The oil slick, the research vessel "Gullbas" and the two sampling boats before spraying, seen trough an ordinary visual video camera.

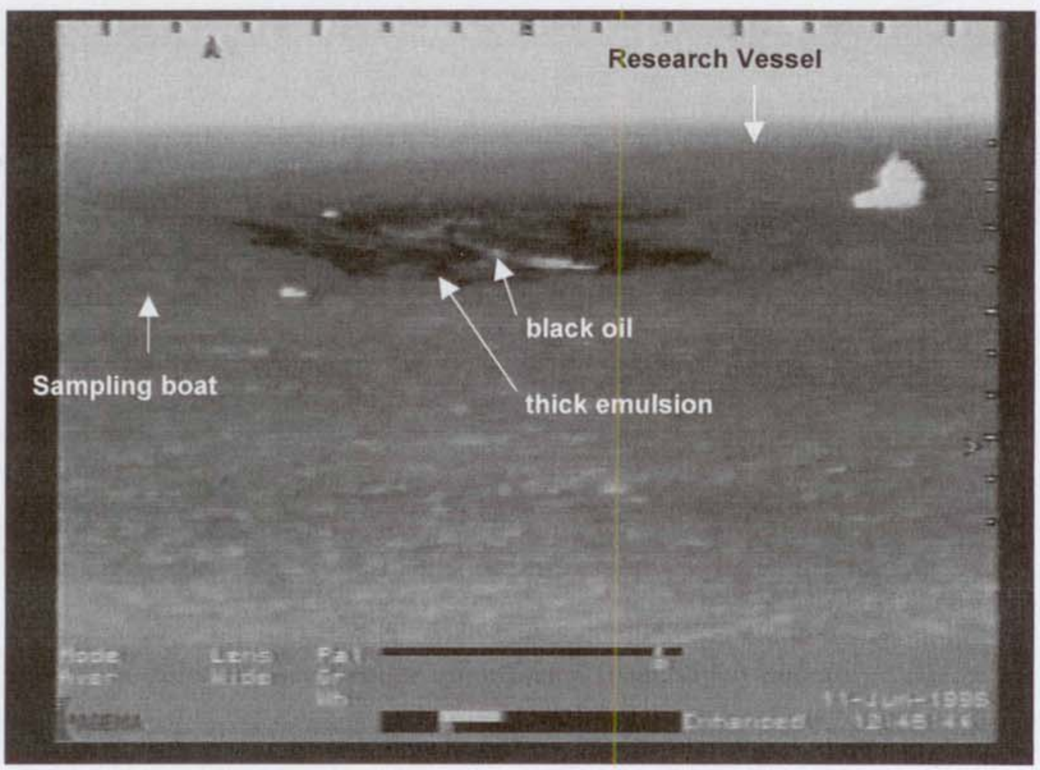

Figure 4.11b Same as above (a few seconds later), but seen trough the FLIR camera.
An underwater release of oil was also performed during the 1996 field trial to simulate a blowout.

45 m^3 of crude were released from 106 meter depth through a nozzle with realistic gas-to-oil ratio (GOR) and pressure. The release rate was 1 m^3/min with oil and 67 m^3/min with gas (compressed air). Further details are given in several reports from this field trial e.g. Rye et al., 1996 and 1997.

Smaller oil droplets were created during this underwater release due to higher shear forces at the release point, compared to the 1995 field trial were only oil was released. Approximate 20% of the released oil surfaced and formed a wide surface oil slick with a low film thickness. Figure 4.12 shows the surface oil slick resulting from the resurfacing small droplets. The resulting surface oil slick in figure 4.12 will in many scenarios be wide (several kilometers) and very thin (e.g. 100-200 microns) such oil slicks will represent a new operational challenge within oil spill contingency planning. Use of traditional mechanical recovery of these thin and wide surface oil slicks might be difficult and the recovery rate (m^3/hour) might be low. Use of dispersants applied by dedicated equipment, using low dosage rates and being able to spray smaller dispersant droplets, could be a more effective approach in these scenarios.

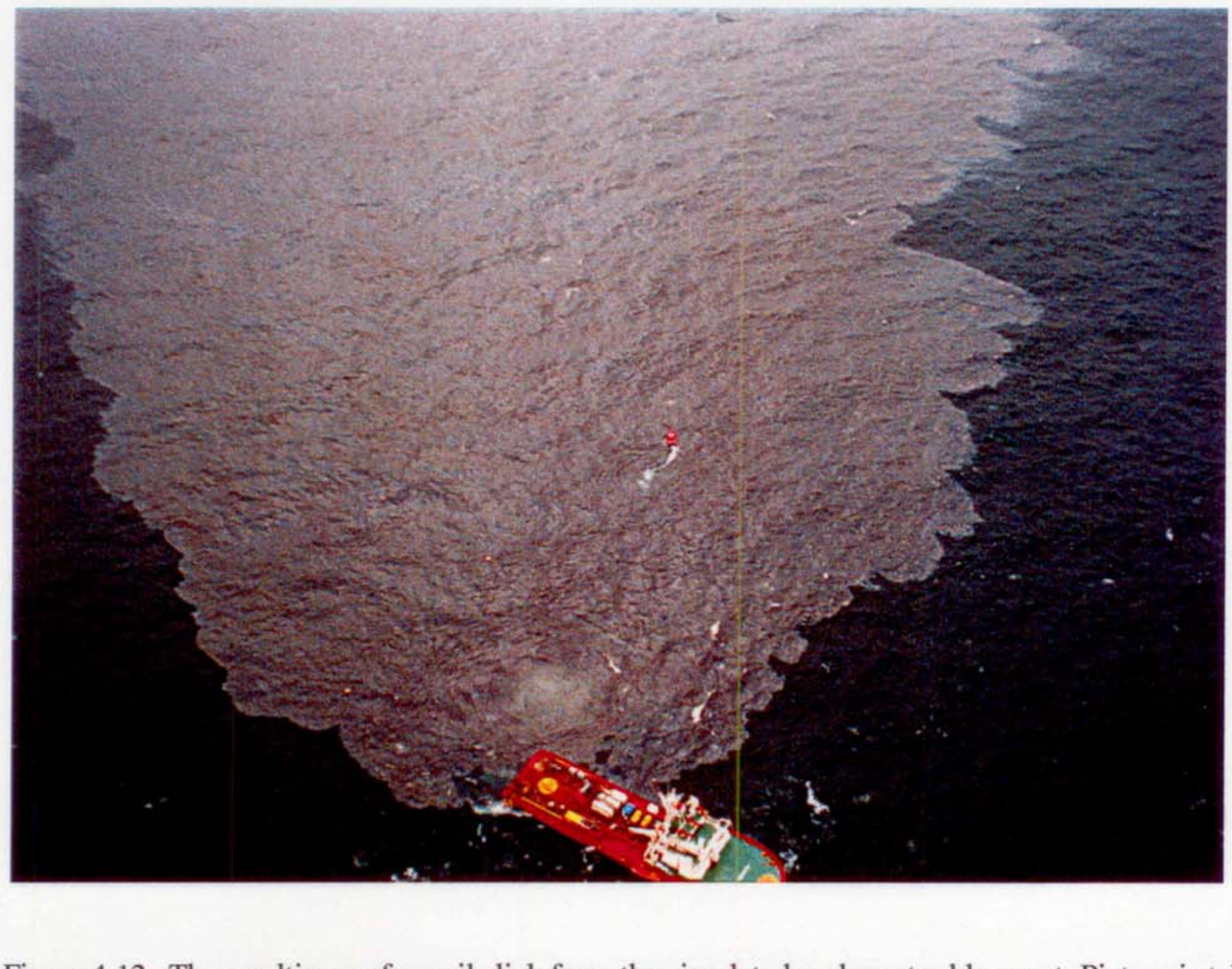

Figure 4.12 The resulting surface oil slick from the simulated underwater blow-out. Picture is taken during the oil release.

The main conclusions from the 1996 sea trial were:

1. Dispersant application. The treatment of the thick emulsified oil with the new Norwegian helicopter bucket was very rapid and accurate due to the use of the FUR camera. The on-site filling of dispersant increase the operational capability to treat oil, since less helicopter hours are used for transporting dispersant.

2. Underwater Release - Blow-outs. This underwater release simulating an underwater blow-out with realistic GaR verified that such release conditions might create very wide surface oil slick with a low film thickness. Use of dispersant sprayed from dedicated equipment would be a good alternative to traditional mechanical recovery in such spill scenarios.

Further details both concerning operational aspects, monitoring, analytical methods and conclusions from this sea trial are described in several reports e.g. Rye et aI., 1997, and Brandvik et aI., 1997.

Use oil spill response simulations for contingency planning and NEBA-analysis

The *"Net Environmental Benefit Analysis"* (NEBA) approach

The general goal of any oil spill response is very clear: the response should reduce the negative effects (environmental, amenity or financial) that could be caused by the oil spill if no response were undertaken. This is easy to define in principle, but much more difficult to translate into practice because it does not define concrete performance targets. It is necessary to predict the total amount of damage that an oil spill would cause before estimating how much of this damage would be prevented by the proposed response. This process has been formalized as the NEBA process *("Net Environmental Benefit Analysis"* of a combat operation (e.g. Baker, 1995 and 1997). It requires considering the overall environmental effects of the response and non-response, rather than concentrating on more limited, but much more easily defined, aspects such as the amount of oil recovered, dispersed or burned or the consequences to one particular natural resource.

"Oil Spill Contingency and Response" (OSCAR) model system

The OSCAR model system has been developed to supply a tool for objective analysis of alternative spill response strategies. OSCAR provides a basis for comprehensive, quantitative environmental impact assessments in the marine environment. Key components of the system, shown schematically in Figure 5.1, are SINTEF's Oil Weathering Model (Aamo et aI, 1993; Daling et aI, 1990, 1991), a three-dimensional oil trajectory and chemical fates model (Reed et aI, 1995b), an oil spill combat model (Aamo et aI, 1995, 1996), and exposure models for fish and ichthyoplankton (Reed et aI, 1995a, 1996a), birds, and marine mammals (Downing and Reed, 1996). The model calculates and records the distribution in three physical dimensions plus residence time of a contaminant on the water surface, along shorelines, in the water column, and in the sediments. The model is embedded within a graphical user interface in WINDOWS NT, which facilitates linkages to a variety of databases and tools. The latter allow the user to create or import wind time series, current fields, and grids of arbitrary spatial resolution.

An oil and chemical database supplies chemical and toxicological parameters required by the model. Results of model simulations are stored at discrete time-steps in computer files, which are then available as input to biological exposure models. OSCAR therefore represents a very strong established basis for development of a comprehensive system for Net Environmental Benefit Analysis. The OSCAR model system is under continuous development, with the present focus on improving the description of the exposure to the water column. This includes e.g. a more detailed quantitative picture of the chemical exposure of dispersed oil, dissolved oil compounds (and eventually dispersants) and of the potential biological effects / risk to marine organisms as function of dilution and oil weathering of different spill scenarios with and without dispersant response.

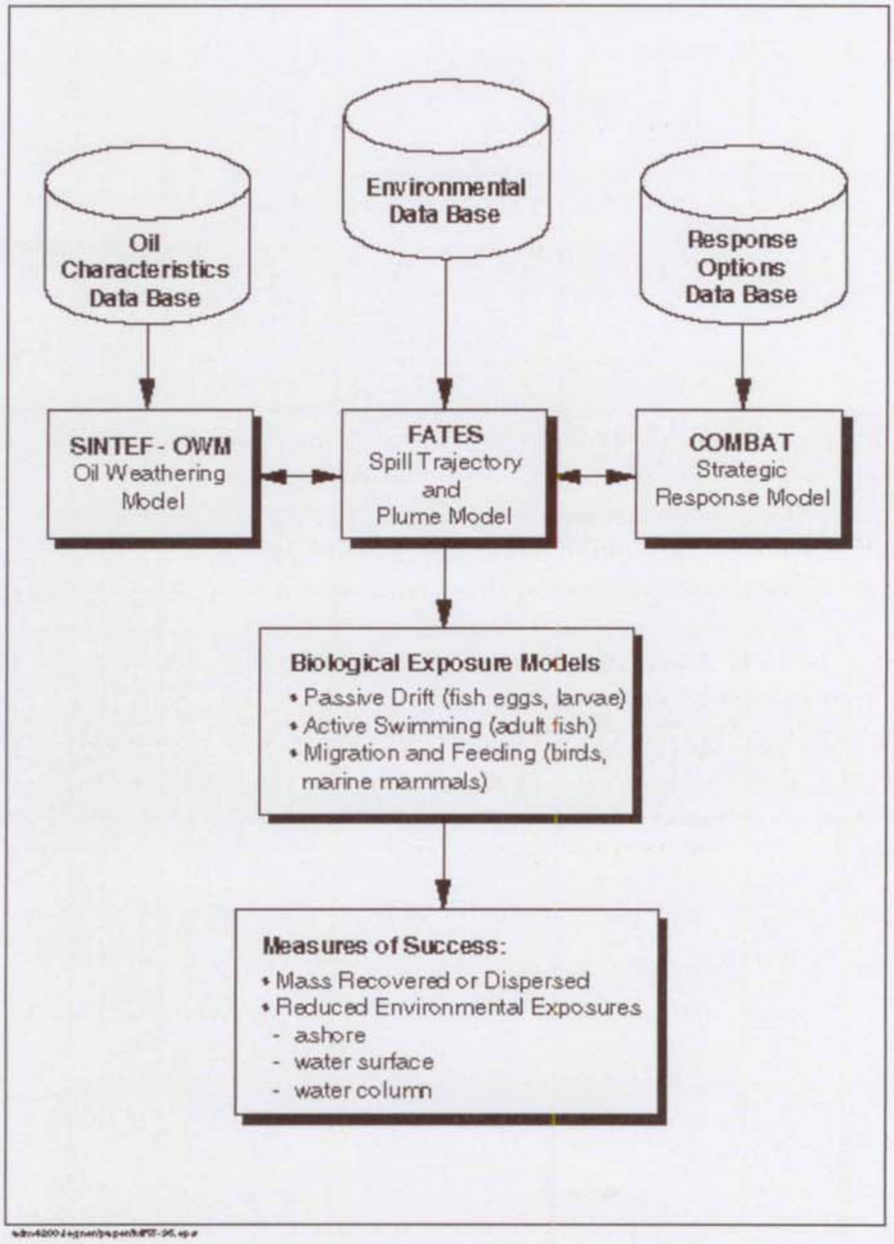

Figure 5.1 Schematic overview of the OSCAR system.

Case study - Use of OSCAR in contingency planning around a coastal oil terminal

Both the Norwegian Authorities and oil companies use OSCAR for designing more optimal, functional and cost-effective contingency solutions for offshore and coastal areas (e.g. Aamo ~~et~~ a1. 1997a and 1997b, Reed et al., 1995 and 1997).

This section gives examples from the development of a dispersant use contingency plan for the Sture oil terminal in Norway. Details of the legislative framework and development process behind the plan are described in Reed et al., 1997). The terminal receives oil via tankers and pipeline. The tern1inal is situated in the open Hjeltefjord (Figure 5.2) with the main axis from north-west to south-east. Typical for most of the Norwegian coastline, the area is rich in wildlife resources, as well as aquaculture installations. Due to strong currents in the fjord (typically 0.5 m/sec.), the potential for use of traditional mechanical booming and recovery can be limited. Dispersant application is therefore an interesting option. However, the decision on whether or not use dispersants in given spill situation must be made extremely rapidly, due to the short oil drifting time (a few hours) from the terminal to sensitive sites.

Oil spill scenario modeling

OSCAR was used to simulate a series of 24 oil spill scenarios to quantify the environmental effects of alternate spill response strategies under various environmental conditions (5 and 10 m/s wind), spill sizes of 10 and 100 m3 were used, representing the most probable events. For each spill scenario, three response options were compared:

1. No response:
2. Mechanical response;
3. Mechanical response, combined with dispersant application from helicopter starting after 1 ~ hours.

In general, the scenario simulations using the OSCAR model show that the existing mechanical response capability is adequate for response to spills up to 100 m3 except in a few situations. In these cases, the inclusion of dispersant application from helicopter, using a large spray bucket, will hinder oil from reaching sensitive shorelines. Further details of the scenario modeling is given by Reed et a1. 1997.

Potential effects in the water column

The proper use of dispersants results in the removal of oil from the water surface to the water column. The resulting dispersion of oil droplets increases the total hydrocarbon concentration (THC) in the water column. In addition, dissolution of oil from the droplet form may increases the dissolved hydrocarbon concentration, and therefore the potential for toxic effects.

The OSCAR Model is three-dimensional, and produces realistic, verified water column concentrations of both total and dissolved hydrocarbons (Reed et ai, 1996). Figure 5.3 depicts the modeled THC in the water column 3 hours after a 100 m3 oil spill, with mechanical response. The wind is from the north-west at 5 m/s; the currents are towards the south at 25 cm/s. The vertical section at the top of the figure gives the concentration profile along the axis of the arrow. Maximum concentrations are in the range 0.1 to 0.5 ppm.

The application of dispersants 90 minutes after the release increases the peak THC-concentrations in the area of application (Figure 5.4) to 10-20 ppm locally. The vertical section in Figure 5.3

Figure 5.2 Natural resources of interest around the Sture terminal in Hjeltefjorden

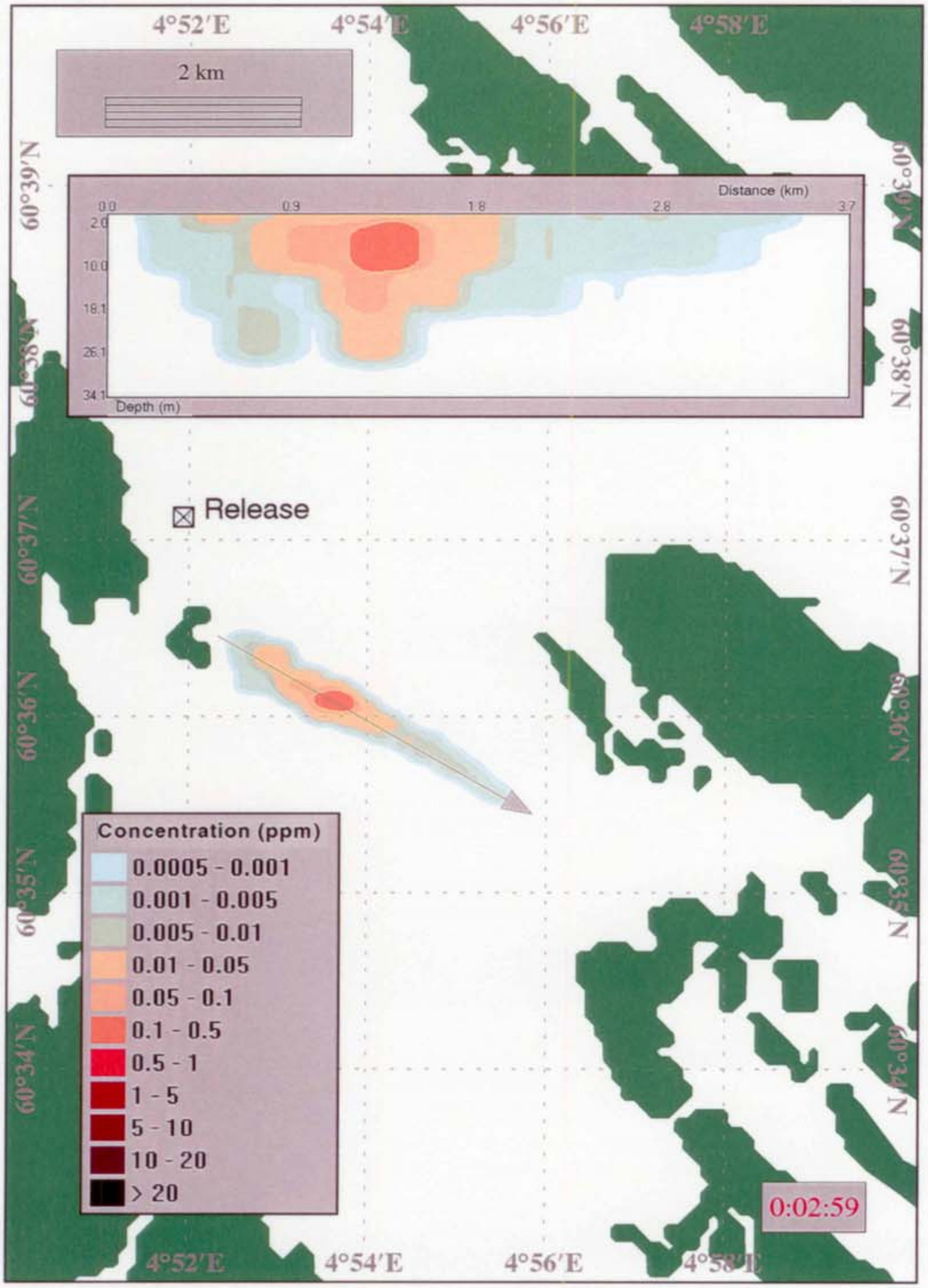

Figure 5.3 Total simulated hydrocarbon concentrations (THC) in the water column 3 hours after release. Mechanical response, 5 m/s wind, 25 cm/s current towards south. Section at top shows vertical concentration profile along axis of arrow.

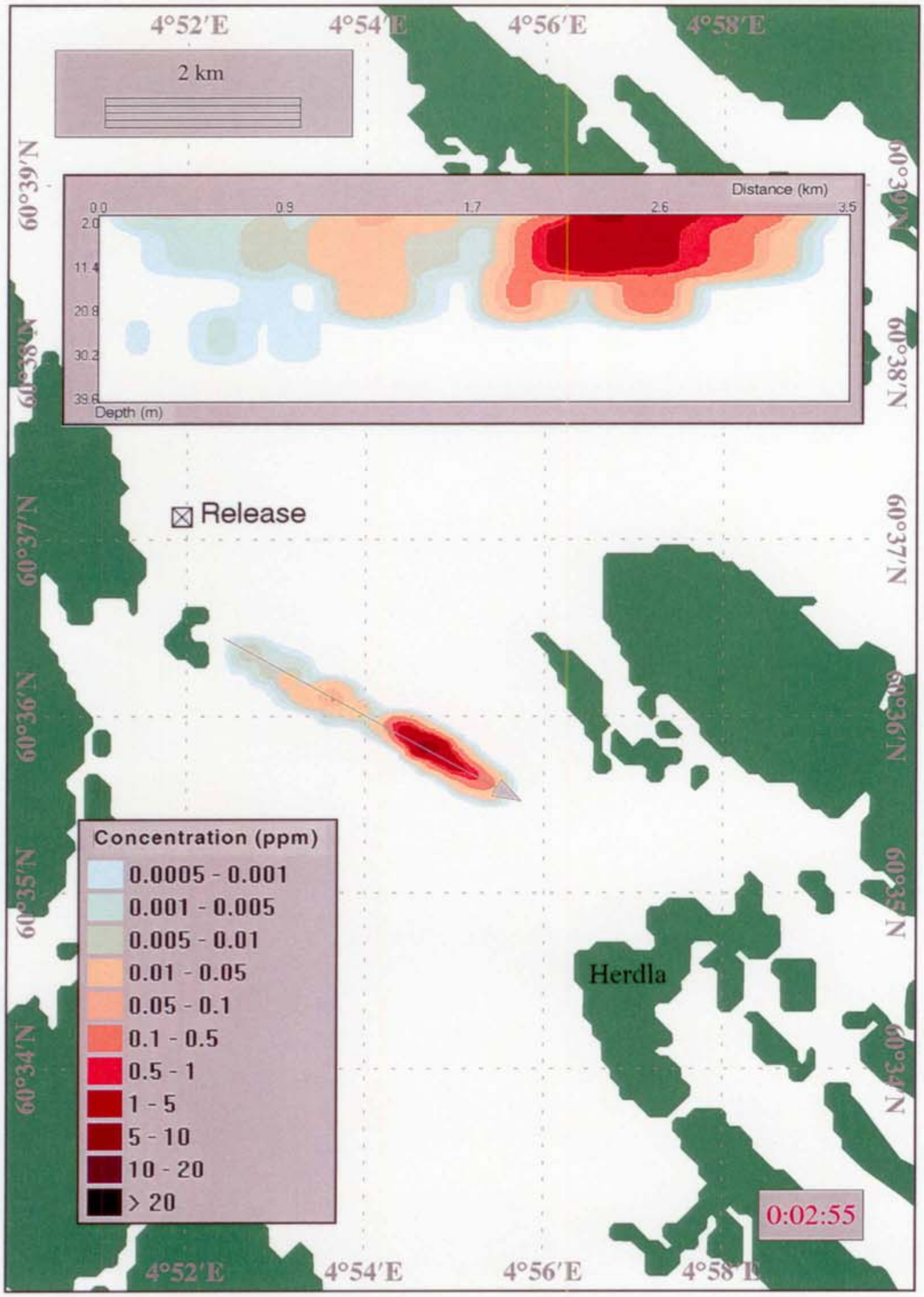

Figure 5.4 Total simulated hydrocarbon concentrations (THC) in the water column 3 hours after release. Mechanical response, combined with dispersant application after 90 minutes, 5 m/s wind, 25 cm/s current towards south. Section at top shows vertical concentration profile along axis of arrow.

shows that this concentration is mixed down to about 12 m, as compared to about 6 - 8 m in the case of natural dispersion (Figure 5.3). This difference in vertical mixing occurs because the application of dispersant reduces the mean drop size from about 350 um to less than 50 um (Lunel, 1993), thus decreasing the buoyancy.

Many Norwegian coastal areas are used extensively for aquaculture, in which fish are confined to relatively small areas within the top 10 or 15 m of the water column. Potential exposure of confined fish is therefore of considerable interest, both in terms of possible toxic effects as well as tainting of flesh. The OSCAR model allows one to record the concentration of soluble aromatics in the water column in space and time. These dissolved oil compounds, called Water Accommodated Fraction (WAF), are generally considered to be the main source for a potential acute toxic effect on marine organisms (e.g. Neff, 1995, McAuliffe, 1987).

Figure 5.5 shows the time series of maximum computed concentrations of the low aromatics (benzene - toluene - xylene, BTX) of the WAF for three cases: no response at 10 m/s, and application of dispersants after 1.5 hour for both 5 and 10 m/s winds. The potential for highest concentration of low aromatics in the water column is within the first hour after release. Thereafter, the concentration will decrease due to the rapid evaporation rate of these aromatics from the surface slick. The concentration becomes higher at 10 m/s wind (breaking waves) compared to 5 m/s (non-breaking waves) due to dissolution into the water column from the naturally dispersed oil droplets. By the time the dispersant is applied, most of these low aromatics have already been removed from the surface oil by the processes of evaporation and dissolution. The BTX concentration profile predicted in Figure 5.5 is in good agreement with measurements under oil slicks (e.g. Brandvik et. al 1996).

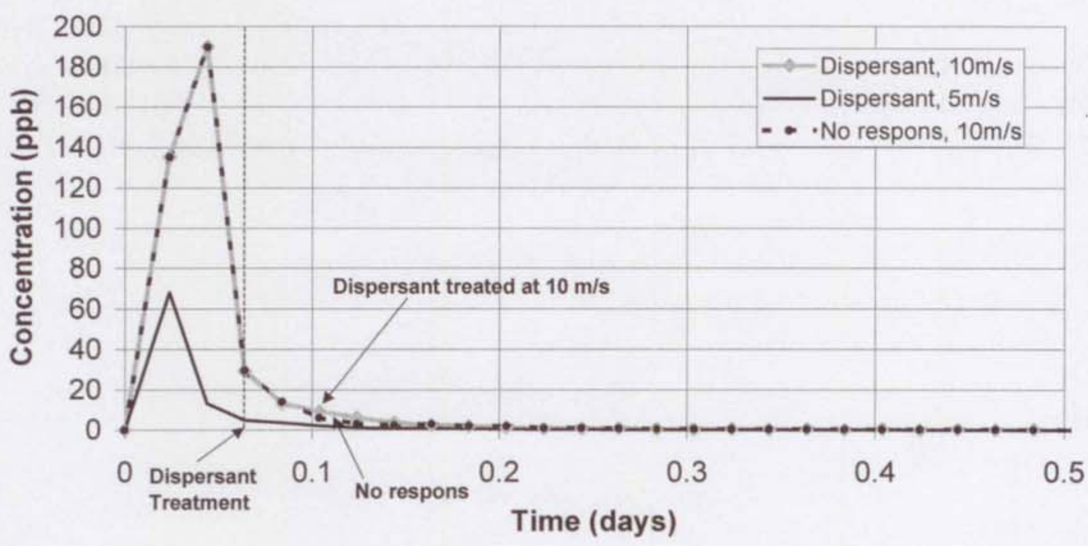

Figure 5.5 Maximum computed concentration of BTX's (benzene-toluene-xylenes) beneath the oil slick during simulation of a 100 m^3 spill.

Development of Dispersant-Effectiveness Maps for Decision Support

Maps to support decision-making were developed for the geographical area around the terminal.

These maps are color transparencies printed to the same scale as the standard marine chart of the area, such that they can be overlaid without obscuring reference points on the chart. The maps show the percentage of a slick which is expected to disperse prior to beaching, given that the slick is properly treated (i.e. 1:20 dispersant-to-oil ratio). Maps were produced both for spills at the terminal, and for slicks which may escape from the terminal area and may be found out in the open fjord.

Figure 5.6 shows a map simulating spill releases at the terminal. Such maps were developed for a given current field and wind speed, with variable wind direction. In addition to the percentage of a slick which is expected to disperse prior to beaching, these maps include time-of-travel contours showing drift time from the terminal. The times-of-travel are minimum expected times, since they are based on maximum observed currents. Figure 5.6 is an example for currents into the fjord (towards the southeast) at 25 cm/s, and winds of 5 m/s in any direction. The figure shows that, for the given current and wind conditions, treatment of a slick with dispersant within 2 hours of release will generally avoid beaching.

Such dispersant-effectiveness maps generated as a part of the oil spill contingency plan, are intended for use as a support for decision-making both during an actual oil spill response action and during table-top exercises.

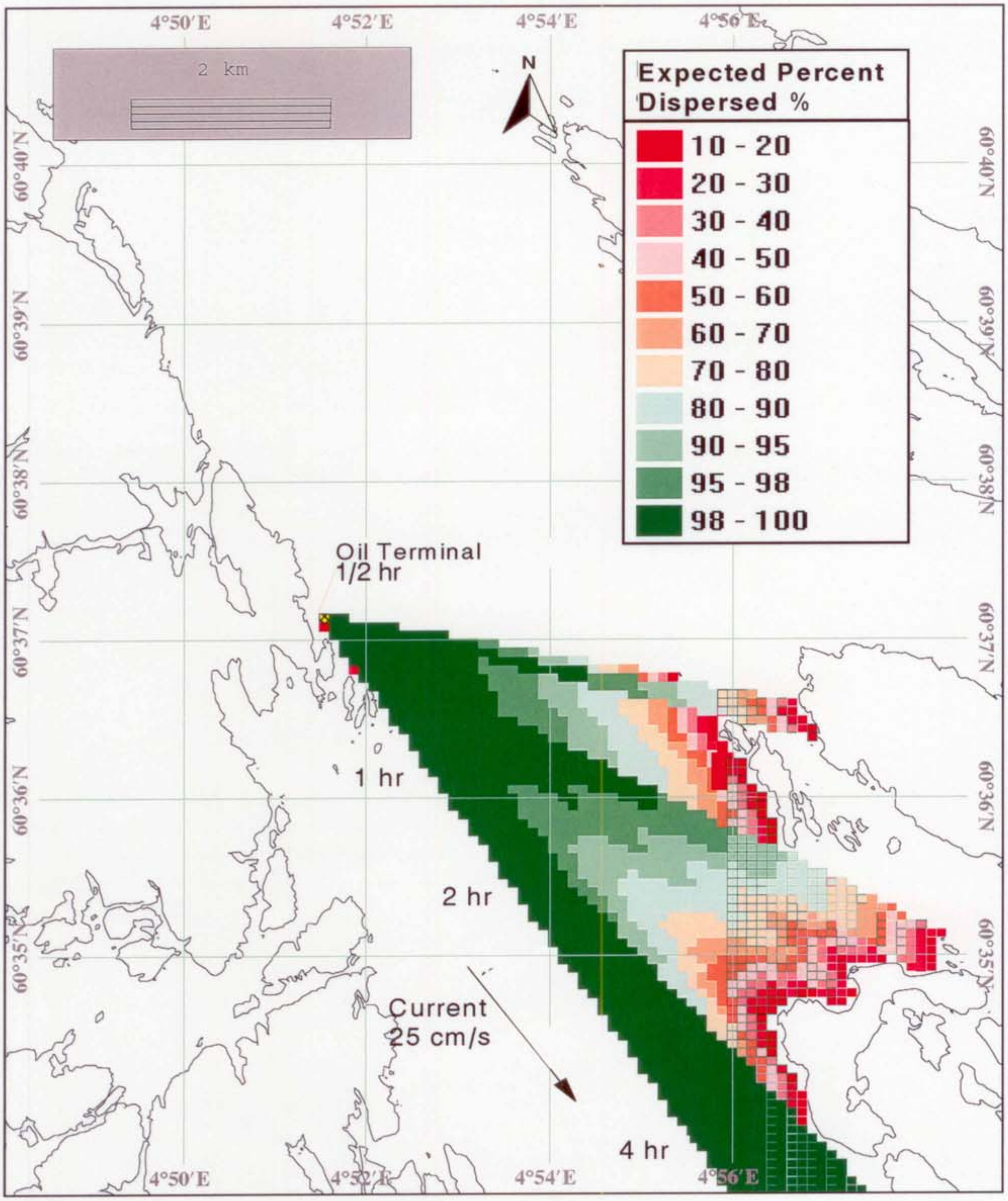

Figure 5.6 Dispersant-use map for oil slicks at the oil terminal, with currents towards the southeast at 25 cm/s, and winds at 5 m/s. The contours show drift times of the spill from the terminal.

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Oil Fate and Effects Issues

Oil Fate and Effects:
An Overview of Issues in Prince William Sound

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Abstract
The Prince William Sound Regional Citizens Advisory Council (PWS RCAC) grew out of the 1989 *Exxon Valdez* oil spill. Through the diligent efforts of many dedicated people, the idea of a citizens' oversight group to advise Alyeska Pipeline Service Company has evolved into a working relationship between Alyeska and PWS RCAC to provide a vehicle for citizen involvement in making oil transportation safer in Alaska.

The work of the PWS RCAC is guided by its contract with Alyeska and the Oil Pollution Act of 1990 (OPA 90). OPA 90 requires Alyeska (and other industry cooperatives) to establish and fund citizens' advisory groups to provide input from people who live and work in the region affected by tanker operations. PWS RCAC met the intent and requirements of OPA 90 and continues to be re-certified annually by the U.S. Coast Guard as the citizens' advisory group for the people of Prince William Sound. As such, PWS RCAC addresses many environmental issues associated with oil transportation including reviews of and input to oil spill response strategies.

In 1993, PWS RCAC developed and adopted a conservative interim position on dispersant use in Prince William Sound. A conservative position was adopted due to a lack of field and laboratory data defining the effectiveness of dispersants, the fate and persistence of chemically dispersed Alaska North Slope (ANS) crude oil in the sub-Arctic conditions found in Prince William Sound and the risks of chemically dispersed oil to Alaskan marine species and the environment. In 1997, PWS RCAC began to address these concerns by funding a literature review to collect and evaluate information defining: 1) the effectiveness of dispersants on ANS crude in cold waters; and 2) the toxicity or risk of chemically dispersed ANS crude to Alaskan marine species and critical coastal habitats. Results of this work indicate that field and laboratory experiments evaluating the effectiveness of dispersants on ANS crude under oceanographic conditions similar to those likely to exist in Prince William Sound are lacking. The results also indicate that data describing time windows for effective chemical dispersion of ANS crude, and the toxicity and risk of chemically dispersed ANS crude and dispersants to Alaskan marine species are also lacking. In light of these unknowns, it is imperative to proceed cautiously with dispersant use in Prince William Sound until adequate laboratory and field studies defining the ecological consequences of dispersant use for marine oil spills in Prince William Sound are conducted and results incorporated into response planning.

Introduction

The purpose of this paper is to provide the reader with a general overview of Prince William Sound (PWS) and to relate dispersant effectiveness and risk issues to PWS. The prospect of chemically dispersing oil spills in PWS is an emotionally charged issue for many citizens living and working in the Sound. Despite claims of effective chemical dispersion (e.g. *Sea Empress*, 1996) the opinions of PWS stakeholders on effectiveness, toxicity and risk associated with dispersant use in the Sound remain highly polarized. For example, while the Coast Guard and Alyeska Pipeline Services have adopted a pro-dispersant use position, many PWS commercial herring fishermen and subsistence users are strongly opposed to chemically dispersing oil spills in PWS. Pro-dispersant stakeholders cite successful laboratory experiments, dispersant field trials conducted in Norway, and the successful dispersion of Forties blend crude and heavy fuel oil spilled into the waters off southwest Wales when the tanker *Sea Empress* grounded at the entrance to Milford Haven in 1996. Those opposed to chemical dispersal of oil in PWS indicate that the effectiveness of dispersants on Alaska North Slope (ANS) crude in PWS has not been demonstrated and that there are too many unanswered toxicity and risk questions especially in a region with strong economic linkages to its marine resources.

Prince William Sound

Prince William Sound, located on the south central Alaska coast, is a large, silled, 4,000 km^2, irregular, fjord-type estuary approximately 145 to 160 km across. The Sound contains diverse habitat including islands, calving glaciers, rocky coasts, sheltered coves, gravel beaches and tidal flats. Associated with the diverse habitats are a wide variety of marine wildlife including humpback whales, killer whales, porpoises, sea lions, harbor seals, sea otters, bald eagles, sea birds, shore birds, migrating waterfowl, salmon and herring. The region is also well known for the fishing and oil communities of Whittier, Cordova and Valdez. PWS is a region where economic, recreational, and aesthetic values are closely linked with rugged physical splendor and rich biological diversity.

The bathymetry of the Sound is complex. The central part of the Sound contains a 500 m deep basin bordered by a shallow shelf on the east and islands and shallow canyons to the west. The western portion of the Sound contains a series of three deep holes (>800 m) among Lone, Perry and Naked Islands. A shallow sill restricts the entrance to the Sound across Montague Strait. The sill is believed to influence water exchange between PWS and the Gulf of Alaska (GOA). The mean tidal range at Cordova, is approximately 3 meters. Tidal currents within the Sound are generally weak, but strong currents occur at the passages linking the Sound to the GOA.

Within the Sound, surface water salinity ranges seasonally from approximately 32 ppt to 15 ppt (Meunch and Schmidt, 1975). The wide range in salinity is due in part to seasonal influx of fresh water. Spring and summer rains, coupled with glacial and snow melt, provide tremendous quantities of fresh water to the Sound. Sea surface temperatures in the Sound range from 0 to 12 degrees C. The amount of suspended sediments in the Sound varies seasonally. During winter months when runoff is minimal, sediment influx is very low. During periods of high runoff, sediment loading to the Sound is high in areas receiving runoff. Sound shorelines are comprised primarily of: 1) mixed fine-grained substrates (mudflats to sand beaches); 2) mixed coarse sediments; and 3) bedrock. The

Sound's seasonally complex physical regimes strongly influence biological processes and give rise to diverse biological resources.

Composition and Toxicity of Petroleum Compounds

Crude petroleum is a complex mobile mixture containing thousands of organic compounds and relatively few inorganic compounds. It is the composition of a crude or a refined petroleum product that determines its behavior, fate and effects on marine life when spilled in the marine environment. A crude oil's organic compounds may range in molecular weights from that of methane (16) to complex polymeric structures such as asphaltenes with molecular weights of 100,000 or more. Although crudes contain the same classes of compounds, they differ in the relative amounts of each constituent. While some crude constituents, the aromatic hydrocarbons for example, are acutely toxic, other constituents, such as tar and weathered oil, are not as toxic but have a greater potential for environmental impact because of their resistance to weathering. The acute toxicity of aromatic hydrocarbons is inversely proportional to molecular weight. However, because of low solubility, aromatic hydrocarbons with four or more rings rarely exist in acutely toxic concentrations in the marine environment. The monocyclic aromatic hydrocarbons (benzene, toluene, and xylenes) are so volatile that they are rapidly lost from seawater. It is the slightly soluble and relatively persistent naphthalenes and phenanthrenes that contribute most to the toxicity of crude and refined petroleum in the marine environment.

Dispersant Effectiveness

There are numerous factors affecting dispersant effectiveness. Those factors include weather windows, safety, accuracy of application, dispersant/oil contact, dosage control, oil viscosity, emulsification, herding, sea energy, temperature, salinity and dispersant type.

Dispersants can be used in severe weather and sea conditions. In fact, sea state should not pose a limitation on dispersant use. Limiting factors in severe weather can be directly correlated to aircraft and personnel safety, accuracy of dispersant application in high winds and, to a lesser extent, dispersant loss in high winds. Several field studies suggest that a non-viscous oil, when thoroughly premixed with dispersant and spilled on the ocean under average sea conditions, will completely disperse more quickly from the surface than untreated oil (Daling and Lichtenthaler 1987; Delvigne, 1985, 1987; Fingas, 1985; Sørstrøm, 1986). However, there are problems associated with obtaining high dispersant effectiveness on actual spills at sea. Chemical addition of dispersant to marine spills takes place after the oil is on the water and not before. Achieving good contact between oil and dispersant is difficult during an actual marine spill. Dosage control is an important consideration when chemically dispersing a slick. Although oil slicks are not a uniform thickness, most contingency plans (e.g. Alyeska, 1995), field guides (e.g. Exxon 1992) and decision matrices (e.g. Allen and Dale, 1995) still consider spills to have uniform, small thicknesses. Unfortunately, dispersant application plans are based on this simplistic yet incorrect assumption.

Other factors affecting dispersant effectiveness include oil viscosity, emulsification, herding and dispersant type. In general, highly viscous oil is a poor disperser possibly due to the fact that dispersants are unable to penetrate the slick.

Emulsification, the mixing of water and oil, may be the greatest hindrance to dispersant effectiveness. Almost all crude oils emulsify and become viscous. Often, this process begins early in a spill's history. Once started, emulsification can proceed rapidly.

Herding occurs when dispersants, which spread on the water at higher rates than oil, begin to move oil into long, barely visible narrow ribbons. When viewed from the air the oil appears to have dispersed when in fact the oil is still on the surface of the water. Herding also occurs when dispersant droplets break through a thin slick and begin to move (herd) the oil rather than disperse it.

Although there are many dispersant products on the market only a few appear to be effective. Some dispersants are designed for salt water and others are designed for fresh/brackish water. Those designed for salt water should not be used in fresh or brackish water and those designed to be effective in fresh or brackish water should not be used in salt water.

Effectiveness and Experimental Systems

Researchers have utilized many methods for determining the effectiveness and effects of chemical dispersion of spilled oil. However, researchers and stakeholders alike must be cautious when interpreting and relating laboratory studies, mathematical models, computer simulations and micro- or mesocosm experiments to highly complex natural ecosystems. Although computer and mathematical models force scientists to think clearly, such models may only explain the obvious and incorporate assumptions that are difficult to justify (Hairston, 1989). In essence, models are simplified versions of the real world. However, if models are well conceived and validated, they have the potential to provide an experimental platform for systems too large and complex to directly manipulate (Herman and Scholten, 1990).

Often, researchers utilize small ecosystem models or field chambers known as micro- or mesocosms to study the effects of oil and chemically dispersed oil on the environment. In these experimental ecosystems, environmental variables are controlled or at least varied in a systematic manner, and often, a single variable is manipulated to address a specific question. However, because these experimental ecosystems are much smaller and less dynamic than a real ecosystem, there are often complications and unrealistic findings (Dame, 1996). One difficult task in developing and utilizing this type of model is the coupling of all the various sub-models into one model. Time and spatial scales for hydrodynamic and physical parameters must be consistent with biological scales. Other potential problems associated with utilizing small-scale ecosystem chambers include pseudo-replication, edge effects, changing controls and stratification (Hariston, 1989).

Field manipulation experiments are also wrought with problems. It is not, for example, possible to exercise control over most of the variables in the system. In this approach, the variable of interest is manipulated in a set way while other variables fluctuate independent of the variable (Hairston, 1989). Ecosystem level field experiments have gained great favor in recent years. This is because many important ecosystem features are at large temporal and spatial scales and, as such, are difficult to understand, model or reproduce in chambers. Such features include water column dynamics and biogeochemical processes. However, ecosystem level experiments are not easily conducted or replicated because of spatial and temporal constraints and costs (Carpenter, 1995).

Although important tools, models, micro- and mesocosm experiments and small-scale ecosystem field experiments have serious limitations and may be a poor representation of reality. Often, a number of model parameters are assumed to be constant and are in reality variable. Model inputs are only approximately known and lead to model uncertainty. The large spatial and temporal scales of real physical and biological processes are difficult to impossible to model in the laboratory. Although ecosystem scale experiments on real systems may yield the most realistic results, they are the most difficult to conduct. This is because researchers cannot control specific complex environmental parameters and because ecosystem scale experiments are costly to conduct and replicate.

Effectiveness of Dispersants in Prince William Sound

Many PWS shareholders are concerned about dispersant effectiveness and dispersibility of ANS crude in the Sound. Although dispersant effectiveness trials have been conducted in the laboratory, wave tanks and field trials, dispersant effectiveness on ANS crude in PWS has not been demonstrated. During the 1989 *Exxon Valdez* oil spill, Corexit 9527 was used to disperse portions of the spill. However, after six trials, dispersant effectiveness on ANS crude was not conclusive and the trials were called off (SL Ross, 1997). Some researchers indicate that ANS crude is, based on limited laboratory experiments, dispersible. Others indicate that ANS crude, based on its bulk constituents, 53% saturates, 37% aromatics, 6% resins and 4% asphaltenes (Jokuty et al., 1996), may not be a good disperser. The Fingas "naive model" for dispersant effectiveness suggests that ANS crude oil at 15 degrees C, low energy, standard salinity, and with pre-mixed dispersant is between 10% and 20 % dispersible. However, it is important to note that this is a low environmental energy value. Fingas' "naive model" of dispersant effectiveness is based on the assumption that the effectiveness of a given dispersant on a given oil is a function of that oil's saturate content less the aromatics, resins, asphaltenes and possibly waxes. Results from swirling flask experiments also suggest that ANS crude is approximately 15% dispersible (Fingas et al., 1995).

Dispersant effectiveness continues to be a hotly contended issue. Dispersant proponents believe that all oils are dispersible while more cautious researchers suggest that some oils may not be as dispersible as others. Some oils may be so resistant to chemical dispersal that the use of dispersants on those oils is a strategy that should not be considered. Until additional laboratory and fields studies are conducted to determine the effectiveness of a specific dispersant on ANS crude, we will not be certain as to the effectiveness of that dispersant or the dispersibility of ANS crude oil in the seasonally complex physical oceanographic regimes of PWS.

Several important physical factors that affect dispersant effectiveness are sea energy and salinity (SL Ross, 1997). There are many examples of marine oil spills that dispersed naturally and quickly because of high wave energies. The most recent example is the 1993 *Braer* tanker spill off the northern U.K. coast (Thomas and Lunel, 1993). The 85,000 tonne spill occurred during high sea conditions with winds greater than 50 knots and virtually all oil dispersed without the aid of chemical agents.

The 1996 *Sea Empress* spill off the coast of Wales is of particular interest to many researchers and stakeholders alike. Approximately 72,000 tonnes of Forties Blend and 370 tonnes of Heavy Fuel Oil were spilled and dispersants were a major component of the response strategy. It is important to note that during this spill, sea energy conditions ranged from moderate to severe and wind direction during the first seven days was away from the shore. Winds on the first day of the spill were 18 to 20 knots. Overnight winds increased to gale force. Later the next day the day winds gusted to 40 knots. For the next four days severe weather conditions prevailed (Lunel et al., 1995). Although chemical dispersion was a major component of the response strategy, its role in dispersing the oil may have been underscored by severe weather conditions and natural dispersion. Inherent problems associated with measuring dispersant effectiveness in the field (Fingas, 1985; 1988) and uncertainties of the role played by natural dispersion, suggest that the effectiveness of chemical dispersion remains unquantified and uncertain in sea trials and accidental spills.

Several physical environmental factors are known to influence natural and chemical dispersion of oil. Those factors include salinity and sea energy. Salinity varies greatly in PWS (SL Ross, 1997) as do sea energy conditions. Seasonally, portions of PWS exhibit a highly structured water column as waters stratify by temperature and salinity. During periods of high freshwater input, salinity may fall to 18 ppt and fresh water lenses may develop in portions of the Sound. Although some dispersants have been formulated for use in salt water and others are effective in fresh or brackish water (SL Ross, 1977), only Corexit 9527, a dispersant formulated and recommended for salt water, is stockpiled locally in sufficient quantities to respond to spills in PWS and GOA. Until dispersant trials are conducted on ANS crude in PWS throughout the annual seasonal fluctuations of the Sound's physical oceanographic regimes, it will not be possible to indicate whether ANS crude can be effectively dispersed in PWS with Corexit 9527.

Fate, Persistence, and Risk Associated with Dispersed Oil in Prince William Sound

Other major concerns for many PWS stakeholders are the questions of fate, persistence, and risks associated with chemically dispersed oil in the Sound. Under average open ocean conditions, oil slicks mix sparingly with seawater. As energy to the system increases (i.e. increasing wind velocity and wave height) some oil is dispersed into the sea. The greater the mixing energy the more oil is dispersed. One example documenting rapid natural dispersion of massive amounts of oil in the marine environment is the *Braer* tanker spill off the northern U.K. coast (Thomas and Lunel, 1993). This massive spill occurred during heavy wind and high sea conditions and virtually all oil was dispersed without the aid of chemical agents.

When dispersants are applied to a slick, tiny droplets of oil form and begin to disperse into the water column forming a cloud of chemically dispersed oil. The cloud of tiny oil droplets may disperse quickly or may reside in the water column for days, weeks or months during the settling process. While settling, the dispersed oil will weather. The longer the settling process the greater the weathering. Once settled to the seabed, it is believed that the heavily weathered, highly dispersed oil poses no significant risk to benthic communities (SL Ross, 1997).

The greatest risk of biological effects and contamination are from the cloud of freshly dispersed oil in the upper portion of the water column below the dispersing oil slick (SL Ross, 1997). Results of laboratory studies indicate that dispersed oil causes mortality, tissue contamination, and chronic sublethal effects in plankton, finfish, crustaceans and shellfish.

There are environmental risks associated with untreated oil spills and with chemically dispersed spills. Spilled oil floats and spreads on the water forming slicks that move in response to winds and currents. When a slick encounters a shoreline, the oil strands and mixes into shallow nearshore waters and subtidal to intertidal sediments. Without the aid of natural dispersion, untreated spills have their greatest effects at the sea surface in offshore areas and in the intertidal and shallow subtidal when the slick strands. An untreated slick in the tanker lanes of PWS would impact marine mammals, seabirds, plankton, herring spawning areas, nearshore herring and salmon nursery areas, and marine mammal haulouts.

The fate and persistence of naturally or chemically dispersed spills will determine its effects. A naturally or chemically dispersed slick will have its greatest effect in the water column. The nature and magnitude of the impact will vary with the size, location, season, prevailing physical oceanographic and meteorological conditions and the biological resources utilizing the upper portion of the water column below or adjacent to the slick. Chemical dispersal of slicks removes oil from the surface of the water and produces a temporary, localized cloud of dispersed oil in the upper few meters of the water column. As such, the area of greatest risk is within the cloud of chemically dispersed oil. At greatest risk from the dispersed oil are plankton, including planktonic eggs and larval fish. The effect of chemically dispersed oil on adult finfish, in open waters, with adequate dilution, is not understood. However, if confined to small bays or inlets, the dispersed cloud of oil may be harmful to adult finfish. It is suggested that there is little risk to bottom fish from dispersed oil due to dilution and weathering of the oil as it settles through the water column. However, chemically dispersed oil will cause mortality and contamination of bottom species if dispersants are used in shallow waters less than 10 meters deep (SL Ross, 1997).

Discussion

There are no easy answers when deciding whether or not to chemically disperse an oil slick in PWS. The decision making process is complex and involves making environmental trade-offs. Decision-making in PWS involves determining the effectiveness of dispersants in a seasonally complex and poorly understood physical oceanographic regime while concurrently assessing risk to coastal habitat and biological resources. Because the nature of environmental trade-offs varies seasonally and with spill locality, it is vital that planners and spill coordinators utilize detailed, seasonally accurate, physical and biological databases when coordinating spill response efforts. If, for example, dispersants are not used on a large untreated spill, it can cause damage to offshore and nearshore environments. However, although chemical dispersion of the slick can reduce or eliminate the risk to the nearshore, it poses a real risk to plankton stocks and larval finfish in the upper portion of the water column. The Sound's offshore plankton communities have pronounced seasonal cycles of occurrence, abundance and distribution linked to physical processes. These cycles and processes must be understood and considered when making dispersant use decisions on large oil spills. Perhaps the most challenging environmental trade-offs from chemical dispersion of oil in PWS involves large spills where effective dispersion and rapid full dilution are not possible. If this occurs in the spring, dispersed oil may damage phytoplankton and zooplankton assemblages, and the undispersed oil slick may damage marine mammals and haulouts, seabirds and rookery areas, migratory waterfowl, spawning herring, subtidal and intertidal habitat and other critical coastal habitat. However, environmental trade-offs may be made more easily for smaller spills when it has been determined that all the oil can be fully dispersed and diluted in deep water away from shorelines and shallow nearshore areas.

To protect PWS's diverse resources, stakeholders must identify and prioritize those resources and adopt and utilize the concept of environmental trade-offs when planning oil spill response strategies. Effective and responsible dispersant use decision making requires input from all stakeholders to: 1) identify and prioritize PWS shoreline, using a high resolution environmental sensitivity index; 2) identify and prioritize PWS biological resources by seasonal cycles of occurrence, distribution and sensitivity to oil; 3) determine the occurrence of seasonal cycles of physical oceanographic conditions (e.g., temperature, salinity) that may render dispersant use ineffective; and 4) develop and utilize Ecological Risk Assessment protocol to provide the framework for documenting and supporting dispersant use decisions.

Conclusions

Prince William Sound is a 4,000 km^2 fjord-type estuary where complex physical processes act to structure equally complex biological systems. The Sound is a region with strong economic, recreational, and aesthetic links to its physical splendor, complex and poorly understood physical oceanographic processes and rich biologic diversity. The region is comprised of numerous stakeholders with many concerns for the Sound's physical and biological resources. One issue that all stakeholders agree on is that Prince William Sound's resources are continually at risk from the threat of oil pollution. This threat will exist as long as oil tankers transport crude oil from the Alyeska Oil Terminal in Valdez Arm to Hinchinbrook Entrance at the mouth of the Sound and in Gulf of Alaska waters adjacent to Alaska's coastline.

There are many tools in the oil spill response strategy arsenal. One tool is chemical dispersion of spilled oil. However, there are arguments in favor and against the use of dispersants in Prince William Sound and the Gulf of Alaska. At this time it is recommended that, prior to utilizing dispersants as a primary oil spill response strategy in PWS and GOA, dispersant effectiveness be demonstrated, ecological risks associated with dispersant use be identified, and critical Sound resources be identified and prioritized for protection.

To accomplish these tasks, the Sound's complex physical and biological regimes must be better understood. Laboratory studies and field trials must be conducted to determine the effectiveness of chemical dispersants on Alaska North Slope crude in conditions that exist in PWS during annual seasonal temperature, salinity, current and flushing regimes. The acute and chronic effects and risks associated with chemically dispersed oil on Alaska's marine species must be better understood. Seasonal cycles of occurrence, distribution and habitat utilization of Alaska's critical marine resources must be understood. Shoreline types and associated adjacent subtidal and intertidal habitats must be better defined.

When armed with these data, stakeholders will need to prioritize the Sound's physical and biological resources for protection and identify and agree on acceptable physical and biological environmental trade-offs associated with dispersant use. The basis for resource prioritization should include seasonal cycles of prioritized resource or species occurrence and distribution, acute and chronic sensitivity of resources to chemically dispersed and persistent oil, and economics which may be defined as the commercial and/or ecosystem value of the resource. Stakeholders must then incorporate current research, defining the effectiveness of dispersants and the ecological consequences of dispersant use and the consequences of not using dispersants on oil spills in Prince William Sound and the Gulf of Alaska into response plans before the next oil spill.

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Environmental Risks and Trade-Offs in Prince William Sound

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Abstract
This brief presentation is an overview of information concerning the environmental risks associated with dispersant use and the application of this information to dispersant planning and decision-making. It considers the risks of lethality, sub-lethal effects and taint from exposure to dispersants and chemically treated oil. It considers the relationships among factors such as toxicity, risk, impact and environmental trade-offs in making decisions about dispersant use.

Introduction
The S.L. Ross (1997) report entitled, "A Review of Dispersant Use on Spills of North Slope Crude Oil in Prince William Sound and the Gulf of Alaska," prepared for the Prince William Sound Regional Citizens' Advisory Council (PWS RCAC) synthesized the recent technical literature on dispersants with a view to determining whether there are environmental advantages to using dispersants in Prince William Sound and the Gulf of Alaska. This report addressed the following two questions posed by the PWS RCAC:

> *Will modern dispersant products be effective in dispersing North Slope crude oil spills in Prince William Sound and the Gulf of Alaska?*
>
> *Do dispersants offer environmental advantages in PWS / GOA considering the possible detrimental effects of intentionally driving oil into the water?*

The first question was addressed by Ross (1998) earlier in these proceedings. This paper deals with the second question.

The role of spill countermeasures is to reduce the environmental impact of an oil spill. The appropriateness of using dispersants can be judged by its capacity for reducing spill impact. In a spill the preferred approach to ameliorating impact is to collect the oil and remove it from the sea. Unfortunately, in most cases it is possible to collect only a small proportion of the oil, leaving the rest to cause environmental damage. Dispersants can reduce the risk posed by this oil by removing it from the surface. Oil spills form slicks which pose risks to organisms at the sea surface (marine birds, hairy mammals), intertidal resources (including vegetated shorelines such as coastal marshes) and species occupying the shallow sub-tidal habitat (such as herring spawn). Dispersants can reduce the risk to these resources by removing the spilled oil from the sea surface, but only at the cost of increasing the level of exposure of resources in the water to dispersed. The appropriateness of dispersant use depends on whether the environmental gains achieved by removing the oil from the sea surface outweigh the environmental losses resulting from putting the oil into the water column. In other words, it is a trade-off of environmental gains vs environmental losses.

Making trade-offs is a challenging task, involving a number of considerations. For one thing dispersed oil threatens some different species (the in-water species) more than the untreated oil (surface dwellers and shoreline species). Trade-offs also involve comparing the potential impact of the dispersed spill on these resources vs that of the untreated spill on the surface dwellers and shoreline species. Estimating impact and making a the comparison involves a numbers of considerations including:

1. the risk that damage might occur, which depends on environmental concentrations of dispersed oil, its toxic potency, and the sensitivity of the target organisms;

2. the likelihood that exposure will occur, which depends on the habitat utilized by the target species, such as the upper part of the water column, or the seabed in deep offshore or shallow nearshore waters;

3 the amount of potential damage which depends on: the vulnerability of the target populations to oil (is it clumped together in a small area or spread out over thousands of square miles); the size of the spill and the amount of dispersant used; the location of the spill and the treatment areas relative to the location of the target resources;

4. the capacity of damaged populations to recover, which depends on the type of injury that has been caused (mortality, sub-lethal effects or contamination), and the capacity of the population to recover by reproduction; and

5. The importance or value of the damaged resources, based on ecological, social or economic criteria.

This paper addresses the appropriateness of dispersant use in the PWS/GOA area by examining the environmental trade-offs. First we will consider the risk of damage from dispersed spills, by analyzing exposure conditions and the sensitivities of various biological resources. Second we will consider some environmental risks and trade-offs associated with dispersant use in PWS. Finally we will consider the arguments in favor and against dispersant use in PWS.

The Fate and Effects of Dispersants and Dispersed Oil

The risks associated with untreated oil are well understood through our extensive experience with spills. On the other hand, our knowledge of dispersed spills is very limited because we have little direct experience with them in actual spills. Most of our knowledge of dispersant risks is from the very extensive body of experimental work conducted on dispersants over the past three decades. This section summarizes our knowledge of risk based on this experimental work and on the studies of the recent *Sea Empress* spill during which dispersants were heavily used. Here we address the specific RCAC request to discuss "the fate and effects of dispersants, dispersed oil mixtures and dispersed oil in the water column (e.g., concentrations, residence time, biodegradation, bioaccumulation, etc.,)." This section first covers the risks associated with the dispersant alone and then discusses the risks associated with dispersed oil.

Fate and Effects of Dispersants Alone

Ideally, all dispersant that is applied during a spill will mix effectively with the oil slick, but unquestionably some dispersant will enter the sea surface alone for one reason or another. This section considers the risks associated with this aspect of dispersant use.

The risks associated with exposure to dispersants alone were assessed by comparing the range of toxic threshold values reported for various organisms against the expected exposure conditions in the upper water column during operations. Exposure conditions were estimated for operational scenarios based on application characteristics of equipment currently owned by Alyeska Pipeline Services. Because, at present only Corexit 9527 is stockpiled in Alaska, only the risks associated with this product were considered. Under these conditions dispersants could potentially enter the water column alone through either a single pass application performed in error over open water or through an ineffective, multiple pass application against a patch of weathered oil in which most of the dispersant rolls off the oil and enters the water alone.

Table 1: Dispersant Application Rates (Single Pass) of Existing Alyeska Dispersant Application Systems[1]

System	Model	Total Swath Width (feet)	Pump Rate (gal. per minute)	Spray Speed (knots)	Coverage Rate (acres/min)	Application Rate (gal/acre)
Helicopter System	Helitask Model TC3-Mk111[1]	20	98	60	16.7	8.4
Vessel System	Frank Ayles Sea Spray[2]	90	12	5	1.1	10.9
				10	2.1	5.7
Large Fixed-Wing Aircraft	ADDS pack[2]	150	800	140	52	15.3
		200		140	93	8.6

1 Most specifications from Shultze et al. 1995
2 Specifications from Alyleska PSC 1995 Supplemental Information Document #15

Peak Environmental Exposures to Dispersants. The spray characteristics for equipment in Alyeska stockpiles are given in Table 1. Application rates for single passes range from approximately 5 to 15 gallons per acre; so we will consider accidental single pass application rates of these amounts. In the multi-pass scenario, the application rate required to treat a 1 mm thick slick at a dispersant-to-oil ratio of 1:20 will also be considered. This application rate is approximately 50 gallons per acre and could be achieved by three passes with the ADDS Pack.

Table 2 shows the potential worst-case concentrations of dispersant in the water column with different dilution depths. These concentrations will decline quickly to very low levels, provided the application is in an open area of deep water which provides adequate dilution. The high concentration of dispersant in the upper water column in the multi-pass scenario (45 ppm) would in all likelihood not be achieved because it would require at least three passes to achieve the dosage. However, after each pass the dispersant would enter the water column and become diluted prior to the next pass so that the total quantity of dispersant would not be concentrated in the upper water column at once. If the interval between passes is long enough or if the dilution rate is rapid enough, the peak exposure concentration would be similar to the single-pass exposure.

Table 2: Estimated Concentrations of Dispersants at Three Depths for Various Application Scenarios(1)

Application Scenario	Application Rate (gallon/acre)	Dispersant Concentration at Dilution Depth (ppm)		
		1 m	5 m	10 m
Minimum single pass application	5	5	1.0	0.5
Maximum single pass application	15	15	3	1.5
Multiple pass with C130/ ADDSPACK sufficient to achieve a 1:20 close rule on a 1 mm thick slick	45	45	9	4.5

In brief, the exposure conditions in the upper water column resulting from a single pass application that misses oil and lands in open water would be at worst 5 to 15 ppm in the upper 1 meter and 0.5 to 1.5 ppm at a depth of 10 meters. In the case of a multi-pass application the exposure conditions could approach several tens of ppm the upper water column and a few ppm at a depth of 10 metres. Because of rapid dilution these exposures would last only minutes.

Effects, Sensitivities and Risks Associated with Exposure to Dispersant Alone. A considerable number of studies have been published over the years on the toxicity of dispersants. The median effect concentrations for Corexit 9527 on a variety of species and life stages are summarized in Table 3. The data suggest that, all other things being equal, sensitivity to Corexit 9527 varies greatly with species and life stage, with median lethal concentrations for a many species in the 10 to 100 ppm range those for highly sensitive species in the range of 1 to 10 ppm..

Certain of the exposure concentrations estimated above exceed these toxic threshold values, suggesting that there is some risk of effects. However, effect thresholds from continuous exposure tests (96-hour tests) are a very conservative indicator of sensitivity to dispersants because real-world exposures will be very brief, lasting only minutes, or at most an hour or two. Table 4 compares the sensitivity data from prolonged-exposure tests against those from brief, "spike exposure" tests that simulate real-world exposures. They show that organisms can tolerate very brief exposures to concentrations that are 3 to 22 times higher than could be tolerated for much longer periods. The median lethal exposure thresholds in the spike tests were well above all but the highest estimated dispersant concentrations in the water column in the above application scenarios.

In brief, the available information suggests that where there is sufficient dilution potential, exposure conditions for dispersants will be below the lethal effect thresholds for all but the most sensitive species. Estimated exposure concentrations, in the upper meter of the water-column for the "single-pass" scenario and in the upper few meters in the multi-pass scenario might be expected to exceed the no-effect threshold for spike exposures for only the most sensitive species. It is worth reiterating that these exposure concentrations will not apply to a large area, but only to a very small area the size of a misplaced swath or a resistant patch of thick oil. Based on this type of information, the NRC (1989) review of dispersants concluded that "major effects (other than effects on the insulation capability of fur and feathers) should not occur in near surface waters due to dispersant alone, provided properly screened dispersants [low toxicity dispersants] are used at recommended application rates."

Fate and Effects of Chemically-Dispersed Oil in the Water Column

This section addresses the risks associated with chemically-dispersed oil in the water column under dispersant-treated oil slicks. The exposures are considered first and the toxicity and risks are considered second.

Table 3:Toxicity Threshold for Dispersant Corexit 9527

Common Name	Species	Life Stage (type of exposure)	Median Lethal Concentration			Spike Exposure (ppm)	Reference
			24 hr	48 hr	96 hr		
Estuarine Mysid	Mysidopsis bahia	juvenile (static)	37	15	2	-	Pace and Clarke 1993
Estuarine Mysid	Mysidopsis bahia	Juvenile	29	34	29	-	Pace and Clarke 1993
Kelp Forest Mysid	Holmesimysis costata	juvenile (static)	-	12	5	-	Pace and Clarke 1993
Inland Silverside	Menidia beryllina	juvenile	52	52	52	-	Pace and Clarke 1993
Kelp Forest Mysid	Holmesimysis costata	juvenile	-	-	6	15	Singer et al. 1992
Topsmelt	Atherinops affinis	larva	-	-	31	83	Singer et al. 1992
Spot	L. xanthurus	embryo-larva	-	27	-	-	Fucik et al. 1995
Inland Silverside	Menidia beryllina	larva	-	43	-	-	Fucik et al. 1995
Inland Silverside	Menidia beryllina	embryo	-	-	>100	-	Fucik et al. 1995
Atlantic Menhaden	Brevoortia tyrannus	embryo-larva	-	42	-	-	Fucik et al. 1995
Red Drum	Sciaenops ocellatus	embryo-larva	-	53	-	-	Fucik et al. 1995
Stickleback	G. aculeatus	immature	-	-	28	-	Wells & Doe 1981
Rainbow Trout	Salmo gairdneri	immature	-	-	192	-	Wells & Doe 1981
Four-horned Sculpin	M. quadricornis	immature	-	-	<40	-	Foy 1979
Amphipod	Gammarus oceanicus	immature	-	-	>80		Foy 1979
Amphipod	Anonyx nugax	immature	-	-	104	-	Foy 1979
Amphipod	Anonyx laticoxae	immature	-	-	>140	-	Foy 1979
Amphipod	Gammarus setosus	aadult	-	-	175	-	Foy 1979
Amphipod	Onisimus littoralis	adult	-	-	115	-	Foy 1979
Mummichog	Fundulus heteroclitis	not specified	-	-	100	-	Exxon (no date)
Brine Shrimp	Artemia salina	not specified	-	50	-	-	Exxon (no date)

Table 4: Thresholds of Lethal Effects for Corexit 9527 (from Singer et al. 1992)

Common Name	Species	Life Stage	Effect Thresholds (ppm)			
			Constant Exposure		Spike Exposure	
			NOEC[1]	LC50	NOEC	LC50
Abalone	Haliotis rufeseus	embryo	1.1	1.6	6.6	15.9
Mysid	Holmesimysis costata	juvenile	3.3	6.2	14.6	140.1
Topsmelt	Atherinops affinis	larva	13.5	30.7	57.0	83.0

1 No observable effect concentration

Oil Fate and Exposure Conditions. From the perspective of risk, a major concern in the water column environment is the short-term fate of the dispersed oil, namely, the concentration and persistence of the dispersed oil that develops in the upper water column under dispersing oil slicks. This is important because this determines the conditions to which organisms are exposed and the likelihood that organisms will suffer adverse effects. The best source of information concerning the concentration of dispersed oil in the water column under dispersant-treated oil slicks are the series of field dispersant trials that have taken place since the late 1970s.

The short-term fate and behavior of dispersed oil in one of these small-scale field tests is illustrated in Table 5, which shows the peak oil concentrations at different depths and times after spraying. It is important to note that these are the peak concentrations, average concentrations were lower. In these studies oil concentrations in the upper few meters of the water column increased into the tens of ppm within minutes after dispersant was sprayed, but declined rapidly within several hours. Oil concentrations at greater depths (9 m) increased slightly, but peak concentrations did not exceed a few ppm.

Measurements taken under dispersed and untreated slicks in a number of trials are summarized in Table 6. Apparently, exposure concentrations observed in the upper water column are of the order of a few ppm to a few tens of ppm total dispersed oil. In these small trials the concentrations at deeper depths (9-10 m) increased, but to a far lesser degree than in the upper water column (up to 1-2 ppm). This latter observation has lead subsequent workers to conclude that it is unlikely that dangerously high concentrations would develop at depths below the top 10 meters of the water column (CCP Workshop 1995).

Table 5. Concentration of Dispersed Oil in the Water Column Beneath a Dispersant-Treated Oil Slick[(1)]

Depth (m)	Time After Spraying		
	0.25 hr	0.6 hr	3.0 hr
1	40	12	1
3	9	14	2
9	0.1	2	.5

1. API Research Spills California 1979. 20 bbl of Prudhoe Bay Oil treated immediately with dispersant H applied from DC-4 aircraft. Estimated single pass application rate is 15 gallons/per acre. Estimated dosage rate 1:19. Estimated dispersant effectiveness 78%. From McAuliffe et al. 1981.

Table 6. Peak Dispersed Oil Concentrations Measured at Various Depths Under Treated Slicks During Field Trials

Oil Type/Volume	Dispersant Application Conditions	Application Rate Single Pass, gallons per acre	D:0 Ratio	Estimated Effectiveness, percent	Time After Spraying, minutes	Depth Beneath Slick		
						1 m	3 m	9 m
Prudhoe Bay,	Aircraft, immediate	14.8	1:19	78	15	40	9	.9
Prudhoe Bay, 20 bbl(1)	Aircraft, immediate	10.4	1:27	60	4-27	6	2.7	0.2
Prudhoe Bay, 10 bbl(1)	Aircraft, after 2 hr by	7.4	1:19	45	7-26	5	4	.5
Prudhoe Bay, 10 bbl(1)	Boat, immediate thick	10	?	62	?	21	9	.4
Prudhoe Bay, 10 bbl(1)	Boat, immediate thick	5-10	?	11	?	2	1	.2
Prudhoe Bay, 20 bbl(1)	Control, no spray	–	–	0.5	–			
Reconstituted fuel oil, 63 bbl(2)	Aircraft, after 2 hours	?(3)	1:75	?	60	18	.8	-
Reconstituted fuel oil, 63 bbl(2)	Aircraft after 4 hours	?	1:5	?	30	32	4	-
Reconstituted fuel oil, 63 bbl(2)	Control, no spray	?	0	?	–	.5	.02	-

1 McAuliffe et al. 1981
2 Lichtenthaler and Daling 1983, Reconstituted fuel oil prepared from Statfjord crude oil fractions to yield a product with density 0.852 g/ml, viscosity 12 cSt @ 11°C, pour point -15°C
3 ? = not known

Recent field trials conducted by agencies from Norway, the U.K. and France have confirmed the conclusions of earlier workers and have provided one more important piece of information that increases our understanding of the process and potential risks (e.g., Lunel 1994, Brandvik et al. 1996). Lunel and Davies (1996) demonstrated that dispersion of oil from treated slicks takes place over an extended period during dispersant application and continues for some minutes after the spraying stops. Over this period the oil disperses at a slow, apparently uniform rate. As dispersant is applied, the oil concentrations increase in the water under the slick for a few moments until an equilibrium is reached in which dispersed oil is carried away from the under side of the slick by diffusion as quickly as it enters the water. As a result, high concentrations of dispersed oil do not accumulate under the slick even in the upper few meters of the water column.

As mentioned elsewhere, there has been only one well documented modern spill in which dispersants have been used in an efficient and controlled way (*Sea Empress*, Milford Haven, U.K., Feb 1996) (see SEEEC 1996, as well as Law et al.1998, and Lunel 1998, in these proceedings). In-situ monitoring of oil concentrations in the water under the dispersant treated slicks was performed to verify effectiveness of the dispersants. Oil concentrations in the water column measured before dispersant spraying were of the order of 3 ppm in the upper 1 metre declining to less than 0.5 ppm at depths of 4.5 metres. During the dispersant application oil concentrations of the order of 3 ppm were measured over the depth range from the surface to a depth of 5 metres. According to Lunel et al. (1997), the elevated oil concentrations and lack of a concentration gradient between the surface and a depth of 5 metres is indicative of an effective dispersant application, with the sea conditions causing the small droplets to be dispersed into the surface waters and to be mixed throughout the upper water column.

Lunel et al.estimated that approximately 50% (or approximately 36,000 tonnes) of the oil spill from the *Sea Empress* was dispersed into the water column by natural and/or chemical means. The long-term fate of the oil is currently being investigated. On February 27, 1996 several days after the dispersant operations were stopped, concentrations in surface waters throughout Carmarthen Bay were of the order of 0.2 to 1.0 ppm. By March 5 concentrations had declined to less than 0.2 ppm and by June they had declined to background levels of 5-20 ppb.

The field trials and the experience in the *Sea Empress* spill provide substantial evidence that exposure concentrations in the upper water column beneath dispersant-treated oil slicks will be of the order of a few parts per million or even as much as a few tens of parts per million dispersed oil even during an effective dispersant operation and that these concentrations will decline quickly after the dispersant operations ceases. However, the data from *Sea Empress* demonstrate that in a very large spill, ambient oil concentrations do not return to background levels within hours or days as was predicted from the small scale test spills of the 1980s. Rather ambient oil concentrations of the order of tenths of ppm persist for weeks. Although this oil is probably somewhat degraded and is therefore probably less potent as a toxicant, the potential risks from this longer term source of exposure should not be overlooked.

Effects, Toxicity and Risks From Dispersed Oil in the Water Column. This section deals with the lethal and sublethal effects, tissue contamination and taint caused by dispersed oil in a variety of types of organisms.

Lethal and Sublethal Effects. One major concern over the use of dispersants in marine waters is the potential impact of dispersant use on fish, water column organisms and the young life stages of commercially important species. This section deals with the types of effects that have been caused by dispersed oil in various groups of organisms and the exposure conditions needed to cause the effects. This information coupled with data on exposure conditions under slicks provide insights into the risks of adverse effects under dispersing slicks.

Our perceptions of the threat posed by dispersed oil is derived from the work of toxicologists and risk assessors of the 1970s and 1980s. The main conclusions of these workers were summarized in the NRC (1989) report. These were as follows.

1. The toxicity of a dispersant/oil mixture is due to the effects of the dispersed oil not the dispersant. This was important because it means that risk can be assessed by considering only the oil component of the oil-dispersant mixture. The contribution of the dispersant as a toxicant can be ignored.

2. In general, chemically dispersed oil, gram for gram, is no more toxic than is physically dispersed oil.

3. Many of the effects observed in laboratory toxicity tests were caused at exposure concentrations greater than those observed in field trials, and in many cases much longer required exposures, than are likely to be observed in real spills. This suggests that many of the species tested would be resistant to the effects of dispersed oil under realistic exposure conditions.

The specific findings of NRC (1989) and more recent studies on water column species are summarized below. In general citations of publications discussed in NRC are not repeated here.

1. Phytoplankton
- effects of chemically-dispersed oil included inhibition of photosynthesis, inhibition of respiration, reduced cell growth and cell mortality;
- effect thresholds - few useful studies; one study showed that the EC50 for inhibition of carbon fixation was approximately 1 ppm dispersed oil, but some inhibition of photosynthesis was observed at oil concentrations as low as 0.5 ppm;
- based on NRC (1989), Trudel (1978), Tukaj (1994) ,Tukaj and Zachleder (1993).

2. Ichtyoplankton
- effects of chemically dispersed oil include both lethal and sublethal effects (e.g., narcosis, heart rate, larval growth, larval deformity);

- effects thresholds - sensitivity to dispersed oil varied with species, but, more importantly, sensitivity varied by as much as ten-fold between life stages of the same species; where data were available, toxic thresholds were in the range of 1 to 10 ppm dispersed oil;
- based on NRC (1988), Middaugh and Whiting (1995), Fucik et al. (1995).

3. Planktonic Copepods
- both lethal and sublethal effects studied;
- effect thresholds in the range of 10 to 100 ppm dispersed oil;
- based on NRC (1988), Foy (1979) Venezia and Fossato (1977), Spooner and Corkett (1974,1979).

4. Shrimps, Crabs and Lobsters (young life stages)
- lethal and sublethal effects (various effects ranging from changes in heart rate and oxygen consumption to more serious effects such as histopathological changes in gill tissues);
- where reported, toxic thresholds range from 10 to 100 ppm dispersed oil;
- based on Bragin et al. (1994), NRC (1989), Shuba and Heikamp (1989).

5. Finfish
- mostly lethal toxicity studies;
- toxic thresholds in the range 10 to 100 ppm dispersed oil;
- studies suggest that fish can avoid dispersed oil; some evidence that homing behavior is not disrupted by dispersed oil;
- based on Wells and Harris (1980), Foy (1979), Anderson (1987), Shuba and Heikamp(1989), NRC (1989) .

From the perspective of risk assessment, the most important recent research estimated toxic thresholds under conditions that simulate the short-term exposures that water column dwellers would experience under dispersed slicks (Anderson et al. 1987, Shuba and Heikamp 1989, Fucik et al. 1994, 1995, Bragin et al. 1994, and Singer et al. 1995). The concept was first developed by Anderson et al. (1987), based on early modeling and risk assessment work (Trudel, 1984). However, the first truly applicable toxicity data was collected by Shuba and Heikamp (1989), who demonstrated that certain species can resist brief exposures to dispersed oil concentrations that would be lethal under prolonged exposure. Bragin et al. (1994) demonstrated, using mysids, that continuous exposures to chemically dispersed oil were 10 to 26 times more toxic than spike exposures. That is, these organisms can tolerate brief exposures to dispersed oil concentrations that were 10 to 26 times greater than those that would cause death under conditions of continuous exposure (from 48 to 96 hours). Some of the results of this work are summarized, along with some earlier work, in Table 7. Some of the toxic thresholds that were measured using 48- or 96-hour LC50 (Singer et al. 1995) are consistent with, though somewhat lower than results from earlier studies. Pointing out that some modern researchers are focusing on sensitivities of the sensitive species rather than those of average sensitivity.

It is important to note that one of the modern studies (Bragin et al. 1994) reported what appeared to be some of the highest sensitivities ever reported for chemically dispersed oil. This study reported toxic thresholds for mysid larvae in prolonged exposure tests that were below 1 ppm total dispersed oil, suggesting very high sensitivities. It appears, however, that these data must be treated with caution for methodological reasons (J. Clarke, pers. comm.).

Table 6.7 Sensitivities of a Range of Species and Life Stages to Chemically Dispersed Oil[1]

Common Name	Species	Life Stage	Oil Type	Toxic Endpoint	Toxic threshold LC50/EC50 (ppm)			Reference
					Continuous		Spike Exposure [2]	
					48 hr	96 hr		
Mysid	Holmesimysis costata	juvenile	Kuwait	mortality	--	(0.65)[4]	(13-25)	Bragin et al 1994
Mysid	Mysidopsis bahia	juvenile	Kuwait	mortality	--	(0.17)[4]	(1-5)	
Abalone	Haliotis rufescens	embryo	PBC[4]	shell	18-33	--	--	Singer et al 1995
Mysid	Holmesimysis costata	juvenile	PBC	mortality	--	10-11	--	Singer et al 1995
Oyster	Crassostrea gigas	larvae	MFO[5]	shell	2.8	--	13.9	Coelhoe et al
Shrimp	Penaeus aztecus	juvenile	Mayan	mortality	--	---	23.2	Shuba et al. 1989
Shrimp	Penaeus aztecus	juvenile	Arab Lt	mortality	--	---	20.2	Shuba et al. 1989
Shrimp	Penaeus setiferus	juvenile	Mayan	mortality	--	---	41	Shuba et al. 1989
Redfish	Sciaenops ocellatus		Mayan	mortality	--	----	255	Shuba et al. 1989
Redfish	Sciaenops ocellatus		Arab Lt	mortality	--	--	104	Shuba et al. 1989
Trout	Salmo gairdneri		No. 2 Oil	mortality	--	57	--	Wells et al. 1980
Stickleback	Gasterosteus aculeatus		No. 2 Oil	mortality	--	24		Wells et al. 1980
Sculpin	Myoxocephalus quadricornis		PBC[3]	mortality	--	59	--	Foy 1979
Amphipod	Anonyx nugax		PBC	mortality	--	45	--	Foy 1979
Amphipod	Anonyx laticoxae		PBC	mortality	--	112	--	Foy 1979
Amphipod	Gammarus oceanicus		PBC	mortality	--	105	--	Foy 1979
Amphipod	Gammarus setosus		PBC	mortality	--	138	--	Foy 1979
Amphipod	Onisimis litoralis		PBC	mortality	--	138	--	Foy 1979

1. In all cases the dispersant is Corexit 9527
2. Based on peak concentration at the beginning of the exposure
3. PBC = Prudhoe Bay Crude Oil
4. Analytical method used to measure oil measured only a portion of the C10 to C27 fraction of the oil.
5. MFO = Mixed fuel oil/Gas oil mixture

From the perspective of risk assessment the most important conclusions of the above are as follows.

1. Most toxic threshold values reported to date for both continuous or spike exposures are similar to or well above the exposure conditions likely to be experienced in the upper water column under dispersing slicks. This suggests that many species will not be effected lethally by exposures in the upper water column. The data suggest that some more sensitive species might suffer lethal effects and many might suffer temporary sublethal effects.

2. There are no data to suggest that exposure to chemically dispersed oil will disrupt the migrating behavior of salmon. By the same token there is some data to suggest that salmon may detect and avoid elevated hydrocarbon concentrations in the water column.

Bioaccumulation and Tainting. The temporary contamination or tainting of local stocks of aquatic organisms with petroleum hydrocarbons is a common aspect of oil spills. It is an important aspect of the impact of spills on fisheries because contamination, taint or even the threat of either generally results in an economic impact on local wild-fish fisheries or mariculture. Contamination and tainting of commercial fish stocks is a concern commonly voiced in connection with dispersant use. This section considers the available information concerning the potential for contamination and tainting of fishery species during a dispersed spill.

A laboratory study by Mageau et al. (1987) conducted as part of the Baffin Island Oil Spill Project (BIOS) illustrates the potential for uptake and loss of hydrocarbons by benthic invertebrates from dispersed oil. Filter-feeding bivalve molluscs and surface feeding sea urchins accumulated measurable concentrations of hydrocarbons in their tissues during brief (< 1 day) exposures to dispersed oil in water at concentrations as low as 5 ppm. The hydrocarbons that were taken up were lost quickly when the contaminated animals were transferred to clean water. The low-molecular-weight (LMW) aromatic hydrocarbon fraction was quickly lost (depurated) within days after the exposure had ceased. The same species exposed in field experiments lost most of the accumulated hydrocarbons within one year. This shows that biota take up and lose dispersed hydrocarbons quickly.

Ackman et al. (1991) and Martinsen et al. (1993) studied the tainting of scallops and steelhead trout, respectively, with chemically-dispersed oil. Both showed that taint could be caused by exposures to dispersed oil concentrations similar to those observed under treated slicks. Ackman observed that exposures to dispersed oil concentrations as low as 4 ppm total dispersed oil caused taste-detectable taint in scallops after only 24 hours of exposure. Maritnsen detected taint in steelhead after four hours of exposure to 0.3 ppm of dispersed Alaska North slope Crude oil. Parallel studies of tainting with water-soluble fraction of crude oil demonstrated that taint acquired by under brief exposures to low hydrocarbons concentrations was lost quickly, within days, after the exposure ceased.

The most important observations in this connection, however, have come from the research and monitoring during the *Sea Empress* spill. Law et al. (1997, 1998 these proceedings) reported on the chemical analyses and taste testing of 600 fish and shellfish samples collected during the monitoring program . The results are summarized below.

1. The majority of finfish samples taken within the oil-contaminated area showed no significant level of hydrocarbon contamination. Samples from only four individuals (1 bass and 3 salmon) exceeded background levels. No taint was detected by taste panels in any finfish from the affected area.

2. No taint was observed in crab or lobsters. Hydrocarbon concentrations in crustaceans remained low other than within the confined and contaminated waters of Milford Haven itself.

3. Bivalve molluscs (e.g., cockles and mussels) exposed to oil within the study area accumulated petroleum hydrocarbons to high concentrations in some cases. Filter-feeding cockles and mussels appeared to have accumulated higher molecular weight (HMW) aromatic hydrocarbons as well as LMW aromatics, apparently acquiring them by ingesting oil particles. Within only a few months of the spill hydrocarbon concentrations in shellfish tissues from areas that showed higher levels of contamination following the spill are quickly declining toward background levels.

There does not appear to be any indication whether the contamination was caused by the dispersed or untreated portions of the spilled oil.

The two laboratory studies have demonstrated that taint can be caused in fishery species by exposures of a few hours duration to concentrations of dispersed oil that are likely to be encountered in the upper water column under dispersed oil slicks. The results of the Martinsen et al. study suggest that finfish species are very highly susceptible to tainting from oil spills and it is remarkable that there has been no follow-up to this work. Second, the taint that was accumulated was lost very quickly once ambient hydrocarbon concentrations returned to background levels. This is consistent with the theory that it is the LMW aromatic hydrocarbons that are causing the taint, since these compounds are taken up and depurated quickly. The results of the monitoring study of the *Sea Empress* spill are very important, because they show that an unexpectedly low amount of contamination in finfish taken in then area contaminated with dispersed oil.

In short, the evidence from laboratory studies suggests that there is a potential for contamination of fisheries resources, at least in the areas sprayed where exposures are greatest. However, the results of the studies of finfish contamination in the *Sea Empress* spill showed no evidence of significant contamination. It would be premature to disregard contamination of fishery resources as a concern in dispersant cases, especially in shallow, nearshore waters, but the results suggest that the subject of contamination requires additional study in order to understand the risks.

Risks to Birds and Mammals

Generally, it is expected that if dispersants are used to get spilled oil off the sea surface, then the overall risk to surface dwellers, such as marine birds and mammals, will be reduced. However, there appears to be some concern that the dispersant itself or the treated, but undispersed oil may pose risks to marine birds or mammals. This section addresses the concern that dispersant use may pose an unanticipated threat to birds or mammals. The objective is to assess: (1) whether dispersants alone could pose a threat at realistic exposure levels in the above scenarios; and (2) whether the presence of dispersant as a contaminant in oil slicks might appreciably increase the toxicity of the oil when externally applied or ingested.

Marine Birds. Workers have considered a number of risks to birds from oil spills and dispersant operations, including:

1. hazards to adults or immatures exposed via ingestion to dispersant alone or mixed with oil;

2. hazards from external contamination of plumage; and

3. hazards to eggs from external oiling as might occur if adults were to pick up oil on their plumage and contaminate the eggs upon returning to the nest.

The research on these effects has been reviewed (Peakall et al. 1987, Trudel 1984) and conclusions were summarized in NRC (1989). The work to date suggests the following.

1. There is little information concerning the sensitivity of marine birds to dispersant if ingested. There is qualitative information to suggest that dispersants cause a breakdown in the waterproofing of birds' feathers, but there is no information concerning the dose required to cause this effect.

2. There appears to be some information to suggest that oil mixed with dispersant disrupts waterproofing of the plumage of marine birds more strongly than oil alone.

3. Peakall et al. 1987 concluded, based on a modeling study that there would be little risk to marine birds from swimming through a cloud of chemically-dispersed oil.

Marine Mammals. Marine mammals are affected by oil in much the same way as marine birds, through chemical toxicity if ingested and through physical effects if contaminated externally. The effect of spilled oil varies with species, with hairy mammals (sea otters, polar bears) being the most sensitive to oil and bare-skinned mammals (whales, dolphins) being the least sensitive. The effects of oil on marine mammals has received considerable study, but the effect of dispersants and oil dispersant mixtures has received very little. The implications of the available information to dispersant use are the following.

1. The apparent effect of surfactants on the insulating properties of the fur suggests that dispersants might pose a hazard to hairy mammals if they are sprayed directly. However there is no information on the amount of dispersant or dosage required to cause those effects. It is therefore difficult to assess weather realistic levels of exposure in the spill area would pose a genuine hazard.

2. The limited information available does suggest that dispersant-contaminated oil is no more effective than crude oil alone in disrupting the thermal insulating properties of the fur of hairy mammals and so poses no greater risk than the untreated oil.

Summary of Environmental Risks from Dispersant Use

The potetial environmental effects of dispersant use include mortality and sub-lethal injuries to species ranging from phytoplankton, zooplankton and finfish to shellfish and critical habitat (e.g., seagrass). These potential effects also include contamination and tainting of exploited species which impact harvesting. Before the *Sea Empress* spill of 1996, workers had little direct experience with the effects of dispersant use. Much of our understanding of risks was based on comparing the apparent sensitivity of organisms against the exposures that organisms might experience during a dispersant treated spill. Using this approach risk assessors reached the following conclusions about the risks from dispersant use.

1. There is little risk of effects with dispersants alone because (for the modern low toxicity dispersants), exposures likely to be encountered in the water column are far below those required to cause effects. This assumes that dispersants are used according to manufacturers specifications.

2. The toxicity of oil-dispersant mixtures derives from the effects of the oil not the dispersant. Therefore the environmental risks associated with dispersant use can be predicted based on the behavior and exposures to the dispersed oil alone.

3. Dispersant operations would result in localized and temporary increases in the concentrations of dispersed oil in the upper layers of water under dispersing slicks. Concentrations of dispersed oil in surface waters would be strongly elevated for up to several hours, as long as the dispersant is being applied. When the spraying ceases the dispersed oil concentrations decline quickly by diffusion. The peak concentrations of dispersed oil under slicks is a few ppm to as much as few tens of ppm.

4. Toxicity studies involving chemically-dispersed oil and a variety of species and life stages suggest that the toxic threshold values for all but the most sensitive species are above the concentrations of dispersed oil encountered under treated slicks. However, the toxic thresholds of some sensitive species are within the range of the peak concentrations under dispersing slicks. This suggests that most species will resist the worst-case exposures to dispersed oil, but that certain, more sensitive species may be affected by them. It follows that there is little risk of toxic effects to any organisms in areas adjacent to those sprayed or deeper in the water column below the treated slicks (i.e., below 10 metres depth).

5. The few available studies of tainting of fishery species (finfish and shellfish) showed that resources could become tainted when exposed to conditions encountered beneath or adjacent to treated slicks. However, taint acquired in this way was lost within days after the exposure ended.

The experience gained from the *Sea Empress* spill confirmed these conclusions and provided additional insights as well.

1. The monitoring program associated with the *Sea Empress* spill contained no accounts of mortalities of fish or shellfish associated with dispersant use.

2. Commercially exploited mollusc and crustacean species in the impacted area became measurably contaminated and tainted with hydrocarbons, resulting in closures of fisheries. Contamination appeared to have been lost more quickly in crustaceans than in molluscs, and at least some fisheries were reopened within months of the spill.

3. Finfish from the area did not appear to acquire measurable contamination or taint and these fisheries which had been closed during the spill were also reopened quickly.

4. There did not appear to have been any measurable contamination of the seabed in the area where dispersants were used.

Environmental Impact and Net Environmental Benefit of Dispersant Use on Spills in Prince William Sound and the Gulf of Alaska

Dispersant use will result in some environmental gains and some losses. One approach to deciding whether or not to use dispersants in a specific spill scenario involves considering the potential environmental gains and losses that might result from dispersant use and assessing whether dispersants offer a net environmental benefit. When using this approach, the environmental effects can be expressed in terms of environmental impact. This section deals with:

1. the question of potential impact of dispersed spills; and

2. the potential net environmental benefit of dispersant use within the study area.

Impact of Untreated and Dispersed Spills

Background. Dispersant use plans seldom offer guidance about how to identify situations in which dispersant use offers a net environmental benefit. The NRC review (1989) described only one general approach to assessing the environmental merits of dispersant use, the environmental trade-off method developed by Trudel and Ross (1987). NRC suggested that this trade-off method might be useful in making the environmental judgements called for in the Alaska dispersant matrix and the US EPA Oil Spill Response Decision Tree. The approach involves making two estimates of the impact of a given spill scenario, one for the dispersed case and one for the untreated case. The two estimates of impact are compared to determine which offers the lesser overall impact.

The term "impact" refers to the amount of injury caused by the spill to a population or community. Impact takes into account both the amount of acute injury to a population or stock and the time required for the stock to recover. The acute injury to a species population involves: i) the life stage(s) affected; ii) the level of effects caused (lethal, sublethal, contamination); and iii) the amount of the population or stock affected (numbers of individuals, proportion of population, proportion of standing stock). The duration of the impact recognizes the length of time required for the injured population or stock to recover (days, years, decades). Impact is determined by a number of factors related to spill conditions, environmental conditions, countermeasures and the target species population.

One simple approach to estimating the potential acute impact of a spill on a vulnerable population involves two steps: i) estimating the location and size of the area within which oil exposures might be lethal to species/life stage(s); and ii) overlaying this "area-of-effect" on the distribution of the target population. The proportion of the target population lying within this "area-of-effect" is a worst-case approximation of the proportion of the stock affected by the spill. An additional step would involve correcting this worst-case value for species-specific vulnerability factors such as seasonality, vertical distribution in the water column and patchiness or aggregation of the population. The latter step requires detailed knowledge of the habits of each of the target species.

Methods and Spill Scenarios. The impact of a spill is strongly determined by spill conditions, so when considering spill impact it is essential to relate impact to specific spill scenarios. In the present exercise we will consider the impact of two tanker spills of Alaska North Slope crude oil; a smaller spill of 1000 tonnes (6300 barrels) and a large spill of 10,000 tonnes (63,000 barrels) occurring in the Gulf of Alaska and Prince William Sound. Details of the methods used in the analysis are given in the 1997 SL Ross report to the Prince William Sound Regional Citizens' Advisory Council (S.L. Ross 1997).

Table 8 contains estimates of the areas of the surface waters in PWS or GOA that would be sprayed with dispersants and would be engulfed in a cloud of dispersed oil during a 1000-tonne spill. The estimated size of this area might vary as discussed, but would fall in the range 7 to 30 km^2. Within this area at least some portion of the algal plankton, zooplankton and ichthyoplankton would be impacted. For more sensitive organisms, that are affected by concentrations in the range of 0.5 to 1 ppm, the area of effect would be somewhat larger and would include adjacent areas into which dispersed oil might spread by diffusion. The dimensions of these areas can be placed into context by comparing them with the size of the deep-water area of PWS, an area of approximately 6000 km^2. Based on this comparison, the area of effect for a fully-dispersed spill of 1000 tonnes of crude oil would be from 0.1 to 1 percent of the total area of PWS. All other things being equal, the worst-case acute impact on the standing stock of organisms, such as copepods or larval fish in the upper water column in PWS would be 0.1 to 1 percent. The corresponding impact for the 10,000 tonne spill would be approximately 1 to 10 percent of the standing crop. These spills would effect a much smaller proportion of the area of the GOA and therefore would impact a smaller overall proportion of the community.

Impact of Untreated Spills. The impact of spills in PWS has been demonstrated by the EVOS and this impact has been documented in Rice et al. (1996) and Wells et al. (1994). The following describes the potential fate and impact of untreated spills in general terms for purposes of comparison with those of the dispersed spills.

Oil Fate. The fate and behavior of spilled oil dictates the nature and extent of the impact of oil spills. Spilled crude oil floats and spreads on water forming oil slicks. The slicks move under the influence of winds and currents. When they encounter shorelines, the oil strands on the shore and mixes into the shallow nearshore waters and subtidal sediments, where it persist for months or years if not cleaned. In the offshore environment, oil mixes only slightly with the surface waters and reaches appreciable concentrations in the upper few meters of the water. As a result of this behavior, untreated spills have their greatest effects at the sea surface in offshore areas and in the intertidal and shallow subtidal areas at shorelines.

Table 8. Estimate of Size of Area Under Dispersant-Treated Slick that Receives Peak Concentrations of Dispersed Oil

Month	Platform	Spill Size, tonnes	Wind Speed m/s	Distance Travelled by Slick km	Size of Area of Greatest Contamination km^2	Approximate Volume of Oil Dispersed, tonnes	Peak Oil Conc. in Upper 5 m, ppm
Jan	C-130	9	27	12.7	1000	800	12
	Vessel	9	61	29.5		800	5
July	C-130	5	15	7.1	1000	800	20
	Vessel	5	34	16.3		800	10

Impact. An untreated spill occurring in the traffic lanes in the Gulf of Alaska would form slicks that threaten seabirds and water fowl on the sea surface and planktonic organisms (including ichthyoplankton) that live near the sea surface. If the oil comes ashore the risks would be far greater involving risks to oil-sensitive shoreline habitat (marshes, mudflats), waterfowl and seabird concentrations, sea otter and pinniped concentrations, and the intertidal species such as razor clams. Were the same spill to occur in the traffic lanes within PWS, the oil slicks would impact waterfowl and seabird concentrations, sea otters and the plankton species in the surface waters in open water areas, as well as herring spawning areas (e.g., Green Island) and nearshore nursery areas for young herring and salmon, sea lion and seal haulouts and possibly salmon hatcheries and pockets of marshes at the heads of fjords and inlets on the eastern shore. The nature and magnitude of the effects would vary with the size, location and season of the spill and the movements of the spilled oil.

Some of these spill effects can be mitigated by spill countermeasures. Mechanical removal of the oil provides protection at little or no environmental cost. When removal is not possible these effects can be mitigated through chemical dispersion, but there will be an environmental cost as described below.

Impact of Chemically Dispersed Spills. The fate and behavior of dispersed spills also dictate their environmental effects. Dispersing oil slicks with chemical agents removes them from the surface but creates temporary, localized clouds of dispersed oil in the upper few meters of the water column.

<u>Oil Fate</u>. When dispersants are used they will be sprayed on the thicker portions of slicks and this oil disperses into the water column in the form of millions of very tiny droplets. These droplets are rapidly mixed down to a depth of approximately 3 to 6 meters, forming clouds under the dispersing slicks. Within these clouds some of the more water-soluble hydrocarbons partition into the water, while the less soluble components stay in the droplets. Droplets and dissolved hydrocarbons diffuse outward from the cloud into the adjacent clean water. Dispersion proceeds at a slow, steady pace for as long as the dispersant is applied; probably a period of a few hours. Once the dispersion from the slick stops, the oil concentrations in the clouds decline quickly toward background levels through diffusion. Other slower processes such as evaporation and degradation also act on the oil and largely eliminate the LMW hydrocarbons from the marine environment within days. The droplets containing the remaining HMW hydrocarbons continue to dilute by diffusion, and in addition are transported by ocean currents and settle through the water column toward the seabed. Settling of droplets as small as the dispersed oil droplets is a slow process, involving rates of only a few metres per day and at these rates would require many days to reach the seabed. After this much time the droplets would have been transported considerable distances, but more importantly they would have been dispersed over a very large area so that the level of seabed contamination occurring in any one location would be very small.

In short, dispersing oil slicks with chemical agents removes them from the surface, but creates: (1) temporary, localized clouds of higher concentrations of dispersed oil in the upper few meters of the water column under the dispersing slicks; (2) a zone of lower and declining concentrations of dispersed oil extending beyond the dispersing slicks; and (3) an extensive area of seabed containing very low, possibly undetectable levels of contamination.

<u>Impact</u>. The area of greatest biological risk from the dispersed spill is within the cloud. The cloud of dispersed oil is potentially hazardous to planktonic plants and animals, including planktonic eggs and larvae of fishes. It may not be harmful to adult finfishes like salmon or herring in open waters with adequate dilution, but might be harmful to these fish if dispersants were used in confined waters of inlets or small bays where both the fish and dispersed oil would be confined. The dispersed oil poses little risk to deep-water bottom fish such as flatfishes, because the oil cloud occurs only at the surface, hundreds of meters above the bottom. Even the risk of contamination of deep-water, bottom-dwelling species is limited because the dispersed oil droplets require weeks or months to settle to the seabed, as described above. Dispersed oil would cause mortality and contamination of bottom species, such as clams if dispersants were used in shallow water, and so dispersant use in waters less than 10 meters deep is usually discouraged.

In quantitative terms, a small spill (1000 tonnes), less than 5 percent as large as EVOS , fully dispersed, would generate a toxic footprint in the upper water column covering approximately 7 to 30 square km or 0.1 to 1 percent of the area of PWS. If the spill were to be dispersed near the shipping lanes in central PWS, in deep water away from shorelines, such a spill might affect up to

0.1 to 1 percent of the planktonic plants, animals and fish eggs and larvae in the Sound. It would not cause damage or contamination to finfish stocks. By contrast the same spill if left untreated could cause mortality to waterfowl and seabirds in the area around Naked Island, contamination of sea otters, and some shoreline oiling over a limited area on the islands of Montague Strait, as outlined above. The environmental merits of chemical dispersion in this case would be a trade-off between impact of the dispersed oil in the upper water column in the central part of the Sound and impacts of the untreated oil on the sea surface and at shorelines over a larger area of the Sound. The same spill occurring outside PWS in the Gulf of Alaska might have proportionately smaller impacts but the trade-offs would be similar.

A larger spill, one-quarter the size of the EVOS, fully dispersed in the deeper offshore waters of GOA would cause mortality of slightly more than 1 percent of the plankton and ichthyoplankton population in the GOA. The same spill if left untreated coming ashore in the Copper River Delta area would cause the heavy impacts described above. A similar large spill occurring within PWS if left untreated would cause corresponding extensive impact in both offshore and inshore areas including impact on birds and mammals on the water, heavy contamination of large areas of shoreline and contamination and impact of large areas of shallow nearshore subtidal areas occupied by young herring and salmon. If dispersed in deeper waters in the central part of the Sound, the spill would cause 1 to 10 percent mortality of the plankton and ichthyoplankton, but in addition, because of possible limited dilution potential, might cause short term (weeks) contamination of salmon and herring, and probably nearby clams.

Net Environmental Benefit of Dispersant Use

Dispersant decisions in PWS/GOA involve making environmental trade-offs. On the one hand, spills that are left untreated threaten to impact marine birds, furbearing mammals, shorelines and species in intertidal and shallow subtidal areas. The impact on these can be reduced through dispersant use, but only at the cost of increasing impact on planktonic species and possibly causing contamination to suspension-feeding bivalve molluscs in shallow, nearshore areas downcurrent from the spill site. The trade-off is between environmental gains and losses associated with dispersant use on a particular spill.

In general, for all spills in the GOA and for smaller spills in PWS, dispersant-use will probably result in acute effects that are temporary and localized, while untreated spills may cause impacts that are longer-lasting and that would almost certainly extend over a larger area. This suggests that decisions might generally favor dispersant use. However, the nature of the trade-offs will certainly vary with the location and the time of year of spill. The result of the trade-offs will vary seasonally. For example, in the spring, when migratory birds are present and herring spawning is in progress in PWS, the trade-offs may favor dispersing small spills in deep water in the central part of PWS in order to keep oil away from shorelines and wildlife concentration areas, even though this would involve impacting a portion of the ichthyoplankton standing crop at a the time of year when some species are at their peak of abundance. On the other hand, if the same spill were to occur in winter, when fewer waterfowl and herring are present, the trade-offs may favor allowing the oil to come ashore and cleaning it up. For spills in PWS the trade-offs are clearest for smaller spills where all of the oil can be fully dispersed in deep water away from the shorelines and shallow nearshore areas, but are more challenging when large spills are involved when full dispersion effectiveness and immediate, full dilution may not be possible.

Trade-offs are seldom based solely on objective considerations of impact, but are commonly influenced by the relative values of the potentially affected resources. During the decision process information concerning impacts may be weighted according to the relative importance of each resource to the local human community. In the authors' experience weighting is usually based on economic, cultural or ecological considerations. The criteria for weighting and the method by which weighting is factored into the decision process vary widely from place to place.

Finally the analyses required for assessing impact and making trade-offs can be time consuming. The impact analyses require considerable information concerning the habitats and vulnerability of the potentially affected resources. Considerable time may be required to assemble this information and conduct the analyses. Unfortunately, during spills dispersant decisions must be made quickly for operational and effectiveness reasons. For this reason, whenever possible environmental trade-offs should be considered during pre-spill planning.

In short, there are circumstances in PWS/GOA where dispersant use may offer clear environmental advantages and others where they do not. Distinguishing between the two involves balancing environmental gains and losses and is a matter for planning.

Should dispersants be considered as an alternative or an enhancement to mechanical clean-up in Prince William Sound (PWS) and the Gulf of Alaska (GOA)?

There are arguments both in favor and against the use of dispersants in the Prince William Sound/Gulf of Alaska area. The arguments in favor of dispersant use include the fact that wildlife (e.g., waterfowl, seabirds, sea otters) and intertidal species (e.g., razor clams, coastal marshes) in Prince William Sound will be adversely affected by untreated spills and there is a need to remove the oil from the sea surface in order to protect these groups. Mechanical removal of the oil would be the primary technique, but dispersants offer advantages at higher sea states and higher wind speeds when booms and skimmers do not operate effectively or safely. Dispersants also offer a potentially effective and cost-effective method of responding to very large spills. On the other hand, dispersant use appears to pose some environmental risks, especially to communities in the upper water column (e.g., algae plankton, zooplankton and larvae of some finfish species). Assessing the environmental merits of dispersant use involves making trade-offs of the potential impact of the untreated spill against that of the dispersed spill. Conventional wisdom is that, in general, untreated oil persists in potentially hazardous concentrations on the sea surface and on shorelines and can have effects for some time after the spill at some distance from a spill site. On the other hand although dispersed oil may have acute effects in the upper water column, those effects are localized and temporary. The results of any trade-off depend strongly on the specific location, timing and circumstances of the spill. In PWS, with small spills in the deeper central areas of the Sound, the trade-offs appear to favor dispersant use, especially if the untreated oil threatens important wildlife concentrations or sensitive shoreline areas. If sensitive resources are not threatened by the untreated oil, the merits of dispersant use are less clear cut. Similarly, in the case of very large spills involving the dispersion of many thousands of tonnes of oil, the merits of dispersant use within the Sound are similarly less clear cut. In the case of small or large spills in the GOA, the trade-offs probably generally favor dispersant use when the untreated slick threatens to move inshore.

In short, dispersants should be considered for use in the PWS\GOA area in the situations where they offer environmental advantages. There are clearly circumstances under which dispersants do offer environmental advantages , some of these have been described above. There are others where dispersants may not be appropriate. Distinguishing clearly between the two cases is a matter for planning.

Conclusions and Recommendations

The following are the conclusions and recommendations of the study.

Conclusion

1. The short-term fate of dispersed oil and the environmental risks to aquatic organisms have received considerable study. In brief, there appear to be risks to the plankton and ichthyoplankton communities in the upper water column, but the risks to pelagic fish and the benthos are very small. A possible exception would be in the event of chemical dispersion of a very large spill within PWS. Under these conditions there would be some concern about contamination of fish.

Recommendations

1. Because of the semi-enclosed nature of PWS, with its reduced potential for horizontal transport and dilution of dispersed oil droplets, it may be prudent to consider the possibility of seabed contamination by sedimentation of dispersed oil particles. This should not be an issue during a smaller spill (1000 tonnes), but may be a source of concern if large amounts of oil are to be dispersed during a very large spill. It would be useful to study the sedimentation rate of dispersed oil droplets in order to eliminate this as a source of concern during very large spills.

2. Limited dilution potential during very large spills may also be of concern from the perspective of contamination of pelagic fishery species. Due to limited dilution potential, in a large spill, dispersed oil concentrations of several tens of ppb may persist for some days as was observed following the *Sea Empress* spill. Although prolonged exposure to low concentrations will pose no lethal or sublethal risk to water column species, it may have influence the flavor of pelagic fishery species. In view of the very modest exposure conditions needed to cause taint in steelhead trout (300 ppb of dispersed Prudhoe Bay crude oil for less than four hours, Martinsen et al. 1993), it may be useful to consider the potential for tainting of salmon during several days' exposure to these low concentrations.

3. There is a considerable body of information concerning the toxicity of Alaska North Slope crude oil to native Alaskan marine species, but there is almost no information available concerning toxicity of chemically dispersed ANS crude oil to Alaskan species. Certainly there has been no toxicological work done using spike-exposure testing methods and more current chemical analytical methods. It would be useful to confirm that the sensitivity of some Alaskan species is consistent with that of species from more temperate environment. It might be most meaningful to test the most vulnerable species/life stages, such as important ichthyoplanktonic species from PWS. This testing would employ the testing methods that have been developed by Singer et al. in recent years.

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The Effects of a Chemically-Dispersed Oil Spill on Fish and Shellfish: Experience from the *Sea Empress* Spill in Wales in 1996

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Abstract

The tanker *Sea Empress* grounded at the entrance to Milford Haven in February 1996, releasing 72,000 tonnes of Forties blend crude oil and 480 tonnes of heavy fuel oil into the waters of southwest Wales. The at-sea response included the aerial application of 446 tonnes of dispersant in order to enhance the rate of natural dispersion of the oil. A fishing exclusion zone was established under the Food and Environment Protection Act 1985 to protect consumers of fish and shellfish, and monitoring was instigated in order to establish the degree and spread of contamination. A wide range of further studies were conducted under the auspices of the Sea Empress Environmental Evaluation Committee (SEEEC) with the aim of assessing the overall impact of the spill. In this paper we report on the establishment and subsequent lifting of fishing restrictions and the effects of the spill on fish and shellfish. Overall the effects of the spill were less severe than would have been expected given the quantity of oil released.

Introduction

The tanker *Sea Empress* grounded on rocks at the entrance to Milford Haven on 15 February 1996. During the next week 72,000 tonnes of its cargo of 131,000 tonnes of Forties blend crude oil and 480 tonnes of fuel oil were spilt (SEEEC, 1998). The coastline around south-west Wales is of exceptional conservation interest, and the area also supports a diverse fishery with extensive shellfish beds in some of the estuarine areas (Gray, 1995). Following the spill a monitoring programme for fish and shellfish in the area was initiated, and subsequently a fishery closure area was established under the Food and Environment Protection Act 1985 (FEPA) as a precautionary measure to protect consumers. Within the monitoring programme concentrations of both hydrocarbons and polycyclic aromatic hydrocarbons (PAH) were determined in fish and shellfish tissues. Further details of the sampling programme and the analytical methods are given elsewhere (Kelly & Law, in press; Law *et al.,* in press). Hydrocarbon analyses in waters and surface sediment samples were also conducted in order to understand the movement and distribution of the spilled oil. The collection and analysis of these samples was co-ordinated with others undertaking similar work, principally within AEA Technology and the Environment Agency, in order to have the fullest possible understanding of the fate of the oil.

Approval and Use of Dispersants in the UK

In theory, the most attractive response to an oil spill from an environmental protection standpoint is the recovery of the oil whilst it is still at sea. However, despite the availability of a wide range of booms and skimmers they all suffer performance limitations in the turbulent sea conditions which often prevail around the UK. During the *Sea Empress* incident wind speeds above 30 knots prevented at-sea recovery operations for much of the initial stages of the spill. In all, eight oil recovery vessels and twenty small support vessels were deployed, both within Milford Haven and outside, recovering *ca*. 3% of the spilled oil (approximately 4000 tonnes of water-in-oil emulsion) (Lunel *et al.*, 1995; MPCU, 1996). If the "do-nothing" option - leaving oil to disperse naturally, particularly if the spill is small or of a light oil product - is not applicable, the most effective response in UK conditions is aerial application of chemical oil dispersants.

Dispersants are licensed for use in the UK by the Ministry of Agriculture, Fisheries and Food and the Scottish Office Agriculture, Environment and Fisheries Department. They are approved on the basis of two series of tests; firstly for safety and efficacy, and secondly on the basis of toxicity (Rycroft *et al.*, 1994). Two separate toxicity tests are performed. Products are approved for use at sea and on amenity beaches with a sandy/pebble substrate if the product does not significantly increase the toxicity to the brown shrimp (*Crangon crangon*) of mechanically dispersed Kuwait crude oil. Exposure is for 100 minutes, followed by 24h in clean flowing seawater. Products approved for cleaning rocky shores must also be shown to be no more toxic to a typical intertidal grazing organism, the common limpet (*Patella vulgaris*), than Kuwait crude oil alone. Here exposure is for 6h out of water, followed by 72h alternately wet and dry in a simulated tidal system.

Because many oils either weather or form emulsions and may no longer be amenable to dispersant spraying after 24h at sea, then aerial dispersant spraying must be undertaken as soon as possible after the oil is released from a vessel. In order to target the thickest slicks of oil on the sea surface the spraying aircraft are directed by remote-sensing aircraft which overfly the spilled oil. Each phase of the spraying operation is subject to consultation before it is undertaken, to ensure that the most appropriate action is being taken. Difficult decisions must sometimes be made in order to mitigate damage from an oil spill and to resolve any conflicts of interest which may arise in protecting sensitive areas which are important for fisheries or mariculture, or for their importance as wildlife habitats. The consultations involve the Fisheries Departments (also the licensing authorities), their scientific advisers (including CEFAS), the Marine Pollution Control Unit, and appropriate nature conservation agencies. These bodies together consider fishery, environmental and wildlife interests in the areas which might be affected by the use of dispersants, aided by the results of predictive modelling of the likely movement of the dispersed oil. Concern over the use of dispersants stems from the possible effects of dispersed oil to organisms. Organisms within the upper few metres of the water column will be exposed to higher oil concentrations if the oil is dispersed (whether chemically or naturally, e.g. by wave action) , but if the water is well mixed the dispersed oil will be rapidly diluted and the toxic effects reduced. However, in shallow habitats with poor water circulation, planktonic and benthic organisms will be more immediately affected by dispersed oil. For this reason, specific approval is required for dispersant spraying in water depths of less than 20 m, or within 1 nautical mile of such shallow waters.

Dispersant Use in the *Sea Empress* Incident

As part of the response to the Sea Empress spill 458 tonnes of dispersants were used; *ca*. 446 tonnes being sprayed from aircraft (mostly between 18 and 22 February) and *ca*. 12 tonnes being used on beaches. Figure 1 summarises the major areas of dispersant use in relation to the spread of bulk oil from the spill (SERIS, 1998). Most of the oil spilt from the Sea Empress was lost as the tide ebbed, so that fresh oil amenable to spraying was initially carried to the south and away from Milford Haven. For this reason most of the aerial spraying took place over the deeper waters off Milford Haven. Descriptions of the residual flow regime in the vicinity of Milford Haven are limited, with previous effort largely devoted to an understanding of the large-scale dynamics of the Bristol Channel and Celtic Sea (e.g. Uncles, 1982 and 1984; Davies & Jones, 1992; Pingree & Griffiths, 1980). Fresh water discharge into the Bristol Channel is expected to generate a net long-term northwards coastal residual flow. The mean pattern of isohalines in winter are orientated northwest-southeast, with fresher water following the South Wales coast and rounding St. David's Head (e.g. Bowden, 1980; Uncles, 1984). However, in the two weeks during and following the Sea Empress incident tidal and wind-induced flows provided the dominant agents for the movement of water borne material. Tidal flows in the region are amongst the strongest on the European Shelf, and Admiralty charts indicate that typical tidal excursions west of Milford Haven are of the order of 20 km during spring tides. Additionally, tidal velocities in the vicinity of Skomer and Skokholm Islands and off St. David's Head are exceptionally strong, exceeding 2 m s^{-1} at springs augmenting advection such that material might be carried up to 30 km on a tide.

During the aerial spraying of dispersants winds were essentially northerly, tending to move material southward. However, dispersed oil would be mixed into the water column with translational velocities significantly less than the 2-3% of the wind speed accepted as the motion of surface oil in response to wind (Brown, 1991). Following the cessation of spraying on 22 February the wind swung to the south-west until 26 February when there was a gradual move to the south and east by 28 February. Model simulations (e.g. Davies & Jones, 1992; Pingree & Griffiths, 1980) indicate that such winds induce flows from the Bristol Channel, passing northwards around St. David's Head and into the Irish Sea. It is probable that the combination of the large tidal excursions associated with spring tides followed by a period of south-westerly to easterly winds were responsible for advecting a proportion of the dispersed oil as far north as St. David's Head and beyond. These widely dispersed oil droplets are likely to be biodegraded in time.

All of the beaches marked on Figure 1 were treated with oil dispersants, but the majority of the dispersant used on beaches was applied to the amenity beaches around Tenby and at Skrinkle Haven. The main areas of at-sea recovery are also indicated in Figure 1. It has been estimated that the successful application of dispersants in this incident prevented an additional 57,000 to 110,000 tonnes of emulsion coming ashore in South Wales, in addition to the 10,000 to 15,000 tonnes which in the event led to the contamination of 200 km of coastline (SEEEC, 1998). Concentrations of oil below the chemically dispersed slick (determined by flow-through fluorescence spectrometry) were initially found to be in the range 1 to 10 mg l^{-1}, but were rapidly diluted to < 1 mg l^{-1} (Lunel *et al.*, 1995).

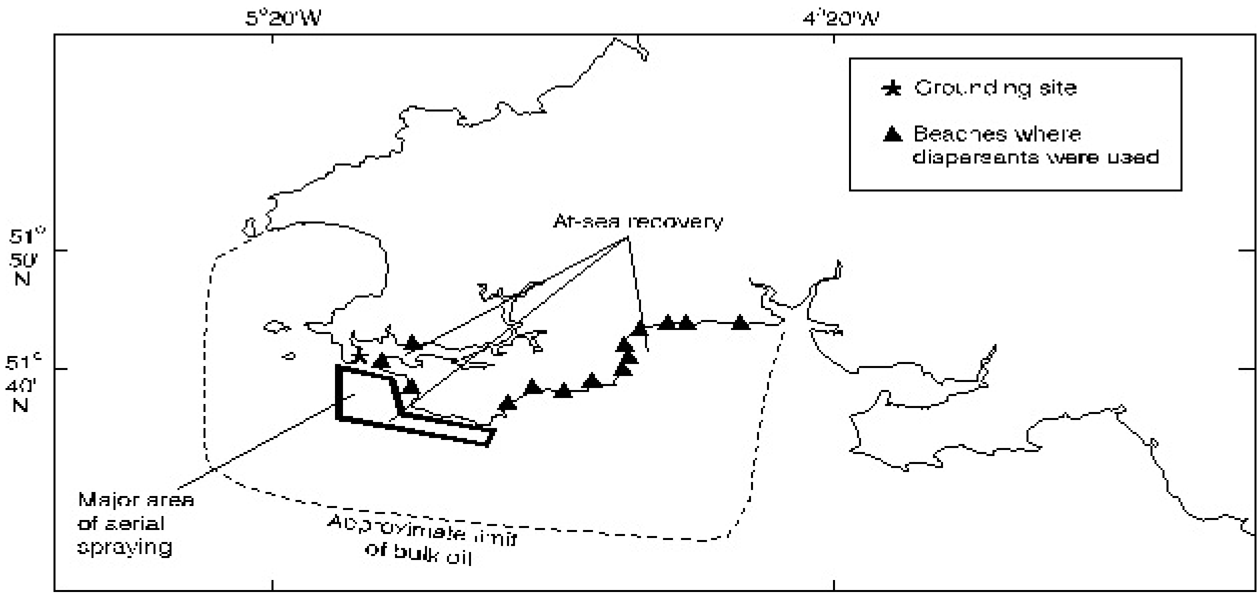

Figure 1: The coast of southwest Wales affected by oil spilled from the *Sea Empress*. The dotted line indicates the outer limit of bulk oil contamination. The Figure also indicates the main area of aerial dispersant spraying, beaches on which dispersants were applied, and the main areas of at-sea recovery.

Effects on Fish and Shellfish

Fisheries and the FEPA Closure Order

The waters of the Bristol Channel along the coast of South Wales support fisheries for both demersal (bottom-feeding) and pelagic fish. There is a year-round demersal fishery for species such as cod, whiting, pollack, dab, flounder, plaice, sole, turbot, dogfish and rays; pelagic fish such as grey mullet, herring, mackerel, sprat and sand eel generally attract a smaller amount of fishing effort, although the high value bass has increased in importance since the late 1980s. Migratory species (salmon and sea trout (sewin)) are also fished both commercially and for sport. Along the rugged coastline there are valuable potting grounds for crabs (edible, spider, and velvet swimming crabs) and lobsters, and the coastal, estuarine and intertidal areas support fisheries for bivalve molluscs. Cockles, mussels, and native and Pacific oysters are gathered according to season, and in recent years a valuable export market has developed for whelks. The fishing fleet consists mainly of small boats, few of which operate more than six miles from the coast, and many of which operate on a part-time basis.

The local fishermen implemented a voluntary ban on fishing immediately after the grounding of the *Sea Empress*. As the tonnage of oil lost from the vessel increased it was clear that there was likely to be severe contamination of, and possible effects on, fish, shellfish and crustacean stocks in the affected area. Once the likely spread of the oil and the area within which fish and shellfish were likely to be contaminated could be predicted with some degree of certainty, controls were implemented under the 1985 Food and Environment Protection Act (FEPA). The restriction was a precautionary measure, intended to protect consumers from potential danger from eating contaminated seafood. The controls were imposed in two parts, for finfish, shellfish, crustaceans and edible plants on 28 February, and for salmon and migratory trout on 20 March 1996. The orders therefore prohibited all commercial and casual collection of fish (including salmon and sea trout), shellfish (crabs, lobsters, cockles and mussels, etc.), and seaweeds. The total area designated under the FEPA orders covered about 810 square miles (2,100 km^2) of coastal waters from St. David's Head to Port Eynon Point, and included all the freshwater rivers and streams discharging into that area (Figure 2).

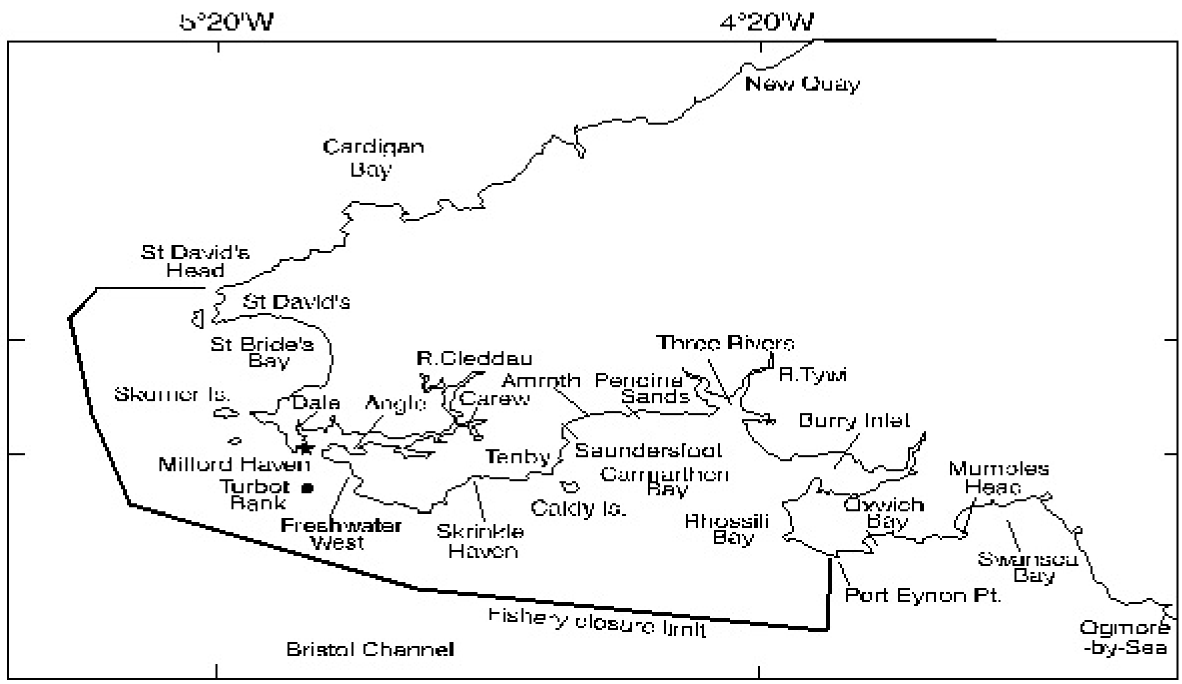

Figure 2: The coast of southwest Wales affected by oil spilled from the *Sea Empress.* The line indicates the outer boundary of the fisheries closure area designated under the Food and Environment Protection Act, 1985, and the star symbol marks the *Sea Empress* grounding site at St. Ann's Head.

Mortalities of Fish and Shellfish

There were no reports of mortalities of commercially-exploited crustaceans or fish (including salmon and sea trout) as a result of the oil spill. Fish are mobile and can move away if they find the conditions are unattractive to them. Also, at the time when oil concentrations in water were at their highest, crabs, lobsters and fish close to the shore would not have been actively feeding, whilst species such as crawfish, spider crabs and many fish would still have been in their winter feeding grounds away from the spill-affected area. Large numbers of dead or moribund shellfish (mostly bivalve molluscs) were however washed ashore during the weeks following the oil spill (SEEEC, 1998), although none of these involved the major commercial stocks. The strandings involved a number of species (including cockles *Cerastoderma edule*; striped Venus *Chamelea gallina* and razorshells *Ensis siliqua*) and locations within the areas of bulk oil contamination (Rutt *et al.*, in press). Also, during April, 7-10 weeks after the start of the incident, many thousands of moribund specimens of the rayed trough shell (*Mactra stultorum*) were stranded along the beach at Rhossili Bay (on the *eastern* side of Carmarthen Bay, outside the zone of heavy bulk oil pollution). Studies of the seabed showed little impact resulting from the spill except for marked reductions in the abundance of amphipods (particularly *Ampelisca* Spp, *Harpinia* Spp, and Isaeidae) in some areas close to the grounding site (Levell *et al.*, 1997; Rutt *et al.*, in press). In a previous survey conducted in October 1993 these taxa were distributed almost exclusively on the lower and middle parts of Milford Haven, below the Cleddau Bridge, and were absent from the majority of sites in October 1996. Overall, the range of conspicuous species badly affected was very similar to those documented for two previous oil spills which occurred in the same general geographic area and with similar environmental conditions. Those spills involved the *Torrey Canyon* (Cornwall, 1967) and the *Amoco Cadiz* (Brittany, 1978).

While there was no clear evidence of damage to commercial stocks of fish and shellfish, SEEEC has suggested in its final report that further assessment may be necessary to establish whether breeding and recruitment of some species (e.g. bass, edible crabs, lobsters and whelks) was successful in 1996 after the spill (SEEEC, 1998). Bass spawned in 1996 were found to be more abundant on the south side of the Bristol Channel than in South Wales nurseries, and particularly scarce within Milford Haven. Also, 0-group bass at sites along the coast of South Wales to the west of Swansea Bay were less likely to have attained the critical 60mm overall length for survival through the first winter than those from nursery areas in North Devon and Cornwall. In 1997, however, there was no indication that 0-group bass were less abundant in any South Wales nursery, including Milford Haven, than on the south coast of the Bristol Channel (Lancaster *et al.*, in press). The herring stock within Milford Haven is also of particular interest as it represents a discrete stock. It was not possible to establish the success of spawning in 1996, but the presence of adult fish in spawning condition in 1997 suggests that there was no long term effect. Data from the routine surveys using the continuous plankton recorder in the Bristol Channel and adjacent offshore areas indicated that the *Sea Empress* oil spill had no dramatic effects on the plankton of the southern Irish Sea between February and October 1996. All of the common taxa showed normal levels of abundance, some taxa suggested in the literature to be susceptible to the effects of oil pollution showed no marked changes, and no striking changes were noted in the phytoplankton and zooplankton communities as a whole.

Contamination of Fish and Shellfish

Migratory Fish (salmon and sea trout)

Levels of hydrocarbons in both liver and muscle of all finfish remained relatively low throughout the incident. The concentrations of PAH in salmon flesh (summed PAH concentrations (PAH) of 12 to 186 $\mu g\ kg^{-1}$ wet weight) were much lower than those recorded following the *Braer* oil spill in

Shetland in 1993, when concentrations of up to 14,000 µg kg^{-1} were found in caged salmon 10 days after the grounding (Whittle *et al*., 1997). The majority of PAH values in our study were actually within or below the range of reference values established for fish taken outside the area affected by that spill, but all of the fish analysed in our case were wild specimens as no farming takes place around south-west Wales. These salmon and sea trout had presumably spent little time in the affected area as they migrated into the rivers to spawn, and also would not have been actively feeding at that time.

Other Finfish

All the species of finfish sampled exhibited low concentrations of both hydrocarbons and PAH (PAH values < 100 µg kg^{-1} wet weight in muscle tissue), and, as they were not significantly elevated over those seen outside the affected area, it was not possible to observe any trend with time. In all cases fish took up primarily low-molecular weight PAH compounds (predominantly naphthalenes), presumably mainly from the dissolved phase by diffusion across gill surfaces. These compounds are more water-soluble than the high-molecular weight PAH (including those with carcinogenic potential), and so would have occurred at higher concentrations in the dissolved phase. Fish muscle generally contains only very low concentrations of PAH as they have an effective mixed-function oxidase system which allows them to metabolise and excrete these compounds rapidly, and so the risk to consumers is minimised (Law & Hellou, submitted). Some of the low-molecular weight PAH do carry the potential for taint, but tests by a trained panel did not find taint in any fish samples taken from Welsh waters throughout the incident.

Crustacea

Other than within Milford Haven itself, hydrocarbon concentrations in crustaceans also remained low and, as in the case of finfish, low-molecular weight PAH dominated. Figure 3 shows data from the GC/MS analysis of a lobster tail sample illustrating the predominance of naphthalenes. The PAH concentration in this sample was 2,450 µg kg^{-1} wet weight, of which > 95 % was due to naphthalene and its C_1- to C_3-alkylated derivatives. Edible crabs, velvet crabs, spider crabs and lobsters were sampled across the closure area. Within Milford Haven PAH concentrations within the range 100 to 2,450 µg kg^{-1} were found in samples of edible crabs, velvet crabs and lobsters sampled in the period February to April, and occasional concentrations in the lower part of the range were still evident in May and June in samples from heavily impacted sites (such as in Angle Bay, and close to the mouth of Milford Haven). These concentrations declined rapidly, and PAH concentrations in edible tissues were well below 100 µg kg^{-1} by the time restrictions were removed. As a prerequisite to lifting the closure order taint tests were conducted; no taint was detected, however, in samples of crabs and lobsters tested by the taste panel.

Whelks

Whelks sampled off Tenby on 25 February, when the first oil was beginning to come ashore in Carmarthen Bay, showed signs of moderate contamination, with a PAH concentration of 3,800 µg kg^{-1} wet weight. This contamination seems to have been very localised, however, as other samples collected from Carmarthen Bay around the same time yielded much lower values for both hydrocarbons and PAH. From the beginning of June onwards whelks taken across the whole area from Carmarthen Bay to the Isle of Lundy in the middle of the Bristol Channel yielded low concentrations, with all PAH concentrations below 50 µg kg^{-1}. As for finfish and crustaceans low-molecular weight PAH predominated, and by this time no taint was evident. The FEPA order affecting whelks was not lifted, however, until somewhat later due to the concerns of fishermen about their export market potential, which necessitated more detailed coverage of the area exploited by the whelk fishermen.

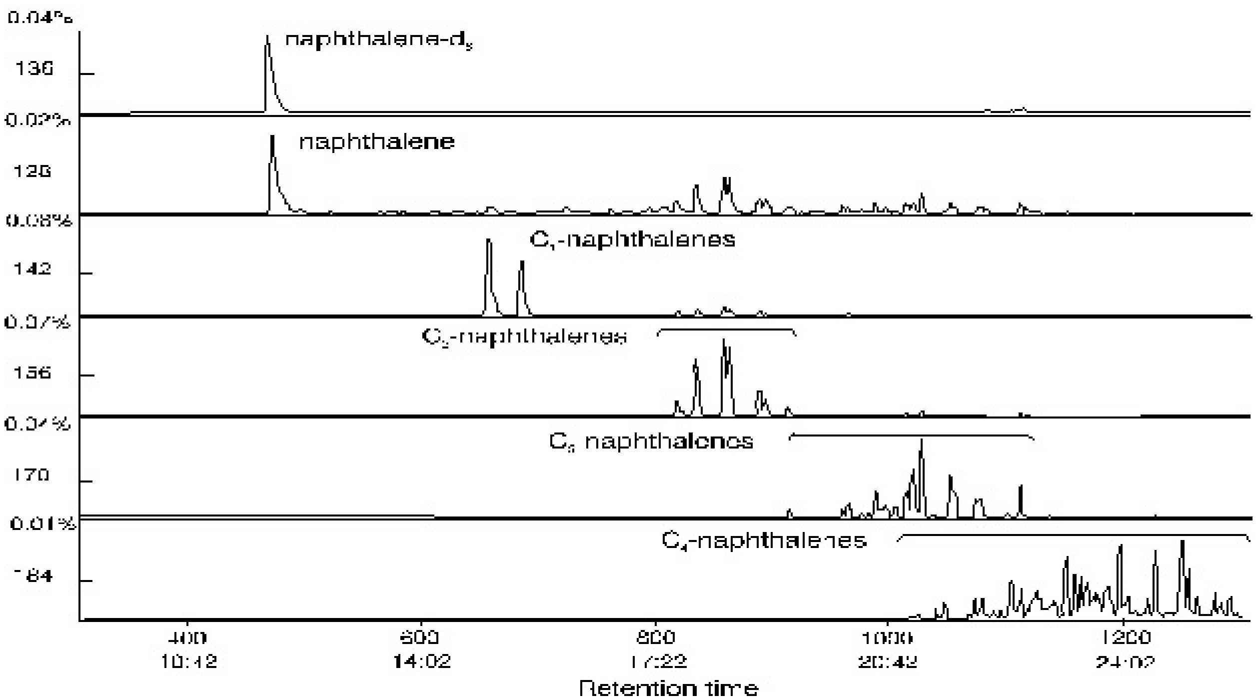

Figure 3: Mass chromatograms of the extract from a lobster tail sample, collected on 22 February 1996 from Monk Haven, at the north end of Dale beach. Mass 136 represents the surrogate standard, naphthalene-d_8. Masses 128, 142, 156, 170 & 184 represent naphthalene and its C_1-, C_2-, C_3- and C_4-substituted derivatives respectively.

Bivalve Molluscs

The main commercial fisheries for bivalve molluscs are for cockles and mussels in the Three Rivers and Burry Inlet areas off Carmarthen Bay, oysters (both native and Pacific) are reared at Carew (above Milford Haven), and scallops are also fished by boats from Milford Haven. All of these species were monitored routinely, and other species (e.g., clams, carpet shells, dogwhelks, periwinkles, razor shells, trough shells) were analysed either following stranding events, or to provide spatial coverage as available. Hydrocarbon concentrations in both cockles and mussels exposed to oil rose very rapidly, and to high concentrations. This was apparent in mussels sampled across the closure area in March 1996, from St. David's in the north to the Three Rivers area to the east, mostly in stocks which are not exploited commercially. At many of the sites within the closure area PAH concentrations in mussels were well above 1,000 µg kg^{-1} wet weight.

Within the most heavily impacted area (between Milford Haven and Tenby) concentrations of PAH generally rose very rapidly and then declined steadily over the next four months. Very little oil seems to have entered the Burry Inlet, possibly as a result of the restricted entrance to the Loughor estuary. A small quantity of oil passed beyond the fishery closure area both to the east of Port Eynon, as shown by a small rise in PAH concentrations in mussels from Oxwich Bay around 35 days after the grounding, and oil also entered St. Bride's Bay, as reflected by uptake in mussels from Skomer Island. The slowest declines were seen in intertidal mussels on the south Pembrokeshire coast, particularly around Skrinkle Haven and Caldey Island where oil persisted subtidally to the end of 1996. The highest concentrations of PAH in mussel tissues were seen at sites within Milford Haven close to the spill site, with PAH concentrations > 100,000 µg kg^{-1} wet weight being reached within about a week of the grounding. This reflected direct uptake of naturally dispersed oil droplets from the water column within a very short time after release from the vessel (Law *et al.*, submitted). As the concentrations of oil-derived PAH declined, a seasonal variation in the concentrations of the higher-MW (combustion derived) PAH became apparent, and was particularly marked in mussels from within Milford Haven. Concentrations of benzo[*a*]pyrene in mussels from Angle and Dale are shown in Figure 4. In both 1996 and 1997, concentrations reached a maximum in March, declining to close to zero in mid-summer. This seems to be related to larger PAH inputs occurring in winter, and to aspects of mussel physiology which are discussed elsewhere (Law *et al.*, submitted). Similar seasonal cycles in PAH concentrations in mussels have also been observed in both Germany and the Shetland Islands (Jacob *et al.*, 1997; Webster *et al.*, 1997).

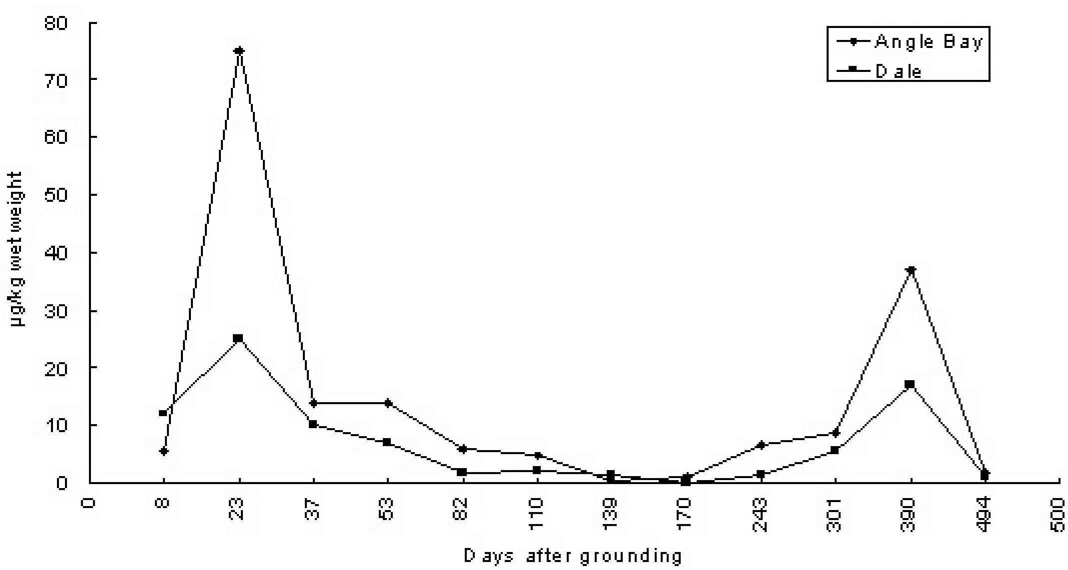

Figure 4: Concentrations of benzo[*a*]pyrene in whole tissue of mussels collected from Angle and Dale after the grounding of the *Sea Empress* (µg kg^{-1} wet weight).

Removal of Fishery Restrictions

The FEPA restrictions were removed in stages as the results of the monitoring study showed that concentrations of hydrocarbons and PAH had declined to levels so low as to pose no further risk to consumers, and that the species involved were free of taint. These criteria were similar to those established after the *Braer* spill in Shetland in 1993 (Topping *et al*., 1997). Background data for PAH in tissues of commercial fish and shellfish taken off south-west Wales before the *Sea Empress* spill were sparse, and samples taken outside the closure area were also analysed within the monitoring programme in order to gather information on contamination resulting from other sources of oil and PAH within the area so as to aid interpretation. Subsequently, this lack has been addressed and baseline data have been gathered for PAH in commercial stocks of bivalve molluscs around England and Wales. A summary of the timescale for the lifting of fishery restrictions is given in Table 1. Controls on fish and crustacea were removed relatively quickly (within 3 to 8 months respectively of the grounding), and the major intertidal cockle beds in the Burry Inlet and Three Rivers were also relatively lightly contaminated and reopened 4½ and 7 months respectively after the grounding. The restrictions covering intertidal mussels in the south-east of the closure area, and oysters within Milford Haven, were the last to be lifted, remaining in place for about 19 months until 12 September 1997. Selective restrictions have remained in place for long periods following earlier spills: seven years for oysters following the *Amoco Cadiz* spill (Berthou *et al.,* 1987), and over five years to date for Norway lobsters (*Nephrops norvegicus*) and mussels off Shetland following the *Braer* oilspill in January 1993. In the former case this was because oil entrained within anaerobic sediments within low-energy inlets (Abers) was periodically remobilised by storms, thereby delaying depuration of the shellfish, and in the latter case similar processes affecting contaminated sediments in the inner sounds and voes are thought to be responsible. Following the spill from the *Exxon Valdez*, dense beds of mussels (*Mytilus trossulus*) left untreated showed high levels of contamination four years after the spill (Babcock *et al.*, 1996; Harris *et al.*, 1996).

Table 1. The timetable for the phased removal of fishery restrictions.

Date	Restrictions Removed :
3 May 1996	Salmon and Sea Trout
21 May 1996	other finfish
3 July 1996	the Burry Inlet
29 August 1996	crustaceans outside Milford Haven
12 September 1996	the Three Rivers area
19 October 1996	whelks, and crustaceans within Milford Haven
10 June 1997	edible plants and seaweeds
10 June 1997	the intertidal area from St. David's Head to St. Ann's Head
12 September 1997	all remaining restrictions

Almost all of the beds showing little reduction in contamination were in protected, low-energy areas, which were not vulnerable to natural disturbances. There had, therefore, been no natural weathering and flushing of the residual oil underlying the mussel beds, and this provided a continuing source of hydrocarbons for uptake by mussels. Similar circumstances did not arise in the case of the *Sea Empress,* except around Skrinkle Haven and Caldey Island where oil persisted subtidally in sandy sediments until the end of 1996.

Biological Effects Studies

In the wake of the oil spill a number of biological effects techniques were deployed in order to assess exposure to PAH and the likely occurrence of sublethal effects. These involved the determination of EROD (ethoxyresorufin-O-deethylase) in fish, measurements of immune function and scope for growth in mussels, DNA-adducts in fish and transplanted mussels, and the application of whole-sediment bioassays to samples from within Milford Haven waterway. These studies are reported in detail elsewhere (Dyrynda *et al.*, 1997; Kirby *et al.*, in press; Law *et al.*, in press; Lyons *et al.*, 1997). A variety of impacts were apparent, but most of these seem to have been short-lived in this instance. The sole exception is the formation of DNA-adducts, where it is not yet possible to fully assess the longer term significance of the findings (Law *et al.*, in press). Two years after the oil spill, the data indicate that chronic exposure to genotoxins at the levels seen in 1997 are unlikely to have any significant mutagenic or carcinogenic consequences.

Conclusions

The effects of the *Sea Empress* spill on fisheries were less severe than could have been expected on the basis of the quantity of oil spilt. There were no reports of mortalities of commercially-exploited crustaceans or fish (including salmon and sea trout) as a result of the oil spill. In fin fish and crustaceans the levels of contamination were low. This may have been partly due to the fact that the spring of 1996 was colder than usual, and feeding activity may have been reduced around the time the oil was released. Most of the crabs and fish may also have been offshore at the time of the spill due to the season. Much higher tissue concentrations were seen in bivalve molluscs, both from within and outside Milford Haven. Mass strandings of a number of species occurred, apparently as a direct result of the oil spill. Major stocks exploited commercially, such as those of the Three Rivers and the Burry Inlet, were not affected in this way. Biological effects studies likewise demonstrated a variety of impacts on local fish and mussels, but most of these seem to have been short-lived in this instance. Whilst there has been no clear evidence of damage to commercial stocks of fish and shellfish, SEEEC have suggested that further assessment may be necessary to establish whether the breeding and recruitment of some species (e.g. bass, edible crabs, lobsters and whelks) was successful in 1996.

There is little doubt that the aerial application of dispersants helped to reduce the impact of the *Sea Empress* spill on fisheries by significantly reducing the amount of oil which reached the shoreline. Contamination by hydrocarbons and PAH persisted longest in mussels from the intertidal area to the east of Milford Haven (Freshwater West to Pendine Sands), and derived from bulk oil contamination of the shoreline. This is in line with observations at previous spills where contamination has persisted for years due to oil becoming trapped within sediments in low-energy coastal environments, resulting in recontamination when the oil is mobilised by storms or tides. The large-scale use of dispersants requires identification of the resources to be protected as part of a contingency plan and detailed consultation before use, but can yield real environmental benefits.

Acknowledgements

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The *Braer* Oil Spill In Shetland, 1993 to 1997

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Goodlad, J. 1998. The *Braer* Oil Spill In Shetland, 1993 to 1997. In Trudel, B.K. (ed). Proceedings of the Conference, "Dispersant Use in Alaska: A Technical Update", Anchorage, Alaska, March 18 & 19, 1998, Prince William Sound Oil Spill Recovery Institute, Cordova, Alaska.

Abstract

The grounding of the oil tanker, *Braer*, on 5 January 1993 resulted in the spilling of 80,000 tonnes of crude oil in the waters off Shetland. The oil was eventually dissipated by the very strong sea conditions around Shetland during January and February. The use of dispersants was minimal.

Notwithstanding this, the oil spill had a serious impact on the seafood industry. In the first place, the physical presence of oil in the water column and on the seabed resulted in fishing and salmon farming being prohibited within a 400 mile Fisheries Exclusion Zone which was established off the south-west of Shetland. This had an obvious and immediate effect on fishing and fish farming activities within the area. The Fisheries Exclusion Zone has gradually been lifted but still remains in force for some shellfish species. In the second place, the enormous world-wide publicity surrounding the oil spill resulted in serious damage to the reputation of Shetland seafood. It became more difficult to sell Shetland seafood at premium prices in the months following the *Braer* oil spill. The situation now appears to be returning to normal. In the third place is the possibility that there may have been some serious long-term biological damage to the marine ecosystem. Although there appears to have been full recovery in most areas, there remains some concern regarding shellfish stocks.

The seafood industry has obtained financial compensation from the Fund for International Oil Pollution Compensation (IOPC) which was set up immediately after the oil spill. Although the Fund has managed to settle most compensation claims out of Court, a number of claims are still subject to litigation.

Introduction

Shetland is a small island community of only 23,000 people. These islands have been host to Europe's largest oil terminal, at Sullom Voe, since 1976. Since this time many Shetlanders have feared an oil spill at Sullom Voe. An elaborate and comprehensive oil spill contingency plan was therefore prepared. Shetland's huge oil spill did not, however, happen at Sullom Voe. It was a freak accident, at the other end of Shetland and totally unrelated to activities at Sullom Voe terminal.

The grounding of the oil tanker, *Braer*, on 5 January 1993 resulted in the spilling of 80,000 tonnes of crude oil in the waters off Shetland. The spilled oil was eventually dissipated by the very strong sea conditions around Shetland during January and February. Although some chemical dispersants were applied during the early stages of the spill, their use was minimal. In contrast to the limited damage to wildlife, there were serious effects on the marine environment and the seafood industry.

The *Braer* spill demonstrates the potential impact of a major spill under the unique conditions in which the oil is dispersed physically rather than chemically. This paper describes the impact of this physically dispersed spill on the seafood industry in Shetland.

The Shetland Seafood Industry

Importance of the Seafood Industry. The Shetland seafood industry dominates the Shetland economy. The Shetland seafood industry (comprising fish catching, fish processing and fish farming) has an annual turnover of around £150 million and employs almost 23% of Shetland's total work force. Shetland fishermen catch over 80,000 tonnes of fish while Shetland fish farmers currently produce 20,000 tonnes of Atlantic salmon. Shetland is not only one of the most isolated and northerly regions of the European Union, it is also one of the single most fisheries dependent regions within Europe.

The real importance of the Shetland seafood sector lies in the fact that there are few realistic alternative employment and economic opportunities outside the fisheries sector. Shetland has poor agricultural land, an adverse climate and is remote from the main European markets. While the oil industry has brought undoubted benefits to Shetland, this industry will decline and disappear when the Sullom Voe terminal eventually closes. In contrast, the seafood industry, if properly managed, can provide a secure basis for the Shetland economy in the long term.

Organisation of the Seafood Industry. The Shetland Fishermen's Association (SFA) represents around 500 fishermen on board 110 boats, which range in size from 12 metres up to 70 metres in length. The 50 fish farming companies in Shetland are represented by the Shetland Salmon Farmers Association (SSFA). There are 21 firms involved in processing fish within Shetland. Their interests are served by the Shetland Fish Processors Association (SFPA).

Prior to the *Braer* oil spill, none of these associations had any experience in dealing with the impact of an oil spill. No contingency plan had been prepared. The associations literally had to react to events as they unfolded. The SFA and SSFA were in the frontline as the oil spilled into the valuable fishing grounds and salmon farming sites off the west coast of Shetland. The SFPA became involved later, as it became clear that there had been an effect on the marketing of Shetland fish. The SSFA decided to use a public relations consultant, while the other two associations did not. All three associations worked very closely together throughout.

The *Braer* Spill

On 5 January 1993 a massive oil tanker, the *Braer*, laden with 85,000 tonnes of light crude oil from Norway en route to Canada, drifted without power in storm force winds and seas. By 11:20am the tanker had grounded on reefs on the west side of the peninsula of Garths Ness. At the time, headlines world-wide asserted that this was the worst spillage of all time and terms such as 'Nightmare', 'Disaster' and 'Catastrophe' were commonplace.

During the weekend of 9 and 10 January, the *Braer* had begun to break-up; she became a total wreck over the next few days. On 24 January divers inspected the broken remains of the vessel and could find no trace of oil in any part of the ship. No opportunity had been given by the relentless winds and waves, sometimes reaching hurricane force, to off-load any oil. Booming and containment in the vicinity of the wreck had been precluded by the surges of the Atlantic swell. Dispersal of the oil by aircraft spraying was limited by the fierce winds. As a result, the entire *Braer* cargo of 85,000 tonnes of oil spilled into Shetland waters (for fuller accounts of the incident, see Ritchie and O' Sullivan, 1994; Edgell; 1994).

The sea moderated towards the end of January. Although there was some coastal contamination, especially near the wreck and for some distance along the west coast, the visible environmental damage was substantially less than anyone might have expected when a load twice the amount of *Exxon Valdez* had been spilled.

Even the emotive and much publicised impact on birds, seals and otters was less than might have been expected, being only a small fraction of the deaths resulting from the *Exxon Valdez* incident. For example, by February the official count was only 1,542 dead birds, 235 live but oiled birds, 17 dead mammals and 13 live but oiled mammals. Some of these mortalities, especially the mammals, might have been unrelated to the direct effects of the oil spill.

The Use of Dispersants. Immediately following the grounding of the *Braer*, the Marine Pollution Control Unit (MPCU) intended to deploy dispersants in order to break down and disperse the oil spilling out of the tanker. In view of the geography of the area and the weather conditions, it was decided that low flying aircraft would spray dispersants onto the oil from the *Braer* wreck northwards.

The decision to use dispersants provoked a generally hostile reaction in Shetland. The seafood associations and the local farmers and landowners expressed serious reservations that the environmental impact of dispersants might be worse than that of the oil itself. In the event the debate on the use of dispersants was resolved by the atrocious weather conditions. Gale and storm force winds meant that the dispersant spray was quite ineffective - most of it being swept away by winds before it reached the oil slick. The aircraft attempted unsuccessfully to spray dispersants on two days - the 6th and 9th of January. A total of 120 tonnes of dispersant was used. After these two attempts, the MPCU effectively abandoned any attempts to use dispersants.

A combination of the storm force winds and heavy swell breaking onto the Shetland cliffs, together with the fact that the *Braer* oil was very light Gulfaks crude, resulted in a large natural evaporation and a large natural dispersant and emulsification effect. The Shetland winter weather had more effectively dispersed the oil than any chemicals might have.

Impact on Fisheries

The impact on fisheries was wide-ranging, serious and, to some extent, still evident. The variety of effects can be considered in terms of direct contamination, market damage and possible long-term biological impacts.

Direct Contamination. There was an immediate problem related to the spill of oil into the sea off the south of Shetland. It was clear that fishing and salmon harvesting had to be stopped. The SFA and the SSFA introduced a voluntary ban on fishing and harvesting of fish on 7 January. The UK Government followed this up on 8 January when an order was laid under Food and Environment Protection Act 1985 (FEPA) which established an Exclusion Zone within which the taking or harvesting of all fish was prohibited (Figure 1). This was deemed necessary as a precautionary measure to prevent contaminated seafood reaching the market. An intensive programme of sampling (undertaken by the UK Government) ensured that fish, shellfish and salmon were continuously tested for taint. The Zone could therefore be lifted as sampling results were analysed and fish pronounced to be clear of taint.

The Fisheries Exclusion Zone has had a major impact on all fisheries (Figure 2). As far as demersal fisheries were concerned, around 12 boats were stopped from fishing in the Zone from 7 January to 23 April 1993. A further 20 boats had normal fishing activities disrupted (i.e:- had to fish alternative grounds in order to mitigate loss). It has been estimated that around 10% of the Shetland demersal fishery was adversely affected during the period from 7 January to 23 April. Since there was no pelagic fishery within the Zone during this time, there was no direct effect on the pelagic fishery.

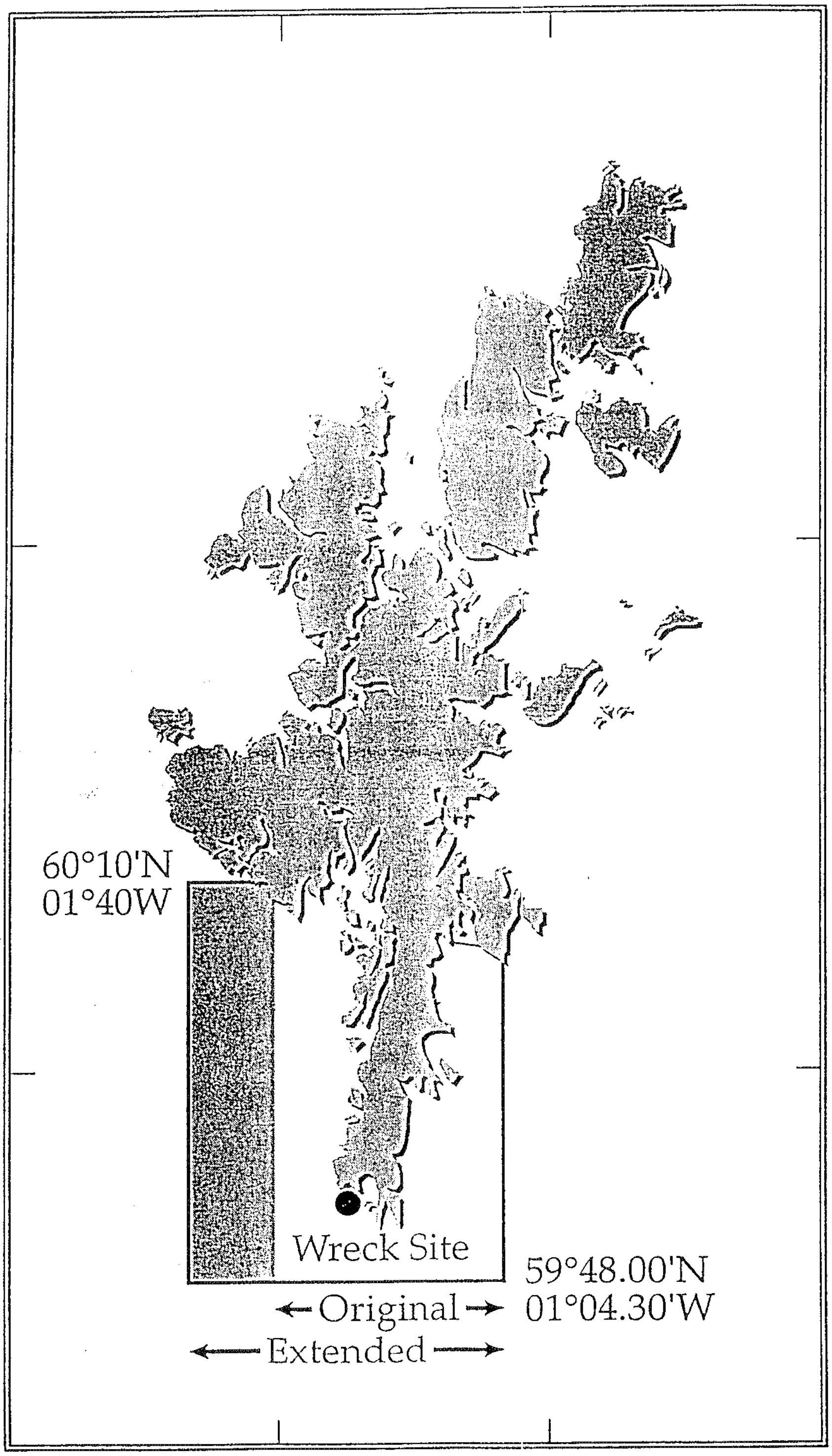
With regard to shellfish, around 50 smaller vessels were affected. Many stopped fishing altogether, while others continued fishing but had normal fishing activities disrupted (i.e:- again had to fish alternative grounds in order to mitigate loss). It has been estimated that the Exclusion Zone accounts for around 40% of all shellfish grounds fished by the Shetland fleet. Although it has been possible to fish for lobsters and crabs since 1 October 1994, the main shellfish fisheries (i.e:- scallops and queen scallops) remained closed until February 1995.

A total of 11 individual salmon farms (representing around 25% of Shetland's total production) were located within the Exclusion Zone. It was confirmed that salmon had been severely tainted. Since salmon are confined within cages, the salmon could not (unlike haddock, cod, herring etc) swim away. Salmon smolts are usually introduced in May of each year and the growth cycle is usually from 18 to 24 months. By January 1993, around 50% of the 1991 intake had been harvested - the remaining 50% were contaminated and had to be destroyed. This amounted to 1,740 tonnes which were destroyed in March and April of 1993. It was hoped that the 1992 intake (which had also been severely contaminated) might have naturally become clear of taint. Although taint levels did improve, the 1992 fish remained contaminated. As a result, some 3,659 tonnes (i.e:- the entire 1992 intake) was destroyed in February, March and April of 1994. This represented over 25% of the total Shetland production that year. Following the destruction of the 1992 stock, the Exclusion Zone was lifted for salmon in May 1994, thereby allowing the normal harvest of the 1993 intake which had been introduced into the Zone in May 1993.

Figure 1. History of the Fishery Exclusion Zone

Industry voluntary ban	-	**7 Janaury 1993**
Original Exclusion Zone established	-	**8 January 1993**
Extended	-	**27 January 1993**
Partially lifted	-	**24 April 1993** (for white fish and pelagic species but remained in force for shellfish and salmon).
Partially lifted	-	**May 1994** (for salmon only).
Partially lifted	-	**1 October 1994** (for all shellfish except scallops, queen scallops, nephrops and mussels).
Partially lifted	-	**8 February 1995** (for scallops and queen scallops but remains in force for nephrops and mussels).

Figure 2. Map of the Fishery Exclusion Zone



Market Damage. The direct contamination of stocks of fish, shellfish and salmon was expected, given the scale of the oil spill. What was rather unexpected was an immediate and serious impact on the marketing of Shetland fish. Shetland seafood had gained a reputation in world markets for consistent high quality. This reputation was almost destroyed after the *Braer* grounding.

Despite the problems within the Fisheries Exclusion Zone, the seafood industry continued as normal in the rest of Shetland. After all, the pelagic fleet was totally unaffected, 90% of the demersal fisheries continued as before, 60% of shellfish grounds were not contaminated and 75% of salmon production continued as normal. Yet the enormous media attention to the oil spill gave the impression that all Shetland seafood was contaminated.

Over 600 journalists and environmentalists arrived in Shetland in the weeks after the *Braer*. There was clearly a problem, but a problem which was contained within the Fisheries Exclusion Zone. But the world media sought dramatic and disastrous news. The subsequent sensational headlines marred the image of all Shetland seafood. The actions of certain environmental groups, such as Greenpeace, helped to fan the flames of media hype, and the inevitable happened. Orders for Shetland seafood were cancelled. Buyers stopped buying. The fish processing plants were unable to sell products and the seafood industry teetered on the verge of collapse. "All Shetland fish is contaminated" was the message the media had transmitted around the world. The final blow came when Marks and Spencers took Shetland salmon off its shelves and Japanese buyers refused to import frozen mackerel.

As one Shetland fishermen said - "Our problem is not 85,000 tonnes of oil - It is 600 journalists and environmentalists." The Shetland seafood industry had survived a major oil spill but, by the end of January, media pollution was threatening the survival of the industry. Faced with what was rapidly becoming a crisis of confidence in Shetland seafood, the local industry clearly had to regain control and present a different message to the world at large.

Press conferences and press releases emphasised that contamination was limited to the Fisheries Exclusion Zone and that no harvesting of any fish, shellfish or salmon was permitted from this area. The SSFA, at enormous cost, initiated a programme of testing of all salmon harvested outside the Fisheries Exclusion Zone so that buyers could be assured that all Shetland salmon was being tested and that no salmon would be sold from Shetland unless it was of the highest quality. This 'zero tolerance' programme was very effective. Food technologists from Marks and Spencers and other retail multiples were invited to Shetland to see at first hand this rigorous and uncompromising commitment to quality. This 'zero tolerance' programme was effective. Marks and Spencers resumed buying Shetland salmon and market confidence gradually returned.

The SFA and the SFPA also expanded normal quality control procedures on the fish markets and in the processing plants. This also helped reassure buyers that quality remained paramount and that normal business was continuing.

Two special buffet receptions for the press were held; one featured a menu of fresh and smoked salmon and the other featured a variety of shellfish and fish. The world's media were invited to feast on Shetland seafood only weeks after the *Braer* oil spill. The results were striking; quality was excellent and the media began to tell a different story - the story of how the Shetland seafood industry had survived the *Braer* oil spill.

By taking this proactive approach, the seafood associations had managed to prevent a catastrophic collapse in the market for Shetland seafood. But serious damage had been done. Orders had to be won back and buyers used the oil spill as an excuse to lower prices and negotiate discounts. There had been an undoubted price damage effect. The associations began to evaluate and quantify the extent of price damage. To this end, professional loss assessors were employed by the associations.

Long-Term Biological Impact. The Shetland seafood industry decided to commission an independent economic and biological impact assessment study. The US based company, Natural Resource Consultants (NRC) were selected because of their experience in helping assess the impact of the *Exxon Valdez* oil spill on the Alaskan fisheries industry. The conclusions of this study have been invaluable in assisting the associations to prepare price damage claims.

With regard to possible long-term biological damage, there are a number areas of concern. In the first place, shellfish are (unlike fish) relatively immobile. Moreover, scallops and queen scallops are filter feeders. As a result, shellfish species are more liable to contamination by oil than fin fish. The UK Government sampling programme has confirmed this to be the case, with the Fisheries Exclusion Zone remaining in place much longer for shellfish. It has also been suggested that the process of depuration (whereby shellfish ultimately get rid of hydrocarbon taint and become clean) could have an effect on future reproductive capability. The NRC Report (1994) suggested that there could be consequential effects for up to 8 years after the oil spill.

The seasonal herring roe fishery (based on catching herring with roe and then freezing these herring for the Japanese market) has traditionally ranged from 2,000 to 8,000 tonnes of roe herring per year. In the summer of 1993 only 30 tonnes were caught, while in the summer of 1994 only 400 tonnes were caught. The NRC Report confirmed that oil on the seabed in the herring spawning areas to the south and east of Shetland (outside the Fisheries Exclusion Zone) may have prevented the herring spawning in their normal spawning areas. Apart from the fact that the herring were not caught as usual, NRC believe there could also be an effect on future spawning levels. A seabed sampling exercise, funding by the IOPC Fund and undertaken during the summer of 1994, confirmed that there are some spawning areas where hydrocarbon levels on the seabed exceeded background levels. Subsequent analysis of this oil has however been unable to confirm that the oil was actually Gulfaks crude.

The IOPC seabed survey of 1994 also confirmed that there is a large area of heavily contaminated sediment off the west side of Shetland, within the Exclusion Zone. The area is known as the Burra Haaf and is a rich fishing ground for smaller demersal trawlers and seine netters. The normal 'background level' of oil in the seabed around Shetland is 50 parts per billion. The inner Burra Haaf areas samples varied from 2,500 to 7,500 parts per billion. Unlike the oil on the herring spawning grounds, this oil is clearly Gulfaks crude. While there is no evidence of fish contamination, fish appear to be avoiding the area. As a result, there is concern that this valuable fishing ground may become a 'desert' for many years to come.

Figure 3. Financial Compensation to Shetland Seafood Industry

PAID TO DATE

Area of Claim	Payment to Date £
1. **Destruction of Contaminated Salmon**	
1991 stock	7,176,000
1992 stock	12,118,000
Sub Total	**19,294,000**
2. **Effect of Exclusion Zone**	
Demersal fleet	1,414,000
Shellfish fleet	5,742,000
Sub Total	**7,156,000**
3. **Price Damage**	
Demersal fleet	500,259
1991 salmon	312,000
Processing plants	3,073,000
Sub Total	**3,885,259**
TOTAL	**30,335,259**

SETTLED BUT NOT YET PAID

4. Claim	Settlement £
Destruction of contaminated salmon (1991 & 1992)	770,000
Pelagic price damage	50,000
Processing plants price damage	67,000
Shellfish fleet	3,234,000
TOTAL	**4,121,000**

STILL OUTSTANDING

5. Claim	Amount £
Processing plants price damage	9,435,000
Salmon price damage	16,700,000
Shellfish fleet	3,200,000
Demersal fleet	2,800,000
TOTAL	**32,135,000**

Financial Compensation. The IOPC set up the *Braer* Claims Office in Lerwick in January of 1993. As already noted, the seafood industry decided at an early stage that cooperation between the three seafood associations was essential. Professional advisors (i.e:- loss assessors and independent consultants) were employed and a thoroughly professional approach to compensation claims was adopted.

As can be seen from Figure 3 the Shetland seafood industry has been paid over £30 million from the IOPC Fund. The largest single claim was the destruction of contaminated salmon. In addition to this there were substantial settlements for disruption to fishing (particularly shellfish) and price damage (particularly for the fish processing industry). The payment to the seafood industry represents the largest single settlement out of the total of £45 million which had been paid out by October 1995. The other successful claims were largely agriculture and property damage claims.

Having paid out a total of £45 million in financial compensation, the Fund began to express concern that the total amount of money available within the Fund (£57 million) might not be sufficient to deal with all outstanding claims. After considerable internal debate within the Fund, it was eventually decided to suspend all payments as from October 1995. At the same time, under the Fund rules, any claims not settled in full within three years of an oil spill must, in order to protect the claim, be lodged in Court. The suspension of payments together with the legal requirement to lodge outstanding claims with the Court of Session in Edinburgh, resulted in an unexpectedly high total claim of almost £80 million against the IOPC Fund. Apart from seafood industry claims, this also consisted of claims for the agricultural, tourist and transport industries together with personal injuries and local government claims. By early 1996, the IOPC faced legal actions of around £80 million - almost twice what had been paid out in compensation. Ironically, the IOPC Fund had been set up in the first place to avoid Court action.

It was however clear that the £80 million of Court action was a case of all maximum possible claims together with certain claims which were probably somewhat speculative. The IOPC was of the opinion that most of these claims were not justified and would not therefore succeed through the Courts.

In the event, following a lengthy negotiation between the IOPC Fund and the SFA, an out of Court settlement was reached for most shellfish claims and pelagic price damage. Out of court settlements were also reached for some fish processing price damage claims and one outstanding salmon destruction claim (see Figure 3). Payment of this settlement (worth over £4 million) can however only be paid when the overall legal position becomes clearer.

At the same time, a number of Court actions have been withdrawn. By December 1997, the total of all outstanding claims had been reduced from £80 million to £47 million. Of this £47 million there is £32 million of outstanding claims in respect of the seafood industry, principally in relation to processing price damage and salmon price damage.

Apart from financial compensation paid by the IOPC Fund, financial assistance was also forthcoming from the European Union (E.U). In February 1993, the E.U Fisheries and Environment Commissioner, Yannis Paleocrassis, visited Shetland in order to see the situation at first hand.

Following this visit the three seafood associations were invited to submit an application for special E.U funding. A funding application was submitted to cover the cost of the SSFA 'zero tolerance' sampling programme. Mindful of the need to restore the image of Shetland seafood, the three seafood associations also submitted an application towards the cost of building a Seafood Centre in Lerwick. Both applications were successful and a total E.U funding package of £460,000 was eventually awarded.

Conclusion

The *Braer* oil spill had an extremely serious impact on the Shetland seafood industry. For a few months, the industry teetered on the brink of disaster. As already discussed, the *Braer* oil spill led to problems of direct contamination, market damage and long-term biological impact.

By adopting a unified and professional approach, the Shetland seafood industry has been remarkably successful in negotiating to date a total of over £35 million in financial compensation from the IOPC Fund. While there are still some important claims outstanding in the Court, the fact remains that the largest proportion of financial compensation has already been paid without the need to recourse to legal action. To some extent this justifies the conclusion that the IOPC system of financial compensation has been successful.

The Shetland seafood industry undoubtedly suffered serious problems as a result of market damage. There does appear to have been a remarkable recovery and it would now be difficult to argue that there has been any long-term lasting effect on the price paid for Shetland seafood as a result of the *Braer* oil spill. This remarkable recovery is in no small part due to the professional market recovery programme which was implemented by seafood associations.

In the longer term, there remains the problem of long-term biological damage. The fact that the Fisheries Exclusion Zone remains in force for prawns and mussels reflects the fact that oil pollution levels are still well in excess of background levels in respect of these two species in the vicinity of the wreck. The continued presence of oil on the seabed in the Burra Haaf area is also a major cause for concern, especially in the long-term since this oil will take many years to biodegrade.

In summary therefore, the Shetland seafood industry has received full financial compensation for most outstanding claims relating to direct contamination and market damage. It is however still too early to reach a conclusion regarding the long-term biological impact of the *Braer* oil spill on fish and shellfish stocks in the vicinity of the wreck.

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Biographical Sketch. John Goodlad is a member of the fishing community in Shetland, an executive in a number of fishermans' organizations and a regular speaker at conferences on fishing issues. He is a salmon farmer, a director of various fish processing companies and a fisheries consultant with Watt and Goodlad Maritime Consultants. He serves as Chief Executive of the Shetland Fishermans Association / Shetland Fish Producers Organization and Vice President of the Scottish Fishermens Federation. In addition, he is a trustee of the North Atlantic Fisheries College.

Observations on the Integration of Laboratory, Mesocosm and Field Research on the Ecological Consequences of Dispersant Use for Marine Oil Spills into Response Planning.

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Abstract
In 1991, industry (represented initially by the Marine Spill Response Corporation) proposed a multi-year, integrated research program to address high-priority environmental concerns related to dispersant use in marine environments. This program has ultimately involved support from industry, state and Federal agencies, as well as international cooperative efforts. After over seven years of effort, the program is nearing completion. It has generated a wide range of data intended to be closely integrated, scientifically defensible, and focused on the concerns of decision-makers. Laboratory research has concentrated on the generation of data on both weathered and fresh crude oils for a variety of species using realistic exposure scenarios (i.e. rapidly declining concentrations). In addition, all of the participating laboratories have agreed to standard protocols to ensure data comparability. Mesocosm and field experiments have been designed to extend and validate these results in the near shore zone (mesocosm experiments) and in the open ocean (field experiments). Finally, considerable effort has been directed towards developing effective ways to communicate and integrate this information into the response planning process. The suggested approach is through the use of a modified Ecological Risk Assessment process specifically designed for use by Area Committees or Regional Response Teams. The results of this seven-year effort confirm that in many situations the environmental consequences of dispersant use may be preferable to the possible results from other response options. Further, dispersant use is not only appropriate as a large-volume, offshore response tool, but should be integrated with other response options and used selectively to prevent undesirable consequences in specific, sensitive habitats. The use of the proposed Ecological Risk Assessment protocols provides the framework for documenting and supporting such decisions.

Introduction
Events world-wide over the past several years would suggest that the oil spill response community has finally left the concerns raised by wreck of the Torrey Canyon behind. For much of the 30 years since this most famous misuse of chemical oil spill treating agents, its legacy has hung over the

response community, discouraging consideration of dispersant use. This has been especially true in the United States (U.S.).
Gradually, however, improved and less toxic dispersant formulations have gained in acceptability. Lewis and Aurand (1997) identified 75 documented uses of dispersants on major spill events from 1966 through mid-1996, and there were many more uses on small spills which did not receive international attention. Most, but not all, indicated (usually anecdotally) that the dispersant appeared effective, with no reported adverse environmental consequences. In the subsequent 18 months there have been many additional reported uses, again without any obvious adverse environmental consequences.

Attitudes about dispersant use as a response option have been changing particularly rapidly in the U.S. in the last several years. The majority of coastal areas now have at least some provision for dispersant use preauthorization in selected areas, whereas only five years ago very few preapproval areas existed. This is a critical step in any attempt to increase dispersant use in the United States, since it encourages the development of stockpiles of equipment and supplies, an expense which is difficult to justify unless there is a strong expectation that dispersant use will be permitted. The U.S. Coast Guard is now actively reviewing their options with respect to developing national standards for dispersant use plans. In the Gulf of Mexico, where dispersant use planning has been most aggressively pursued, dispersants were used as recently as February 1998 on a relatively large spill from an offshore pipeline. In this instance the response appears to have been a "textbook" application, with no residual effect on the environment (Fritz, 1998). On the basis of the favorable results to date, there is growing interest in expanding the preauthorization area in the Gulf.

While many individuals and organizations may have become more liberal in their view of dispersant use, that is not equivalent to not having continuing concerns about the potential ecological consequences, nor does it mean that response planners in all areas feel the same way. Relatively conservative limits are in place as to where preauthorization will be granted in most regions, which reflect these lingering concerns. Kucklick and Aurand (1997) documented that the majority of the spills in the U.S. where dispersant use might have been considered do not occur in the existing pre-approval zones. These zones would need to be extended nearer to shore and into shallower water to make dispersant use a viable option in most candidate spills. If this is to occur, then the concerns that still remain for many response planners need to be addressed by the scientific community. However, simply collecting additional scientific data is not the answer; a large part of the present problem is sorting through the mass of information already available. There needs to be attention given to how the information will be presented to, and then used by, oil spill response planners and managers. Without a defined approach to interpreting the available scientific information, there is little likelihood that it will be correctly interpreted.

Based on events of the past several years, now is an excellent time for all planning organizations to take another look at what role dispersants may play in their area of responsibility. This paper examines three issues, the status of a major cooperative research program to develop new data on the ecological consequences of dispersant use, concerns over the interpretation of existing data, and the role that Ecological Risk Assessment (ERA) might play in improving oil spill response planning.

Overview of the Integrated Research Program

In 1991, industry, working initially through the Marine Spill Response Corporation (MSRC), embarked on a multi-year research program designed to improve the scientific data base related to dispersant use, and encourage its appropriate use in the response planning process (Aurand, 1995). Ultimately, this has involved cooperative efforts with the states of California, Texas, Florida and Alaska, several international organizations, and some support from various Federal agencies. This section summarizes the current status of that program.

Objectives

The industry-proposed research program was designed to ensure that appropriate scientific information on the comparative ecotoxicological and ecological effects of spilled oil, chemically dispersed oil, and to a lesser extent dispersants is available and properly used during the planning for oil spill response as well as during the response itself. The proposed criteria for success in achieving this goal was implementation of scientifically defensible pre-approval criteria in the various Regional Response Teams (RRTs), and the creation and utilization of a scientific support network (both local and national) to assist in decisions during actual spill events. Key to the research program was the objective of involving state and Federal agencies in the effort.

The program focused on four elements; improved methods for laboratory toxicity evaluations and data interpretation, development of a realistic mesocosm testing program, field experiments to correlate laboratory and mesocosm data to real world situations, and improved use and synthesis of existing information.

Accomplishments to Date

Laboratory Programs. In order to promote the development of improved toxicity data on dispersants, crude oil and oil products, and dispersed oil, a series of cooperative toxicity testing programs were initiated. The intent was to bring together ecologists, toxicologists and resource managers to plan and execute appropriate laboratory research projects for improved dispersant decision-making. In 1993 the first phase of this multi year program began with cooperative efforts between MSRC, the California Office of Oil Spill Prevention and Response (OSPR) and Exxon Biomedical Sciences, Inc. (EBSI). Approximately one year later the Texas General Land Office (TGLO) joined the program. When the MSRC research program ended in December 1995, the American Petroleum Institute (API) assumed oversight for the program, a role which it still fulfills. In 1996, the Florida Department of Environmental Protection (FL DEP) joined the group, and in 1997 the Alaska Department of Environmental Conservation (ADEC) initiated a program. The currently available data are presented by Singer and Tjeerdema, 1994, 1995a, b: Pace and Clark, 1993; Bragin et al., 1994; Bragin and Clark, 1995; Van Vleet and Wetzel, 1997).

Each state agency selected a state university to participate in the testing program, each of which are jointly funded by the state and industry (the first year of the Alaska program was fully funded by the Alaska DEC). Industry is represented by EBSI. As of March, 1998, the Universities participating in the program are:

- University of California, Santa Cruz (UCSC)
- Texas A&M University (TAMU)

- University of South Florida (USF)
- University of Alaska, Fairbanks (UAF)

Each of these institutions is working to complete a standard series of toxicity tests, using consistent protocols and equipment. Tests using a standard oil and a standard test species are conducted by all laboratories to ensure data comparability. Each state program reflects local choices of test oils and test species.

In order to manage this effort and help coordinate other aspects of the integrated program, the sponsors organized an informal work group, the Chemical Response to Oil Spills: Ecological Effects Research Forum (CROSERF). This group meets twice a year to discuss the ongoing programs, and the results are available as published proceedings. To date, eight meetings have been held, and seven proceedings are currently available (Kucklick, 1994, 1995: Aurand and Kucklick, 1995: Aurand and Coelho, 1996: Coelho and Aurand 1996, 1997a, b).

The purpose of CROSERF, as defined at the first meeting, is to provide state, Federal, and international agencies, industry, academic researchers and consultants engaged in research on the ecological effects of oil spill response chemicals, especially dispersants, with an informal forum for the exchange of ideas and coordination of research. Specific objectives of the Forum include:

- Discuss and resolve scientific issues related to ecological effects of chemicals used in oil spill response;

- Encourage the standardization of laboratory toxicity test procedures;

- Foster cooperative laboratory and mesocosm ecological research programs on oil spill response issues of mutual interest;

- Encourage the application of appropriate laboratory data collected under realistic exposure scenarios to the oil spill response decision process; and

- Contribute to the development of appropriate risk assessment protocols.

The major accomplishments of this group, including the progress within the toxicity testing program, are summarized below.

<u>Testing Protocols</u>. The need for defined test protocols is clear - oil and water don’t mix. The problems this can create are discussed in Sections 3.2 and 3.3, but the end result is that it can be very difficult to compare results from one set of tests to another. Since the preparation of test solutions can have a dramatic effect on exposure, even seemingly insignificant changes in test protocols can greatly affect results. As a result, detailed chemistry is critical, even if standard protocols are

followed, in order to confirm the actual chemical exposure. Researchers must also be careful about which compounds or classes of compounds are reported, as their abundance can change with experimental conditions and the oil being tested (see Section 3.1). To date, CROSERF has developed the following protocols:

- Preparation of Water Accommodated Fraction (WAF)
- Preparation of Chemically Enhanced (CE)-WAF
- Chemical Characterization of Test Solutions
- Round-Robin Chemical Characterization of a Reference Oil
- Round-Robin Chemical Characterization of a Standard WAF
- Protocols for Conducting Flow-Through Spiked Exposure Toxicity Tests

In addition, the participants have identified and adopted appropriate published protocols for a range of other activities, such as oil weathering or standard 96-hour exposure tests.

Table 1 lists the oils and test species being used or proposed for use by the CROSERF participants. Not all species will be tested against all oils, but *Menida beryllina* is being used as a standard species to allow cross-comparisons between laboratories. Each set of tests is subjected to a standard set of exposures, which are the key to developing an integrated and useful data set for management decisions. They have been designed to be appropriate for comparison to mesocosm and field results, as well as allowing for the interpretation of traditional laboratory exposure regimes. Four different basic exposures have been used:

- Dispersant alone (Corexit 9500 and/or 9527)
- Weathered versus fresh WAF
- Weathered versus fresh CE-WAF
- Continuous versus spiked exposure for all combinations.

The spiked exposure regime being used by all laboratories is based on a specific test apparatus and protocol first described by Singer *et al.* (1991). The most recent version of the protocol was described in Singer *et al.* (1993). This protocol requires a standardized exposure chamber approximately 300 mL in volume. A desired initial exposure concentration is established in the chamber and then allowed to dilute at a constant rate by the addition of fresh sea water. The standard protocol specifies a flow rate into the chamber of 2 mL per minute, which means that a 50% dilution occurs approximately every 2.5 hours. Participating laboratories all target this rate, and generally achieve rates between 1 and 2 mL per minute. Continuous exposure tests conform to either U.S. EPA, ASTM or other standard test protocols. Most tests, either continuous or spiked exposure, are 96-hour tests. Weathering is intended to simulate an oil that has been released for approximately six to twelve hours, and all laboratories will use oil weathered by the same protocol.

<u>Results to Date</u>. As of March, 1998, the laboratory program is approximately 50% complete. All testing is scheduled to be completed by the end of 1999. Testing using dispersant only is now largely finished, and most laboratories are engaged in full-scale data collection for WAF and CE-WAF for oils and species of concern. Since the programs started at different times, there is a lot of variability

in their status. The currently available data on dispersant alone is summarized in Table 2, while Table 3 presents the results for WAF and CE-WAF tests. No data are currently available on the effect of weathering. These data confirm the general decrease in toxicity as you move from a continuous to a spiked exposure for all toxicants. It is also obvious that there is considerable variability between species and between oils, as would be expected. Where data from multiple laboratories are available, reproducibility for a particular species and toxicant is good. The dispersant only data for *M. beryllina* is inconsistent with the rest of the observations, and additional information is being collected.

	Species Used in or Proposed for Testing
Arabian light crude Alaska North Slope crude Venezuelan crude Kuwait crude Forties crude Sture blend crude Medium fuel/gas oil mixture (MFO)	*Menida beryllina* (inland silversides minnow) *Macrocystis pyrifera* (giant kelp zoospores) *Scophthalmus maximus* (turbot) *Atherinops affinis* (topsmelt) *Scianops ocellatus* (red drum) *Cynoscion nebulosus* (seatrout) *Mysidopsis bahia* (mysid) *Holmesimysis costata* (kelp forest mysid) *Haliotis rufescens* (red abalone) *Crassostrea virginica* (American oyster) *Argopectin irradians* (Bay scallop) *Eurytemora affinis* (copepod) *Acartia tonsa* (copepod) Microtox (luminescent bacteria) *Chionoecetes bairdi (*Tanner crab)
Total Oils 7	Total Species 14

Table 1. Oils and Test Species Being Used (or Proposed for Use) by CROSERF Participants

Laboratory	Organism	C 9527 LC50 Continuous	C 9527 LC50 Spiked	C 9500 LC50 Continuous	C 9500 LC50 Spiked
TAMU	Microtox	276.0	no data	no data	no data
UCSC	*M. Pyrifera*	10.5	no data	no data	no data
UCSC	*H. rufescens*	2.0	15.9	no data	13.6
EBSI	*C. gigas*	3.1	13.9	no data	no data
UMCBL	*E. affinis*	no data	no data	5.2	no data
EBSI	*H. costata*	9.7	195.0	no data	no data
UCSC		7.1	136.0	no data	no data
UMCBL		15.3	no data	no data	no data
EBSI	*M. bahia*	29.2	>1014.0	35.9	>789.0
UMCBL		25.3	no data	no data	no data
TAMU		30.4	no data	no data	no data
USF			no data	37.2	1038.0
EBSI	*S. maximus*		no data	74.7	>1055.0
UCSC	*A. affinis*	27.9	86.2	no data	no data
EBSI	*M. beryllina*	52.3	58.3	no data	no data
UMCBL		33.5	no data	no data	no data
TAMU		54.6	no data	no data	no data
USF			no data	85.1	21.6

Table 2. Estimated 96 Hour LC50 Values for Various Species and Corexit 9527 or Corexit 9500 Under Both Constant and Spiked Exposure Regimes. Values in PPM (Coelho and Aurand, 1997)

Organism	Oil	Dispersant	WAF 96 Hr. LC50 Continuous	WAF 96 Hr. LC50 Spiked	CE-WAF 96 Hr. LC50 Continuous	CE-WAF 96 Hr. LC50 Spiked
M. bahia (*)	Kuwait	C 9527	0.6	2.9	0.7	17.2
M. bahia (*)	Forties	C 9500	no data	no data	0.4	15.3
M. bahia (**)	Venezuelan	C 9500	0.2	0.7	0.5	12.6
M. beryllina (**)	Venezuelan	C 9500	< 0.1	0.6	0.7	2.8
M. beryllina (*)	Kuwait	C 9527	1.0	2.0	0.6	6.5
M. beryllina (*)	Forties	C 9500	no data	no data	0.5	9.1
S. maximus (*)	Kuwait	C 9527	2.0	16.5	no data	no data
C. gigas (*)	Kuwait	C 9527	0.5	1.9	0.8	4.0
H. costata (*)	no data	no data	0.1	>2.8	0.2	5.0
Laboratory : * EBSI; ** USF						

Table 3. Estimated 96 Hour LC50 Values for Various Species and Oils (With and Without Dispersant) Under Both Constant and Spiked Exposure Regimes. Values in PPM (Van Vleet and Wetzel, 1997; Bragin et al., 1994)

Mesocosm Testing. From the inception of this program, mesocosm testing was viewed as an essential program component. Systems which model shoreline or nearshore systems, rather than open water simulators, are of the most interest, since the intertidal and nearshore shallow subtidal zones are the most vulnerable in most spills, and most previous mesocosm studies have not been directed at that habitat. Mesocosm systems are attractive because they allow experiments to be "scaled up" from laboratory systems, while still maintaining some level of control and replication. They are much cheaper than conducting full-scale field experiments, and do not require as much permitting or regulatory review (except for possible waste disposal or emissions).

In 1993, MSRC and TGLO began a cooperative effort to plan and build a state-of-the art mesocosm facility for use as a nearshore simulator. The resulting facility, known as the Coastal Oilspill Simulation (COSS) Facility, is located in Corpus Christi, Texas and was completed in the spring of 1997. Constructed with funds from TGLO and industry, it is now owned and managed by TGLO. The COSS Facility consists of a control building and laboratory, a wastewater treatment plant, nine wave tanks (110 feet long and approximately eight feet wide and eight feet deep), a flow-through sea water system and various support facilities. Features available in the tanks include an adjustable two-foot (or less) tidal range, variable flow rate, and random wave capability. Sediment can be added to the tanks to create bottom habitat and to develop an intertidal "shoreline" at the end of the tank opposite the wavemaker.

The first large-scale dispersed oil project in this Facility is scheduled for April, 1998. The results will be available as an API report. The project is a cooperative effort between TGLO, API, and Exxon, and focuses on the fate and effects of oil and dispersed oil in the nearshore and intertidal zone. The purpose of the experiment is to determine if shoreline protection can be achieved by dispersant use without undue risk to the nearshore zone, in the event that dispersed oil is present in very shallow areas. It involves the release of untreated or dispersed weathered Arabian light crude oil in three COSS tanks each, followed by its distribution in the water column and in the intertidal zone and then its gradual dilution out of the tank. Two other tanks will serve as replicate controls (without oil or dispersed oil). In all tanks a two-foot semidiurnal tide and waves ranging from three to six inches in height will be present. An onshore wind will be simulated for the first 24-hours after addition of the oil or dispersed oil. The beach will consist of medium sand typical of the Texas shoreline. In all tanks, the fate and effects of the treatment will be evaluated using a series of biological, chemical and physical measurements. Biological effects will be evaluated using caged animals (five species) and in laboratory tests of sediment toxicity (amphipod test). Both acute effects as well as bioaccumulation of hydrocarbons will be examined. Detailed hydrocarbon chemistry data will be collected for both the water column and the sediments. The fate of the oil will be followed for approximately ten days.

Field Testing. There have been at least fourteen field or field/laboratory studies which related to the ecological effects of dispersants and/or dispersed oil (Aurand, 1995). Three of these in the 1980s were relatively elaborate experiments which yielded a considerable amount of data on the consequences of dispersant use in intertidal and nearshore areas. The experiments were conducted at a site on Baffin Island in the Canadian Arctic (BIOS Study) (Sergy, 1985), at a small embayment near Searsport, Maine (Gilfillan *et al.*, 1983, 1985) and in a tropical embayment containing mangroves, sea grass beds and corals in Panama (TROPICS Study) (Ballou *et al.*, 1989). All three experiments were reviewed by NRC (1989) and McAuliffe (1989). In all three, using different application mechanisms, both dispersed and untreated crude oil was released slightly offshore or subtidally, and allowed to strand on the intertidal zone.

In the experiments in Maine and the Canadian Arctic, initial impacts in the water column and in benthic organisms in contact with the oil plume were higher in the presence of dispersed oil, but the effect was temporary and conditions returned to normal within one year in the arctic and more quickly in Maine. In both cases there was significant shoreline contamination in the high intertidal zone by the untreated oil, which was not seen with the dispersed oil. The Searsport study was only short term, but monitoring at the BIOS site continued for several years and documented long-term contamination of the sediments from erosion of beach sediments at the untreated oil site.

In Panama, the TROPICS sites were monitored for two years following the experimental spill. At the end of two years the authors concluded that the undispersed oil had severely damaged or killed the mangrove trees in the test area, while there was little or no damage to trees from dispersed oil. Sea grasses themselves were not affected by either treatment, but invertebrates present in the sea grass beds were severely affected by the dispersed oil. Recovery appeared complete after two years. Corals were also significantly affected by dispersed oil in the first two years, but not by untreated oil. In 1994 the Panama sites were revisited to evaluate the effects after ten years as part of the MSRC effort to implement the field study portion of this integrated research program (Dodge *et al.*, 1995). This most recent study emphasized the significant effect of untreated oil on mangroves, since the area now contained even fewer living trees (approximately half of the original population). In contrast, there was no explicit mortality of trees exposed to dispersed crude oil. The corals, which had shown an affect from dispersed oil at the two year point, had now recovered and there was no significant difference between sites.

Surprisingly, the information gained from these studies, which clearly supports the benefits of shoreline protection with dispersants, appears to only infrequently enter into planning discussions. It is unclear why this is so, but the lack of widely available summary reports may be one factor. Like many field studies, these efforts lack adequate replication for statistical analysis of the results, which is an important but not overriding concern. In any case, additional nearshore field studies could build on these results, but the first phase of any such effort would need to be a comprehensive re-evaluation of the existing information.

Because of the existence of these studies, cost, and the difficulties in obtaining permits to conduct shoreline studies in the U.S. the field study portion of this program has focused on refining the available data on ecological effects of dispersed oil in the water column. While there have not been any recent field studies specifically targeting such ecological effects, there have been opportunities to conduct such research as add-ons to other dispersant-related field testing. In 1994, 1995 and 1996 it was possible to combine toxicological studies with British and Norwegian field experiments in the North Sea on various aspects of dispersant action. In all cases the toxicological studies were conducted on water samples from below untreated oil slicks, chemically dispersed oil slicks, and field control sites. All of the tests involved a static exposure to the sample water.

Additional samples for hydrocarbon analysis were also collected. Because all of the tests involved continuous exposures over at least 48-hours, they overstate any likely effects (Wright *et al.*, 1994; Coelho *et al.*, 1997). Despite difficulties in working in the field, the data confirms the general conclusions that dilution is very rapid and that little or no toxicity is likely to be observed except in the immediate vicinity of the slick (less than 5.0 meters depth) under the conditions modeled by the experiments (moderate sized spill, rapid spreading and dilution in a well-mixed, high energy open environment.

Information Synthesis and Dissemination. Early in the planning for this program, MSRC developed a program in risk perception and risk communication to determine what issues needed to be addressed in order to respond to the needs of the response community. The initial task was to identify concerns of Federal, state and regional regulators as well as environmental and marine resource user groups regarding the use of dispersants to clean up oil spills. This was done using a risk communication protocol drawn in large part from previous mental models research where the mental models of the audience are compared to an expert decision model to identify differences between the two. This information was then used to develop a list of specific topics for summary reports on concerns which are critical to response decisions. The methodology used was summarized by Bostrom *et al.* (1995), and the results of the initial issue identification task were presented by Bostrom *et al.* (1997). Currently, the API is sponsoring the preparation of three summary reports tentatively entitled, "Fate and Transport of Oil in Marine Waters", " Dispersability of Oil in Marine Waters", and "Links Between Fate and Transport and Exposure and Effects Processes". Finally, at the 1997 International Oil Spill Conference, an Issue Paper on dispersant concerns was commissioned by the sponsors in an effort to stimulate discussion (Lewis and Aurand, 1997).

Future Objectives

Many of the elements of the original research plan (Aurand, 1995) are now complete, or will be completed within the next year. The laboratory data set currently being developed and due to be completed by the end of 1999 should be adequate for most needs, although testing with additional oils or species of concern is always a possibility. These tests deal only with water column exposure, and several sponsors have indicated a potential need to develop a similar set of data for sediment toxicity testing, if dispersant use in shallow water is to be a real possibility. The mesocosm experiment scheduled for next month is the only one currently funded. While it should yield valuable information, future studies should look at additional oils, both weathered and fresh, in order to develop an adequate data set. Based on the results summarized in Section 2.2.3, there appears to be little need for further toxicological testing as a part of open water field studies. The situation is more complex in shallow near-shore environments, and additional field studies might be appropriate. These are potentially expensive and difficult to implement, and so a significant effort should be made disseminate the results of completed studies more widely within the response community. This leads to the final element of the program, Outreach and Communication. As the end of the scheduled research program comes closer, the outreach effort is critical - and it is now the main concern of the sponsoring organizations. It is important that all participants commit to the use of the integrated data set, and encourage its use by others. Proposed outreach activities include:

- workshops at RRT meetings
- interactive outreach meetings

- technical and general interest publications, and
- development of a CROSERF Webpage.

It is not clear at this time whether funding for these activities will continue beyond the end of the aquatic toxicity testing program in 1999.

Issues in the Integration of Scientific Data into Management Decisions

When the research program described in Section 2.0 was initially developed, the need for an improved effort to communicate the research results was considered essential (see Section 2.2.4). As a result of those efforts, a number of issues, including four that appear critical in the interpretation and utilization of scientific information in the oil spill planning process, were identified. These four are discussed briefly in the following sections.

Chemically Characterizing Oils - an Art or a Science?

It is infeasible to quantify all of the compounds which may be present in an oil, which can number in the thousands. Even so, studies to assess toxic effects require detailed knowledge of specific compounds, or at least classes of compounds, to avoid confusion and properly interpret results. The best way to get such detailed information is to use gas chromatography - mass spectroscopy (GC-MS) analysis to quantify the more significant compounds present (Betton, 1994: Neff and Sauer, 1995; Sauer and Boehm, 1995). Even GC-MS derived data, however, can vary considerably between laboratories and researchers.

Since it is neither meaningful nor practical to report the concentration of individual compounds when dealing with a spill, oil pollution studies often report measures of bulk oil present (which tells the reader nothing about composition), or refer to the concentration of “total petroleum hydrocarbons” (TPH) or “total hydrocarbon content” (THC). This terminology is potentially misleading, since there is no single definition of or method for TPH determination. Some, but not all, of the methods are based on GC analysis. While GC-MS results are the most reliable, they may also vary significantly, depending on the protocol used. The range (based on the number of carbon atoms present in individual components) of compounds included in the definition of TPH (e.g. $TPH_{C10-C36}$) and a list of the specific target compounds or classes of compounds included in the analysis is particularly important. As a result, reported values in the literature may not be directly comparable, even though the same reporting units may be used. Unless the analytical method is clearly defined this potential error cannot be evaluated. Experience within the CROSERF group has demonstrated that this can, indeed, cause considerable confusion when interpreting and comparing results. The situation is compounded by the fact that most petroleum hydrocarbons are poorly water soluble, and that there is a wide range of volatilities for the various compounds, which leads to rapid and often dramatic changes through time in the nature of an “oil” after it is released into the environment (see subsequent section on “weathering). The changes in relative abundance of the various constituents of crude oil, some of which are toxic and others not, can be obscured by the use of TPH values.

Weathering and Fate of Oil in the Environment - Where Does it Go?
The general concepts of oil weathering are clearly essential information for informed response planning, but the process is complex and highly variable, and as a result is not well understood by many in the response community, especially with respect to its influence on ecological effects. Weathering consists of a series of chemical and physical transformations which begin as soon as oil is released into the environment. Neff (1990) listed the following fate mechanisms under the general category of weathering:

- spreading
- evaporation
- dissolution
- dispersion in the water column
- photochemical oxidation
- formation of emulsions
- microbial degradation
- adsorption to suspended particulate matter
- sedimentation to the sea floor.

In most cases, the quantitative effects of weathering have been well communicated to the response community, but the qualitative effects have not. For example, while it would be correct to state that “evaporation can account for the loss of one-third to two-thirds of oil spilled on water, depending on the oil”, the concept of the selective loss of the more volatile, light hydrocarbon compounds present in the original oil is lost. Most technical experts recognize the chemical changes and fractionations which occur during weathering, but this has proven difficult to express clearly, either visually or in words, since there are so many possible changes.

As soon as oil is spilled on water it begins to spread. Crude oils and heavy distillates form two phases during spreading, a thick phase (1 to 20 mm thick) consisting of viscous, partly emulsified oil and a thin sheen 0.01 to 0.001 mm thick (Neff, 1990). Slicks rarely remain coherent for any length of time, and include areas of sheen and thicker patches of oil that tend to break apart due to horizontal water currents and eddies. Emulsified oil, or weathered oil of higher viscosity, may align as windrows or accumulate in convergence zones on the sea surface (McAuliffe, 1989). The leading (downwind) edge of a slick tends to be thicker than the interior, and usually moves faster (Elliott, 1986).

Evaporation is by far the most important process in the first few hours or days after an oil spill. Evaporation affects both the chemical and physical properties of the slick, and rapidly removes many of the compounds of most concern with respect to toxicity. Components up to C_8 can be expected to be gone after five hours (Betton, 1994). As the lighter, volatile compounds evaporate, the density and viscosity of the slick increases, and emulsion formation is enhanced (Neff, 1990). The process is quite rapid, and 50 to 70% of the amount that will ultimately be lost by evaporation occurs within the first 12 hours (McAuliffe, 1989). Depending on the oil, this may also be a considerable part of the original volume, in some cases up to 70 or 80%.

Dissolution, as a mechanism to remove compounds from an oil slick is in competition with evaporation, but proceeds much more slowly, so dissolved hydrocarbons rarely accumulate in the water column (McAuliffe, 1989). Harrison *et al.* (1975) predicted evaporative rates for aromatic hydrocarbons that were 100 times faster than their rates of solution. The rate for alkanes was 10,000 times faster.

Dispersion is caused by turbulent mixing and wave action, and, in contrast to the dissolution process, results in the formation of oil "droplets" of various sizes which are driven into the water column. Once a slick has been reduced by evaporation, this becomes the most important process (Neff, 1990). Small droplets rise so slowly that they are effectively dispersed permanently, and are then transported with the water mass. There is some question as to the exact size of droplet where this may occur. Payne and McNabb (1985) suggested a limit of 0.1 mm (100 μm), while Lunel (1995) defined dispersed droplets as less than 50 μm, and suspended droplets as greater than 70 μm, which they considered to be the critical size.

Photochemical reactions occur when solar radiation acts on oil on the surface or in the water column to yield new compounds. The primary mechanism is photo-oxidation, which yields compounds that tend to be more water soluble and more toxic than the parent compounds. The process also yields high molecular weight byproducts which are not soluble in oil or water. In most oil spill studies this process is assumed to be relatively minor.

Some oils, especially after weathering, may accumulate and retain water droplets in the oil phase as a result of turbulent mixing, producing a thick, gummy residue known as "chocolate mousse". These can be up to 75% water and are more viscous than the parent oil (Neff, 1990). This emulsification process has the greatest likelihood with heavier crude oils with high viscosities, which also form the most stable emulsions. The formation of emulsions is due to stabilization of water droplets in the oil mass by the surfactant action of the resins and asphaltenes in the oil. The tendency of weathered crude oils to emulsify quicker than fresh crude oil is due to the requirement to achieve a resin/asphaltene concentration of approximately three percent before they begin to act as surfactants (Fingas *et al.*, 1993).

Ultimately, biodegradation becomes the dominant weathering factor. The hydrocarbons and other compounds found in crude oil are all natural materials, represent a potential energy source for organisms, and all but the most refractory can be degraded by biological processes, especially microbial action. Biodegradation occurs in the water column, in slicks, on the shoreline, and in the sediments (Bartha and Atlas, 1987). All compounds degrade simultaneously, but the rates for the various components vary considerably. Degradation rates in sediments, either subtidal or intertidal, are strongly influenced by temperature and by the availability of oxygen. In very cold, very hot, or anaerobic environments the more refractory compounds can remain for decades. While studies of this duration are rare, the retention of oil residue has been demonstrated in the Canadian sub-arctic (Owens *et al.*, 1993), a boreal salt marsh in Chile (Sell *et al.*, 1995), a salt marsh in Massachusetts (Teal *et al*., 1992), and beaches in Saudi Arabia (Hayes *et al*., 1993). Under most other circumstances, however, the various compounds will gradually be removed from the environment.

Suspended particles (including biological particles such as microscopic organisms) in or on the water column interact with spilled oil by physical collision with and adherence to dispersed oil droplets, or by adsorption of dissolved hydrocarbons from the water phase (Neff, 1990). The affinity of a particle for oil depends upon its chemical and physical properties, as well as those of the oil. Clays have been known to have a high affinity for oil for some time. The adsorption process is obviously most significant in areas where there is a high suspended particulate matter load in the water column, or after oil has stranded on the shoreline. In most spills where oil actually strands, the adsorption process which occurs in the intertidal zone far outweighs any adsorption occurring in the water column. Bragg and Yang (1995) did extensive studies on clay-oil flocculation in Prince William Sound after the *Exxon Valdez* accident, and concluded that stable oil-mineral fines-water complexes were created and stabilized by glacial flour (particles of clays, quartz and feldspar one to 100 µm in diameter). The presence of these aggregates encouraged the removal of oil from the shoreline. Once oil has been adsorbed onto a particle its fate is determined by the fate of the particle, and so accumulation may occur in depositional areas. At that point, it may or may not biodegrade, depending on environmental conditions. In most instances, oil does not accumulate to any great degree in subtidal sediments in the vicinity of oiled shorelines. This was the case in both Prince William Sound (Bragg and Yang, 1995), and in the area of Saudi Arabian coastline heavily oiled in the Iraq-Kuwait War (Michel *et al*., 1993). Accumulation in offshore sediments was noted during the *Braer* incident (Ritchie and O'Sullivan, 1994) in the Shetland Islands.

Laboratory Tests - What Good and What Not

Toxicity data is most useful when relative comparisons are made, under constant conditions, between species or among life history stages. Estimates of toxicity are relative, not absolute, and are dependent upon the test conditions and populations being exposed (NRC, 1989). Comparisons are difficult if not impossible when there are significant differences in the analytical procedures used. This has shown to be the case not only for crude oil (Markarian *et al*., 1993), but also for much of the research related to dispersants, and particularly chemically dispersed oil (NRC, 1989). Test results can be influenced by factors such as the nature and degree of agitation, the type of test container, whether the test containers are open or closed, the oil:water ratio, the source of the crude oil, or its weathering state, to name only a few. The results from many early experiments are even further compromised by the use of nominal rather than measured concentrations of hydrocarbons, which has often led to considerable overestimation of exposure for experiments with crude oil. Indeed, the NRC concluded flatly that "...results stemming from use of this technique (nominal concentrations) are in error, and much data are of little use" (NRC, 1989).

Tables 4 and 5 list questions which should be answered every time an experimental toxicity data set is considered. If the answers to these questions are not known, then there is a significant chance that the data may be misinterpreted or misapplied. While there is no absolute criteria for acceptance or rejection of a particular data set, the lack of direct estimates of toxicant concentration for hydrophobic chemicals, and/or the lack of sufficient detail to repeat or verify the test, will generally mean that the data should be rejected or used only with great caution.

Interpreting Toxicity Data

The key element in interpreting laboratory data related to dispersant and dispersed oil impacts in the real world is the definition and interpretation of the exposure regime. This is driven by the assumptions, either explicit or implicit, that are made concerning concentrations that are likely to occur in real spill situations. There are two possible sources of information on this issue. Estimates may be made on (1) the basis of models, either simple conceptual ones, or very complex mathematical ones, which incorporate information on physical processes, oil weathering and chemical properties to predict oil concentrations in the environment, or (2) the available field data from both experimental releases or actual spill events can be examined. The influence of weathering must always be considered when interpreting information from either source with respect to ecological effects. Figure 1 illustrates one very simple approach to estimating water column concentrations of oil, where a 0.1 mm thick slick is assumed to evenly mix into the water column to varying depths, demonstrating the rapid decline in concentration under even conservative assumptions about dilution.

Field studies have compared the concentrations of hydrocarbons in the water column under both treated and untreated slicks, and collected data on the fate of the oil slicks. These experiments involved the release of oil in replicate slicks, followed by aerial dispersant application. The volumes used have varied considerably, but many of the early releases were of 20 bbl or less per slick, and the more recent North Sea experiments on the order of 200 to 250 bbl per slick. Under undispersed oil slicks measured hydrocarbon concentrations are in the ppb range, while under dispersed oil slicks concentrations are variable but can range up to 20 to 50 ppm in the top one to five meters. Dilution is rapid, and concentrations below approximately 10 meters are one ppm or less (Lichtenhalter and Daling, 1985; Canevari *et al.*, 1986; Brandvik et al., 1996; Lunel, this conference) . The composition of the oil droplets depends on oil type and weathering state, but effective, and early, application of chemical dispersant can result in higher levels of volatile compounds in the water column. These data support a rapid decline to values of less than one or two percent of the initial level within two or three hours when dispersant is sprayed on test slicks at sea. This would equate to a half-life of approximately 0.5 hours or less (Aurand 1995). This situation should apply to small or moderately sized accidental spills.

Quantitative observations under larger slicks are rarely available, but since most of the decline can be explained by vertical mixing, it is reasonable to assume that a similar dilution pattern prevails in most instances, assuming a moderate level of turbulence and vertical transport and similar slick thicknesses. Treatment of thicker slicks would lead to higher initial concentrations. In the case of the grounding and subsequent destruction of the MV *Braer* along the Shetland coast, the severe weather and chemical and physical properties of the spilt oil (Gullfaks crude) led to essentially total physical dispersion of the approximately 85,000 tonnes of cargo, along with a small volume of fuel oil. In the three months following the incident, over 800 water samples were taken for hydrocarbon analysis. Most of these were taken near the southern end of the Shetland mainland, or near Fair Isle, located 39 km to the southwest. Concentrations of total hydrocarbons in the water column near the tanker were in the range of several hundred ppm soon after the grounding. In the following few days, concentrations were generally in the 50 ppm range in areas affected by the spill. By 16 January 1994, ten days after the incident, concentrations in Quendale Bay (approximately 2-3 km from the wreck) were less than 10 ppm (Ritchie and O'Sullivan, 1994).

The wreck of the barge *North Cape* on the coast of Rhode Island in January 1996 led to the loss of nearly 20,000 barrels of home heating oil, similar to No. 2 fuel oil in physical and chemical properties. The oil was highly dispersable and weather conditions were extreme. As much as 80% of the oil may have dispersed within the first eight hours (Oil Spill Intelligence Report (OSIR), January 1996). After two days, TPH concentrations in the vicinity of the wreck were about 6 ppm and oil was evenly distributed within the area of the plume to a depth of 20 meters. Within five days TPH values were below the detection limit of 0.1 ppm (Research Planning, Inc., 1996). In contrast to the *Braer* incident, the biological consequences of this spill have become highly contentious (OSIR, 15 January 1998). There is some evidence that mortality, especially in lobsters,

Table 4 Questions Which Must be Answered Regarding Test Media Preparation and Conditions Prior to Determination as to Whether or Not the Test Data are Relevant for the Scenario Under Consideration (modified from Betton, 1994)

1. What type of medium was prepared?
    - Was it a Water Accommodated Fraction (WAF) preparation?
    - Was it a Chemically Dispersed Oil (CDO) preparation?
    - Was it a dispersant only preparation?

2. What type of water was used?
    - Was it freshwater or saltwater?
        - What was the salinity, temperature, and pH prior to product addition?
    - What was the source of the water?
        - Was it natural water or artificial water?
        - Was the water filtered or sterilized?

3. What products were used?
    - What type of oil was used?
    - What type of dispersant was used?

4. What type of loading rate was used?
    - What was the initial volume of water used?
    - What was the volume or mass of product(s) used?
        - How was the product added?
        - Was the water already mixing?
        - Was product added to surface? to a vortex (if present)?
        - Were the products pre-mixed or added in rapid succession?
    - What was the temperature of water and product when measured?

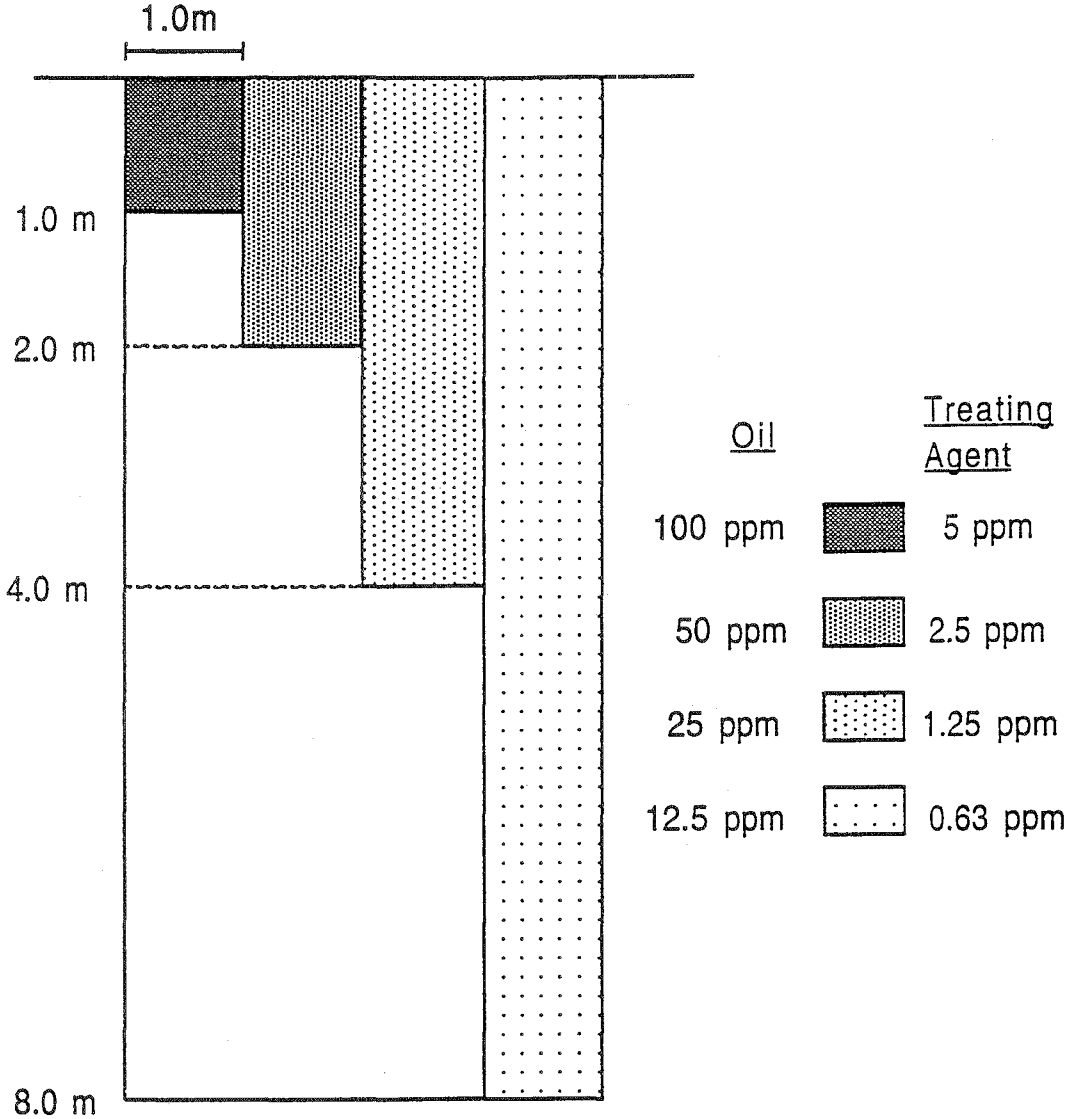
5. What type of mixing vessel was used?
    - What was the geometry and size of the vessel?
        - What was the surface area ratio of water to product(s)?
        - Was headspace present? if so, what was the volume?
    - Was the vessel sealed or open during mixing?

6. How was mixing accomplished?
    - What was the method of mixing?
    - What level (energy input) of mixing was used?
        - Was there a vortex?
    - How long was the medium mixed?
    - At what temperature was the medium mixed?
    - Was the medium allowed to settle after mixing? if so, for how long?

Table 5 Questions which should be answered for all toxicity tests prior to a determination as to whether or not the test data are relevant for the scenario under consideration (Aurand and Coelho, 1995).

1. What species is used?
    - Is it the species of interest?
    - Is it closely related taxonomically?
        - What conclusions can be drawn between taxonomically close species?
    - Is it a freshwater, estuarine or marine species?
2. How sensitive is this species?
    - Is it used as a standard test organism by any agencies?
    - Are there other toxicological data on this organism?
3. What life stage is used?
    - Is it a single life stage test?
    - Is it a complete or partial life cycle test?
    - Is this a sensitive life stage(s)?
4. What endpoint is reported?
    - Is it an acute test (LC_{50})?
    - Is it a chronic test (EC_{50})?
        - Is the effect quantifiable?
        - Is it reproducible?
        - Is the effect biologically significant (to the species of interest)?
5. Was the species checked against a reference toxicant?
6. Was the test repeatable?
    - Were controls used?
    - Are confidence limits reported?
    - Were adequate sample sizes used?
    - Were replicates performed?
7. Were concentrations of the toxicant measured or estimated (nominal)?
    - What method was used?
    - At what points during the test were chemical samples collected?

Figure 1. A Schematic Diagram of a 0.1 mm Thick Slick Evenly Dispersed Along a Vertical Axis to Various Depths. Source: Aurand and Coelho (1995).



was caused by narcosis due to exposure to oil in the water column, followed by physical damage related to the severe turbulence.

Finally, in the *Sea Empress* spill in Milford Haven, UK (see papers in this volume) dispersants were used extensively, and a robust data collection effort was conducted. Little evidence of adverse effects was found and the dispersant application was credited with dramatically reducing shoreline impacts.

Despite these data the research community has been slow to adopt experimental designs that reflect a declining exposure regime, and the regulatory community continues to make very conservative assumptions about exposure during spill response planning. These conservative approaches can lead to greatly inflated concerns about possible effects in the real world. Figure 2 compares the expected exposure regimes in a standard 96-hour continuous flow or static exposure test (a) to the "spiked exposure" regime (b) (Singer *et al.*, 1991) used by the CROSERF laboratories when the system was run with a flow rate which yielded a half-life ($t_{1/2}$) of 2.5 hours, by plotting the percentage decline in the initial concentration against time. The additional curves in Figure 2 are based on a 3-hour square wave exposure (c), a hypothetical concentration curve for a shallow well-mixed estuary where there is 50% exchange every 12 hours (d), and finally, an estimate of the decline curve in the open ocean (e). If the rapid dilution observed in the field experiments is accurate for small to moderate-sized spills, static 96-hour tests would over-estimate oceanic exposures by more than 100-fold, while the spiked exposure regime used by Singer *et al.* (1990,1991, 1993) and by the other CROSERF participants would over-estimate oceanic exposure by a factor of five, but would be much more appropriate for nearshore situations where dilution is less rapid.

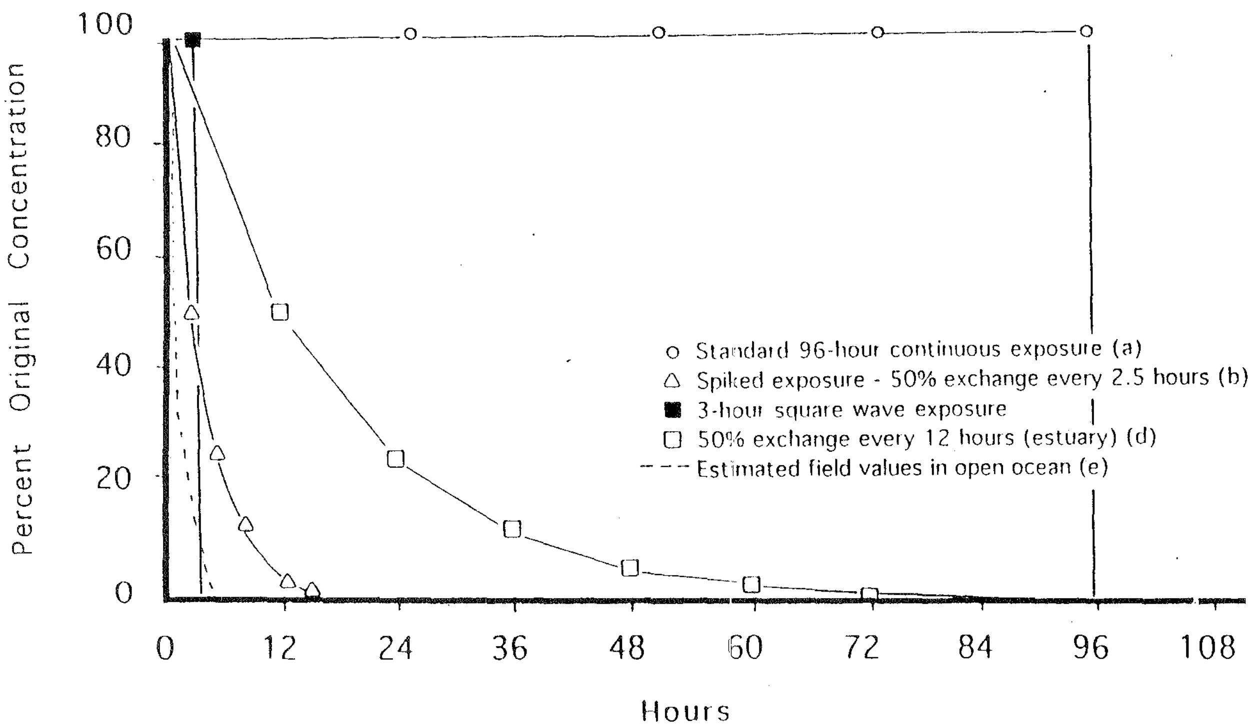
The logic in these comparisons is essentially the basis for the concept of the ppm-hr (Anderson *et al.*, 1984), where the two factors, exposure and concentration, are considered to be direct multipliers. Experimental evidence for this approach is limited, and, intuitively, there are limits beyond which the concept does not apply. The general conclusion by the NRC (1989) was that the approach was probably valid for time periods of 1 hour to 4 days. It has been used by many other authors, including Capuzzo (1989) as the best method to draw inferences between test results. The data presented in Tables 2 and 3 suggest that, while the general concept (i.e. exposure as a function of concentration and duration) is appropriate, the variability between oils and species makes it of limited practical value.

Using Ecological Risk Assessment Principles to Facilitate the Use of Scientific Information

Once oil is on the water in a marine or coastal situation, the goal is to determine what combination of response options will limit environmental impacts most effectively, since no technique is 100% effective. It is also critical to avoid "single resource management decisions", which may protect one resource at the expense of others or of the system as a whole. One way to accomplish this objective is to integrate Ecological Risk Assessment (ERA) protocols in to the response planning process (see Aurand, 1995).

Ecological risk assessment is a formal process, either quantitative or semi-quantitative, to evaluate the possible ecological consequences of human activities and natural catastrophes. Response

Figure 2. Comparison of Ideal Dilution Curves for Various Laboratory or Field Exposure Regimes for Chemically Dispersed Oils or Water Accomodated Fractions.



planners sometimes base their risk perceptions (which is not analysis) on expected consequences (both negative and positive) of individual options, rather than a rigorous analysis of how all available response options could be combined to minimize ecological effects and encourage recovery, which could be facilitated by preparing an ERA. Opposition to dispersant use often focuses on toxicity of the dispersant, which is usually not the critical factor with the current generation of dispersants (Butler, 1992), and misses the central issue, which is whether or not the use of dispersants will enhance overall ecological protection and recovery, relative to other options.

Implementing an Ecological Risk Assessment Approach

How Does Ecological Risk Assessment Relate To Other Oil Spill Planning Considerations? Ecological consequences are only one element that risk managers (e.g. Federal or State On-Scene Coordinators, natural resource Trustees, industry emergency response managers) must consider. The use of ERA methods helps ensure that the ecological considerations are properly analyzed and presented, but they still must be integrated with other factors (social, economic, aesthetic, legal).

What Are The Necessary Steps To Conduct An Ecological Risk Assessment? Federal and state regulatory agencies and industry are all actively investigating or implementing ERA methods in support of their environmental programs. In the U.S., the primary Federal proponent of the approach is the Environmental Protection Agency (EPA). In 1996, EPA published "Proposed Guidelines for Ecological Risk Assessment", which is the basis for the following summary (EPA, 1996).

ERA includes three primary phases - problem formulation, analysis, and risk characterization. The first (problem formulation) involves identifying goals and assessment endpoints, preparing a conceptual model, and developing an analysis plan. In this stage, the early interaction of risk managers (spill response managers) and risk assessors (ecological or natural resource technical experts) to clearly define the problem is essential. Without this interaction, the results of the analysis may not be appropriate to aid in the management decisions. The development of assessment endpoints is critical. These are "explicit expressions of the actual environmental value that is to be protected" (e.g. reproductive success of anadromous fish or the size of a kelp bed). These can then be related to the potential stressors (in this case oil or response options, either alone or in combination) by developing a conceptual (or general) model which defines interrelationships between stressors, exposure, receptors and endpoints. Selection of appropriate endpoints influences all subsequent activities.

The analytical phase involves characterization of exposure and ecological effects. The conceptual model is used to direct the analysis. The result is a series of short reports which define and summarize the analysis for each component in the model.

Finally, a risk characterization is completed. This involves estimating and interpreting the risks in relation to the defined endpoints. In addition, the strengths, limitations, assumptions, and major uncertainties are summarized. A report is prepared which describes the results of the analysis.

After the risk assessment is completed, the risk managers must decide on how to integrate this information into the decision process, along with other relevant considerations.

How Can This Be Adapted To Support Oil Spill Response Planning? Conceptually, there are a number of ways to develop an ERA in support of oil spill planning. To encourage active participation by stakeholders, build consensus, and control costs Aurand (1995) recommended developing the risk assessment in a workshop environment where much of the analytical work can be completed by local technical experts and managers. The proposed process consists of two multi-day workshops separated by several months. At the first workshop, risk managers and assessors work together to define the problem, and then the assessment team develops the proposed endpoints, conceptual model and analytical approach. At the end of the workshop, specific analytic assignments are given to individuals for completion prior to the second workshop.

At the second workshop, the analysis and risk characterization phases are completed. An outline of the draft report is developed and then presented to the risk managers at the end of the meeting. This entire process will be facilitated by a management team which also coordinates the exchange of technical information and the development of working documents and the final report.

Who Needs to be Involved? In order to effectively adapt ERA protocols to oil spill response planning, it is essential that there be broad, multi-stakeholder involvement. Because of the nature of oil spill response and oil spill response planning, consensus-building is a critical element. This means that Federal, state and industry response managers, natural resource Trustees, environmental advocacy groups, and technical experts all need to participate. In addition, other groups, such as local government, concerned private citizens, and the press, must have access to and understand the process. Individuals who agree to participate in this process would be expected to support the analysis through:

- their attendance and participation at the workshop
- the identification and summarization of appropriate technical data, and
- the preparation of analytical papers or summaries needed to complete the risk assessment.

This means that individuals, or groups, would prepare overview material in their area of expertise for consideration at the first workshop, and would also prepare the data necessary for the risk characterization in the interval between the two workshops.

Key Considerations in Applying Ecological Risk Assessment Methods to Dispersant Use Planning. The typical ERA usually involves either (1) a single chemical being evaluated in advance of a decision to approve its use or release into the environment, (2) the determination of appropriate remediation strategies for a specific contaminated site, or (3) the evaluation of geographically limited, well-defined proposed action. In oil spill planning, the scenario is different in that the base stressor (the accidentally spilled oil) can vary dramatically, based on the type and amount of oil spilled, the effects of weathering, and on the circumstances, location and timing of the event, all of which are unknown in advance. The analysis must focus on evaluating scenarios which cover the expected range of incidents, and should provide information which can be tailored to meet the circumstances of a particular spill. If properly developed, such information will also be valuable in examining unexpected options during an actual response. Several major elements of this approach require some clarification, as discussed below.

Use of Endpoints. An endpoint is an explicit and measurable expression of an environmental value that is to be protected. The use of defined endpoints is a key element in the assessment process, and there must be agreement as to what constitutes an appropriate endpoint prior to the development of the conceptual model. The U.S. EPA terminology recognizes one type of endpoint, assessment endpoints. “Assessment” endpoint refers to effects at the population level or higher which are of ecological importance within the system under evaluation. It includes both an ecological entity and specific attributes of that entity. For example, it might be determined that a reproducing population of a particular commercial fish species is a critical assessment endpoint. Some literature on ERA recognizes a second type of endpoint, the measurement endpoint. The EPA approach defines this as one type of “measure” used to evaluate the assessment endpoint (EPA, 1996) and refers to it as a “measure of effect”.

Assessment endpoints are often difficult or even impossible to measure directly, especially in advance of the action under evaluation. In that case, “measures” must be identified to evaluate the risk hypotheses related to the assessment endpoints. These are identified in the analysis plan. For example, toxicity data for a single species (which can then be combined with life history and distribution information to estimate population effects) is an example of a “measure of effect”.

Assessment endpoints should have biological and societal relevance, an unambiguous operational definition, accessibility to prediction and measurement, and susceptibility to the hazardous substance. Assessment endpoints may include habitat loss or physical degradation of habitat below some effects threshold, as well as biological effects. All participants in the assessment process must accept the endpoint definitions.Susceptibility has two components, sensitivity and exposure. Sensitivity refers to how readily an ecological entity is affected by a particular stressor. It is related to the proposed mode of action of the stressor as well as to individual and life history stages. Exposure refers to co-occurrence, contact, or the absence of contact, depending on the nature of the stressor and the properties of the ecological entity in question. It is a central assumption of risk assessment that effects are directly related to exposure. Life history considerations are often very important in determining susceptibility, and can be very complex. Delayed effects must also be considered.

Consideration of management issues is critical in endpoint selection because, ultimately, the value of the risk assessment is determined by its ability to support quality management decisions. Managers find it easier to use the information if it is based on values or entities that people know about and understand. With planning, such considerations can be integrated into the assessment without compromising its relevance to the ecological system in question.

Conceptual Models as a Tool. The ERA should focus on the ecosystem or ecosystems at risk, not on individual species, and must be a comparative analysis of the risks and benefits of all of the response options. In order to accomplish this, a conceptual model is used. This model must describe the affected system in sufficient detail so that the major consequences of the perturbations can be defined. This does not imply that effective analysis must involve an in-depth knowledge of all components of the local environment. Rather, the assessment team must develop an understanding of the basic structure and functioning of the system so that analysis can focus on key components rather than just on the collection of data which will not facilitate the decision process. A list of basic characteristics of ecological systems relevant to conceptual model development during oil spill response planning includes (Aurand, 1995):

- **Complex Linkages -** ecosystem effects may be both direct and indirect.

- **Density Dependence -** effects may vary depending on the population density of a species with unexpected consequences for the ecosystem as a whole.

- **Keystone Species -** certain species play a major role in the structure of the system (i.e. framework corals in coral reefs, dominant tree species in mangrove forests, or predators which limit the population of an otherwise dominant species)

- **Time and Spatial Scaling -** some ecosystems are naturally patchy, others are continuous, seasonality may be an overriding consideration.

- **Uncertainty and Variability** - all ecosystems contain elements of randomness and uncertainty as well as variability, which can lead to unexpected events or consequences.

- **Cumulative Effects -** oil spills often occur in polluted areas or in combination with other environmental stresses.

- **Definition of System Boundaries -** the area which operates as a functional unit must be correctly defined, both in space and time.

The conceptual model, if responsive to these considerations, should be adequate to define the ecosystem(s) under consideration. The assessment team must balance the level of detail against available resources (including time and funding) and the type of information which will be of value in the decision process. Complexity which does not improve analytical utility must be avoided; the model will be of little value if it is incomprehensible to the planning community.

Definitions of Ecological Significance. Endpoint selection must include an evaluation of ecological significance. Determination of the ecological significance of an event requires that it be placed in the context of:

- the types of other anticipated events associated with the stressor
- the magnitude of the other events caused by the stressor
- its role in the structure and function of the system in question, and
- its relationship to other events within the system (cumulative analysis).

Harwell et al. (1994) define ecological significance as "the distinction that must be made for determining (1) whether a change that is detected or projected in the ecological system or its individual components of concern is a change of importance to the structure, function, or health of the system and whether the change exceeds a variance estimate (i.e., the context of natural variability) and (2) whether such a change in the ecological system is of sufficient type, intensity, extent, or duration to be important to society". Biological significance can be estimated by evaluating the importance of a change to a higher level in the organism or the ecological system's hierarchy (cell, tissue, organ system, individual, species, population, community, ecosystem) (Capuzzo, 1967; Suter, 1993). Determination of significance in any ERA requires that the ecological endpoints are appropriate. If the changes caused by the stressor do not involve the selected endpoints, then the change has no significance (Harwell, 1994).

Dealing with Uncertainty. Uncertainty can enter into all phases of an ERA. In detailed risk analyses, considerable effort is spent trying to quantify the sources of uncertainty. In oil spill planning applications, however, this analysis will almost certainly remain qualitative. The major areas of uncertainty are:

- conceptual model formation
- information and data
- natural variability (stochasticity), and
- error (in the sense of mistakes by participants) (EPA, 1992).

It is important to include natural variability in the analysis because it determines limits for the reliability of the assessment, which can be overwhelmed if natural variability is high (Smith and Shugart, 1994). In terms of the risk analysis phase, an evaluation of uncertainty will assist in the following ways (Smith and Shugart, 1994):

- an evaluation of the uncertainty associated with data or information helps rank the value of the information
- uncertainty analysis can help in choosing between approaches for analysis
- it can be used to identify and minimize weakness in models
- it can help choose between remedial actions
- helps determine the need for additional information, and
- can be used to develop a distribution of possible outcomes.

The development of the conceptual model early in the process requires that the study team identify the various components of the ecosystem in question and define their function. Since the data for this process is always incomplete, it involves summarizing information, making choices, and then defining the uncertainty associated with this process. It is fundamental to the risk assessment that the conceptual model be defensible, and part of this defense is a discussion of the uncertainties related to the factors important to the model (Smith and Shugart, 1994).

During the analysis phase, the two main components of error are the definition and modeling of exposure, and the definition of the ecosystem effects after an exposure or exposure regime has been defined. Estimating the error inherent in the exposure process is particularly difficult because of the range of factors involved, including frequency, duration and intensity of exposure, synergism or antagonism, and secondary effects. Inaccuracy in measuring the stressor (in this case the active components in oil) may be a significant source of error.

Once an assessment is finished it should be the best estimate possible available of the risk, but it is also important that the uncertainties associated with the estimate be explicitly discussed in the report. Smith and Shugart (1994) offered some suggested questions for consideration at this final phase:

- What led to the choice of endpoints and what are the consequences of this choice?
- What are the limitations of the existing data and how do they affect the assessment?
- Why were particular models chosen?
- Which model components are well-studied and which are not?
- What are the effects and limitations of extrapolations?

The Importance of Continuing Communication

A significant proportion of the historical controversy over dispersants related to the way information is presented to and interpreted by the various participants in the decision process. Once the ERA is complete, it is important to make sure that the results are effectively communicated to the response community and the public in order to ensure its proper interpretation and inclusion in the planning process. This must include consideration of the fact that, since major oil spills are very sporadic events, the participants may change between incidents, and in many cases they may only participate in response planning as a collateral, or secondary, duty.

The issues related to communication and perception were discussed by Lewis and Aurand (1997) and there have been many attempts to develop approaches that will help the response community stay abreast of new information. Workshops such as this represent one attempt to resolve such problems, and have proven to be generally successful. It is not possible, however, for workshops to identify and resolve all issues in a two-day period, and they do not address the need for continuous training. Further, only the participants can benefit from the experience and issues of bias are not totally avoided.

Currently available summary documents, such as the API (1987) publication on dispersant issues (Canevari *et al.* 1986). the Office of Technology Assessment (OTA) report "Coping with an Oiled Sea", published in 1990 (OTA, 1990), or the report series published by the International Petroleum Industry Environmental Conservation Association (IPIECA), which includes a volume on dispersants (IPIECA, 1993), are useful, but have not been fully successful because they are not part of an organized risk communication program. The reports discussed above are similar in nature, and will probably also be of the most benefit if they are widely disseminated as part of a broader education effort. In short, what is required is a cooperative, interactive, and long-term program of information dissemination, rather than a series of good, but sporadic attempts at issue resolution. In the United States, the most logical forums for this continuing education process are either the Area Committee or the Regional Response Teams.

How Does This Relate to Issues in Prince William Sound

The overriding considerations in advocating dispersant use are protection of sensitive shoreline habitats or the protection of marine mammals or birds offshore (NRC, 1989; McAuliffe, 1989; Baker, 1995). Both are significant concerns in Prince William Sound, but the former seems to be a more significant issue. As was clearly demonstrated in the aftermath of the *Exxon Valdez* oil spill, the economic and environmental costs are directly related to the type and extent of shoreline and nearshore habitat which becomes contaminated. Since there are large areas of Prince William Sound where deep water (affording good opportunity for dilution) is very close to shore, dispersants might offer significant benefits with little potential risk. This might be especially true for smaller spills, or if dispersants were used as a selective measure to protect specific resources. The data being collected in the integrated research program, especially that being obtained by the University of Alaska, should assist in such an analysis.

ERA can be a potential benefit by providing a mechanism of comparative analysis which can be generally applied in a variety of circumstance. The most significant advantage of this approach is its emphasis on an ecosystem approach and cross-media resource protection. It would also prevent the use of a "worst case" analysis for individual response options.

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Glossary

Acute Toxicity - adverse effects that develop in response to short-term exposure (relative to the animals life cycle) to high toxicant concentrations. Lethal endpoint (LC_{50}) tests fall within this category.

Chemically Enhanced Water Accommodated Fraction (CE-WAF): A lab prepared solution derived from the standard 20-25% vortex mixing of test material and chemical dispersant in which a relatively stable population of bulk material droplets (1-70 micron diameter) is present.

Chronic Toxicity - adverse effects that develop over long-term exposure (relative to the animals life cycle) to low toxicant concentrations. Life cycle tests and early life stage tests generally fall within this category.

Continuous Exposure: refers to a constant exposure in which the aim is a constant concentration. In this type of exposure, the organisms are placed in a chamber and exposed to a test solution for a certain time period. The exposure may be flow-through, static non-renewal, or static renewal (see definitions). The tests are typically carried out for 48 or 96 hours.

Continuous Flow-Through: refers to a continuous exposure in which the organisms are placed in full strength test solution in the flow-through test chambers. The pumps are turned on and the chambers are pumped with a constant concentration test solution (i.e.,- no dilution of the test solution occurs). When performing this type of exposure, care must be taken to assure that components of the test solution are not being lost through the tubing walls.

EC_{50} (Median Effective Concentration) - the amount of a toxicant that produces a specified effect in 50 % of the test population over a given time period. The effect that is used as the endpoint can be behavioral, physiological, cellular, etc. and is chosen by the researcher conducting the experiment. Endpoints that can be quantified (such as growth rate) are much more useful than those that cannot be precisely measured (such as erratic swimming).

Exposure - the term exposure refers to the amount of toxicant that the animal encounters. Exposure takes into account both the concentration of the toxicant in the water and the duration of contact to the animal.

Flow-Through Exposure - an exposure system in which water (and the toxicant) is continuously renewed at a constant concentration. This can also be referred to as a continuous flow exposure. Flow-through tests can be good estimators of toxicity in field conditions where there is a continuous effluent of the toxicant.

LC_{50} (Median Lethal Concentration) - the amount of a toxicant that produces 50 % mortality to a test population over a specified period of time. LC_{50} values are generally given for 48-hour or 96-hour exposure periods. LC_{50} values are meaningless without a reported exposure time.

Lethal Endpoint - a way of assessing the effects of a toxicity test by observing the degree of mortality within the exposed test animal population. Tests that have a lethal endpoint are commonly known as acute toxicity tests.

Physically Enhanced Water Accommodated Fraction (PE-WAF): A lab prepared solution derived from high to very high energy (≥25% vortex) mixing of test material and water only (no chemical dispersant) in which a relatively stable population of bulk material droplets (1-70 micron diameter) is present.

ppb - (part per billion) - a unit of measurement commonly used in toxicological testing; it equates to 1 microgram per liter of water (or 1 microgram per kilogram of solid material).

ppm - (part per million) - a unit of measurement commonly used in toxicological testing; it equates to 1 milligram per liter of water (or 1 milligram per kilogram of solid material).

Spiked Exposure - an exposure system in which the toxicant is initially present, and is subsequently diluted with addition of clean water. Spiked exposures probably give the most realistic estimate of toxicity in field conditions where there is a release of toxicant into well-circulated waters.

Static Exposure - an exposure system in which water (and the toxicant) is not renewed during the test. Static exposure tests often over-estimate toxicity because they do not account for dilution effects that would occur in field conditions.

Sublethal Endpoint - a way of assessing the effects of a toxicity test by observing a non-lethal response of the animal (such as erratic swimming or decreased food consumption). Tests that have a sub-lethal endpoint are known as chronic toxicity tests.

Water Accommodated Fraction (WAF): A lab prepared solution derived from low energy (no vortex) mixing of test material (an oil or petroleum product) which is essentially free of particulates of bulk material (>1 micron diameter).

Deriving Fate And Effects Information to Assess Petroleum Risk

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Abstract

Chemical risk is represented as the probability of an adverse outcome resulting from a chemical exposure. Petroleum certainly falls within the category of a chemical, albeit a complex mixture of chemicals. Risk, in its most basic form, is represented by the simple relationship of exposure divided by a measure of median potency, such as an LD50 or ED50. Therefore, in order to best assess petroleum risk it is imperative that both its potency, as well as exposure concentrations and frequencies, be measured. In addition, any factor influencing exposure, thus bioavailability, such as the presence of dispersants, must also be considered. Therefore, the California Office of Spill Prevention and Response and the University of California embarked on a collaborative research program several years ago to address questions of both potency and exposure. In doing so, the information may ultimately be used to assess petroleum risk to the marine environment, which will allow for the better management of potential impacts.

Introduction

The toxic actions of petroleum hydrocarbons in the marine environment have been of interest almost since the introduction of petroleum as a fuel source. A complex mixture of simple and branched alkanes, cyclohexanes, mono- and polycyclic aromatic hydrocarbons, and heterocycles, petroleum has been known to cause a myriad of toxic effects in marine organisms. Whether activated or not, petroleum hydrocarbons may alter nerve function, covalently bond with proteins and nucleic acids, and intercalate DNA bases, resulting in effects ranging from narcosis to death. However, a thorough understanding of potency alone will not allow us to best understand the actions of petroleum hydrocarbons in the marine environment.

Chemical risk is defined as the probability of an adverse outcome resulting from a chemical exposure. It is best described by the following simple relationship:

$$\text{Risk} = \text{Exposure} \div \text{Potency}$$

In such a relationship, potency is represented by a typical median-effect dose, such as an LD50 or ED50. Therefore, risk may be easily increased by either increasing chemical exposure (in terms of concentration and/or frequency) or by decreasing the median-effect concentration (thus increasing potency). Alternatively, it may be decreased by moving the exposure and/or potency numbers in the opposite direction.

In attempting to assess the effects of petroleum hydrocarbons on the marine environment, it is most appropriate to do so by estimating petroleum risk, which means it is necessary to measure both potency as well as its exposure concentration and frequency. In addition, it is also imperative that exposure be characterized, as not all hydrocarbons present may be realistically available for uptake by organisms (termed "bioavailability").

With marine organisms, petroleum bioavailability may be influenced by its aqueous form. For instance, treatment of spilled oil with surfactant-based dispersants may increase the functional water solubility of the hydrocarbons by reducing interfacial surface tension, but the resultant micelles may actually reduce the availability of hydrocarbons for uptake via passive membrane diffusion by marine organisms. Thus, an estimation of petroleum risk may be reduced with the presence of dispersants as they, in essence, reduce the available concentration of hydrocarbons; both exposure and measured potency are reduced.

In California, the Office of Spill Prevention and Response and the University of California are attempting to assess petroleum risk to marine organisms by measuring both hydrocarbon potency and exposure in the absence, versus the presence, of dispersants. The information will allow better management of the impacts of petroleum in the marine environment. This paper provides a brief review of the three projects we are currently undertaking, with pertinent references to provide additional information.

Surfactant Influence on Hydrocarbon Accommodation

Organismal exposure to petroleum hydrocarbons is significantly influenced by the use of surfactant-based oil dispersants. Therefore, we recently implemented a modified version of the Swirling Flask Test (SFT) as the standard method for evaluating the comparative effectiveness, as defined as the amount of hydrocarbon mass accommodated by the water column, of dispersants on petroleum hydrocarbons transported through California waters (Blondina *et al.,* 1997, 1998a). Use of such a "standardized ruler" provides for consistent and comparable data, a prominent aid to on-site oil spill decision making. The information derived may be used to estimate both comparative disperant efficacy, as well as dispersant influence, on the exposure of water-column organisms to petroleum hydrocarbons.

Implementation of the test involved modifications to address problems encountered with the existing SFT procedure as specified by the US Environmental Protection Agency (EPA). They involve the actual laboratory procedures, chemical analysis, and data reduction techniques. Primary differences between our modified methods and those of the EPA include the use of closed test vessels, chemical analysis via gas chromatography (with flame-ionization detection; GC-FID), and correction for dispersant contribution when estimating efficacy. The new procedures have been compared against those of the EPA to evaluate the relative efficacy of two dispersants, Corexits 9500 and 9527, with Prudhoe Bay crude oil (Blondina *et al.,* 1997, 1998a).

In addition, the influence of receiving water salinity on the effectiveness of Corexits 9500 and 9527 have also been investigated using our modified version of the Swirling Flask Test (Blondina *et al.,* 1998b). The dispersants were tested with 10 different oils (heavy to light varieties), representing a wide range of physical-chemical properties, with test salinities ranging from 0 to 35 ppt, and temperature held constant at 158C. Results showed Corexit 9500 to be generally more effective on most of the dispersable oils (medium and light varieties) at most salinities, but performance of both products was significantly affected by salinity. Both dispersants performed best at salinities above 25 ppt, with Corexit 9500 displaying a substantially wider range of salinities over which it was effective. Correlations between dispersant effectiveness and various oil physical-chemical properties were highly variable.

Such information provides an assessment as to what extent dispersants, as well as changes in salinity, influence the accomodation of petroleum hydrocarbons. In addition to providing an estimate of comparative dispersant efficacy, such information also provides an insight into the influence of dispersants on hydrocarbon bioavailability to pelagic organisms. In terms of the risk equation, this will improve our estimation of exposure. We are now in the process of describing the influence of temperature on dispersant efficacy.

Surfactant Influence on Hydrocarbon Bioavailability

In order to better understand the influence of dispersants on hydrocarbon bioavailability to aquatic organisms, we have also conducted numerous studies to determine whether micelle formation upon dispersion may inhibit hydrocarbon uptake at various levels of a model marine food chain. The information may help to address the question of whether spill dispersion increases hydrocarbon bioavailability to aquatic organisms, as commonly assumed or, due to micelle formation, actually decreases it.

Marine Phytoplankton

We have recently used the golden-brown algae *Isochrysis galbana,* a primary producer, to determine the influence of Corexit 9527 on the bioavailability of naphthalene (Wolfe and Tjeerdema, 1996; Wolfe et al., 1997a, b, 1998c). Cells were exposed to laboratory preparations of either the water-accommodated fraction (WAF) of Prudhoe Bay crude oil (PBCO) or a dispersed oil (DO) mixture of PBCO and Corexit 9527 spiked with radiolabeled naphthalene (NPH). Uptake was determined by the amount of algae-associated radiotracer. High-pressure liquid chromatography was used to fractionate and quantify metabolic products, and a 24-h bioaccumulation factor (BAF) was calculated in the absence of steady state.

The presence of Corexit 9527 had significant influence ($p<0.001$) on the uptake of NPH, but no significant effect on the 24-h BAF (168 and 180 from WAF and DO, respectively), or metabolic fate of NPH in *I. galbana.* Interestingly, the results indicate that dispersants have the potential to increase organismal exposure to certain petroleum hydrocarbons without increasing their aqueous concentration.

In addition, comparative studies have been completed to determne the influence of a dispersant on the bioavailability of NPH from crude oil to *I. galbana* under changing temperature and salinity conditions (Wolfe and Tjeerdema, 1996; Wolfe *et al.,* 1997a, b, 1998b). Conditions were selected to represent a range (two temperatures, 12 and 208C, and two salinities, 22 and 34 ppt) encountered in Pacific waters, where extensive crude oil transport and refining occurs; cells were exposed to laboratory preparations of either the WAF of PBCO or a DO mixture of PBCO and Corexit 9527 spiked with radiolabeled NPH.

Uptake was observed to increase by as much as 50% in DO (208C) exposures performed at 22 ppt (0.24 µmol NPH/g algae in WAF, 0.37 µmol NPH/g algae in DO). A 24-h BAF calculated in the absence of steady state indicated increasing bioaccumulation with decreasing temperature. No significant variation in relative metabolite composition occurred under the different experimental conditions. Results of these experiments showed that the use of dispersants enhanced the uptake of NPH by microalgae under a variety of temperature and salinity conditions, independent of aqueous concentration.

Marine Zooplankton

In general, use of chemical dispersants as oil spill cleanup agents alters normal behavior of petroleum hydrocarbons by increasing functional water solubility. The bioavailable fraction may be increased through higher hydrocarbon concentrations in the water column and altered interactions between dispersant, oil, and biological membranes. The objective of this research was to determine the impact of dispersing agents on hydrocarbon bioavailability and trophic transfer. Uptake, depuration, and metabolic transformation of the model hydrocarbon NPH were measured and compared for PBCO dispersed with Corexit 9527 (DO) and undispersed preparations of the WAF of PBCO (Wolfe and Tjeerdema, 1996; Wolfe *et al.,* 1997a, b, 1998a). The model food chain consisted of *I. galbana* as the primary producer and the rotifer, *Brachionus plicatilis,* as the primary consumer. Direct aqueous (AQ) exposure in both the algae and rotifers was compared with combined dietary and aqueous exposure (AQ&D) in the rotifers.

Results showed the uptake of NPH by rotifers was not increased significantly ($p>0.05$) in the presence of disperant. A significant ($p<0.01$) increase in depuration of NPH was observed in rotifers during DO exposures. However, uptake of NPH increased by up to 45% via trophic transfer in both WAF and DO exposures.

An unidentified metabolite was found associated with algae and rotifer tissues but not detected in controls or exposure media. It constituted an increasing percentage of radiotracer recovered in both AQ and AQ&D exposures and remained associated with the organism during depuration. Characterization of WAF and DO media again showed that aqueous concentrations of NPH were not significantly different. This research demonstrated that dispersants altered uptake and depuration processes for NPH, independent of water concentration, in representative species of primary trophic levels of a marine food chain, which may in turn modify bioavailility and bioaccumulation at higher trophic levels. In terms of the risk equation, the research approach allows a more realistic assessment of hydrocarbon exposure to pelagic organisms, which in turn will improve our estimation of overall petroleum risk.

Hydrocarbon Potency to Aquatic Organisms

The decision-making process surrounding the use of dispersants in oil spill response is necessarily an environmental cost-benefit analysis; both the toxicity and efficacy of proposed dispersants must be assessed and the consequences of both use and non-use of dispersants must be weighed for these environmental costs and benefits to be identified (Singer *et al.,* 1998). Therefore, an understanding of the effects of dispersants on natural oil toxicity is needed to provide an understanding of the consequences of their use as well as guidance about when they may, or may not, be appropriate. This understanding can only be achieved when the toxicity of the dispersant and oil alone, and in combination, are evaluated.

Through the use of standardized test protocols and species, and rigorous analytical verification, directly comparable estimates of the acute toxicity of different dispersants, oils, and dispersant-oil combinations can be generated, and thus provide a valuable tool for evaluating the potencies of this complex multiphase system. Over the past several years, and using such standardized protocols (Singer *et al.,* 1990a, b; Tjeerdema and Singer, 1991; Tjeerdema *et al.,* 1991; Weetman *et al.,* 1995), we have evaluated the acute effects of PBCO, Corexit 9527, and their mixture and found potentially significant differences between WAF and DO solutions (Singer *et al.,* 1996b, 1997; Singer and Tjeerdema, 1996, 1998). Care must be taken, however, in this type of evaluation, because of the significant qualitative (fractional) differences which contribute to the quantitation of these toxicants, and because of the possibility of arriving at different results with different analytical techniques.

While previous studies have emphasized the toxic actions of oil spill dispersants alone (Singer *et al.,* 1990b, 1991, 1992, 1993, 1994a,b; Singer and Tjeerdema 1994, 1995; Singer *et al.,* 1995a–c, 1996a), recently the acute effects of both untreated and Corexit 9527-treated Prudhoe Bay crude oil on the early life-stages of three marine species, the red abalone (*Haliotis rufescens*), mysid (*Holmesimysis costata*), and topsmelt (*Atherinops affinis*), have been investigated (Singer *et al.,* 1996b, 1997; Singer and Tjeerdema, 1996, 1998). Identification of whether WAF or DO was considered "more potent" was dependent on species, time, and endpoint (and by inference, test protocol). In general, the data showed that at roughly equivalent hydrocarbon concentrations WAF resulted in higher initial (narcotic) effects (<1 h) in mysid and topsmelt tests, whereas DO solutions elicited higher levels of larval abnormality in abalone tests, and mortality in mysid tests. While differences in test protocols existed among the species tested, topsmelt were the most sensitive species to WAF, with mysids being most sensitive to DO.

Returning to the risk equation, the studies of the types described above will provide the potency information necessary to better estimate risk, from both WAFs as well as DO, to the marine environment.

Conclusions

In order to best understand the environmental impacts of oil spills, it has become increasingly evident that we must take a closer look at petroleum risk, as the assessment of both potency and exposure are important to obtain a clear sense of the real actions of hydrocarbons in the marine environment. In addition, when assessing petroleum exposure it is crucial to address the issue of hydrocarbon bioavailability, especially when chemical dispersing agents are present. A complete understanding of petroleum risk will not only improve our ability to assess it, but to also manage it for the betterment of the marine environment.

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Alaska's Dispersant Effectiveness and Toxicity Testing Program

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Background

It is the policy of the state to conserve, improve and protect its natural resources and environment and control pollution, in order to enhance the welfare of the environment for the people of the state. Insuring that measures are implemented for the prevention of an oil spill is a key trustee responsibility. It's also imperative that when an oil spill occurs that adequate and appropriate response actions are taken to minimize the impact to the environmental.

The use of chemical dispersants in Alaska is considered as one of several response options for combating an oil spill. The decision to use a chemical dispersant involves balancing the potential harm of the ailment against the side effects caused by the treatment. Chemical dispersants are neither 100 percent effective nor 100 percent guaranteed. Field testing of most dispersants are not common, and various monitoring methods implemented to assess effectiveness do not often produce scientific or a technical consensus. Besides the normal questions of effectiveness and usefulness, there remain important questions about the effects of both the dispersant and the dispersed oil on the marine environment.

To better understand the potential impacts and consequences of dispersant application as an oil spill response option, it is important to have data which provides general information on toxicity, data that is specific to indicator organisms more indicative of the species found in Alaskan waters and Alaskan water conditions.

Toxicity Testing Program

The dispersant research being conducted under contract by the University of Alaska Fairbanks (UAF), for the State of Alaska is being coordinated through the Chemical Response to Oil Spills: Ecological Effects Research Forum (CROSERF). CROSERF is a working group composed of individuals from federal and state government, academia, and industry dedicated to improving laboratory and mesocosm research on ecological effects of chemical agents used for oil spill response. CROSERF is essentially a forum for the exchange of ideas and coordination of chemical oil spill research.

The toxicity studies being implemented by the UAF involve conducting a series of acute toxicity tests using Corexit 9500 in combination with Alaska North Slope crude oil on Alaskan species. The species selected are the standard EPA mysid and the Alaskan Tanner crab larvae (Chionoecetes bairdi). If funding, logistics, and availability allow another species will be gathered in Resurrection Bay, Alaska for possible testing. The Alaskan Tanner crab was selected because of commercial, economical and general sensitivity of the larva's stage to toxins. The EPA mysid species is standard and results obtained will be compared to the data results from the other universities/members within CROSERF. The dispersant Corexit 9500 was selected over Corexit 9527 because there is no cold water, toxicity data on Alaskan marine species for this product.

The CROSERF toxicity tests cover species that range in a suite from bacteria, algae, mollusc, copepod, mysid, yolk-sac fish and juvenile fish. The toxicity tests being conducted under the CROSERF protocols are the only standard tests where comparisons can be made between each participating organization.

Correlation of Toxicity Tests with the Microtox Test

One of the concerns associated with dispersant application, centers around the inability to provide quick and accurate measurements of potential toxic effects of the dispersant and dispersed oil-dispersant mixture in a "real-time" fashion. Toxicity tests take extended periods of time and can only provide relatively quick information on acute lethal toxicity. If dispersants are to become a viable response option in Alaska and the United States, there must be a way to monitor not only concentrations in the water column, but also potential toxicity in a quick, reliable and accurate way.

The American Petroleum Institute (API) has initiated some effort for investigating the Microtox Toxicity test as a real-time toxicity method. The method has compared favorably in sensitivity to traditional toxicity tests. Microtox analyzer utilizes a suspension of luminescent bacteria that emits light as a natural product of their metabolic processes. When exposed to toxic substances, the light emission is inhibited. The analyzer measures the degree of light reduction associated with the toxic sample water. To date, there are no data that compare Microtox method to the toxicity database being generated by CROSERF, nor are their studies that directly relate to Alaskan species with respect to the applicability and correlation of Microtox tests.

In addition to the standard toxicity tests, the UAF will be conducting a series of Microtox tests using the same concentrations as those in the acute toxicity tests. Information about the relationship between the data will provide a means for calibrating field derived results to laboratory data.

Effectiveness Testing

The UAF will be also conducting laboratory effectiveness testing of the dispersant Corexit 9500 on Alaska North Slope crude oil. The tests will involve looking at the effectiveness of dispersants with respect to temperature, time of application after the spill, amount of energy in the system when the dispersant is added, the amount of time between application and energy input, and the amount of dispersant added.

The project is separated into two phases. The first phase involves a review of literature for techniques and conditions under which dispersant effectiveness has been tested in the laboratory, as well as a review of in-situ, field-based, dispersant effectiveness measurement methodologies. The second phase of the project will involve laboratory testing of dispersant effectiveness by the "swirl-flask" method developed by the researchers working with CROSERF, as well as an optimal technique determined by the results of the project's first phase.

Biographical Sketch. Leslie Pearson serves as an Environmental Specialist within the Prevention and Emergency Response Program, Division of Spill Prevention and Response. Alaska Department of Environmental Conservation. Leslie has served with the department for the past 8 years, beginning with the Exxon Valdez oil spill and working within the department's oil spill prevention, response, planning and research programs. Leslie received a Bachelor of Science degree in Geology/Environmental Science from The Evergreen State College, Olympia, Washington and is presently pursuing a Masters of Science in Environmental Science at the Alaska Pacific University.

Monitoring the Effectiveness and Effects of Dispersant Operations

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Abstract.
Monitoring is systematic observation for purposes of management and decision-making. In general, in the U.S., the Regional Response Teams' dispersant use guidelines call for three types of monitoring: compliance monitoring; operational monitoring; and environmental effects monitoring. The purposes and methods of the former two types are becoming well understood, but there appears to be uncertainty concerning effects monitoring and at present there is little specific guidance to assist the practitioner. The available guidance for these types of monitoring regarding purpose and methods were reviewed.

Introduction
Now that dispersants are becoming more accepted for use in the U.S. and elsewhere, attention is being focused on operational aspects of their use, such as monitoring. In general, monitoring is systematic observation for purposes of management and decision-making. In the context of spill response, monitoring is conducted for a variety of purposes, including: protecting human health and safety; managing the spill cleanup; and managing environmental restoration and compensation activities. The monitoring of dispersant operations is conducted for all of these same reasons, plus certain additional, unique reasons as well. These unique reasons for monitoring relate to our uncertainty over the fate and impact of the dispersed oil. Dispersant monitoring has been addressed by a number of authors in recent years in both the technical literature and regulatory guidelines. This paper summarizes the information concerning the objectives of dispersant monitoring and the level of development of the methods.

Generally speaking, dispersant monitoring activities are conducted for three very different purposes: compliance; operational efficiency (which includes effectiveness monitoring); and environmental effects. These types of monitoring differ in terms of their technical challenges and level of development. Operational monitoring, in particular effectiveness monitoring, has received the most attention and there is considerable information concerning effectiveness monitoring in the open literature (e.g., Lunel et al. 1997, IMO 1995). Within Alaska, Alyeska Pipeline Services Company - SERVS has a detailed plan in place for monitoring dispersant effectiveness (Hillman et al. 1997). On the other hand, there is very little technical information available concerning environmental effects monitoring. Most of the existing material is to be found in the dispersant use guidelines of the various response regions (Regional Response Team (RRT) regions) in the U.S. This material is summarized in Table 1, below. Within Alaska, the RRT dispersant use guidelines contain no requirements for dispersant monitoring of any kind. State regulations, on the other hand, require that when cleanup methods other than mechanical recovery are anticipated, an environmental monitoring plan is required. However, there are no standards or guidelines to guide the planned effort. This paper deals with all three types of monitoring, but most of the discussion is devoted to environmental effects monitoring.

Compliance Monitoring

Compliance monitoring helps dispersant operations to comply with regional and state regulations for dispersant use and with pre-arranged and approved dispersant plans. In most jurisdictions little formal guidance is provided for compliance monitoring other than to specify the aspects of the operation to be monitored and who is responsible for conducting the monitoring activity. Generally, monitoring is conducted by trained observers from specified federal and state agencies, or in some cases by the responder. Monitoring objectives, criteria and standards are based on regulations or accepted standards of good operating practice including the following.

1. Brand of dispersant. The product used must meet state-specified acceptability criteria. In the U.S., this means that the product must be listed on the EPA Product Schedule.

2. Application method, dilution rate and application rate. The product must be applied at the the minimum effective dosage, in the form of an even spray of fine droplets.

3. Location of application. The use of the product is restricted to specific geographic areas specified by regulatory agencies.

4. Wind/wave conditions. Approval is contingent on there being sufficient mixing energy to ensure efficient dispersal.

Operational Monitoring

Operational monitoring involves observing the operation and the behavior of the oil in order to ensure that the dispersant application is effective and as efficient as possible. Historically, it has been effectiveness monitoring that has provided the greatest technical challenges. The subject has received considerable attention from research teams in the U.K. and Norway (Lunel 1994, 1995, Lunel et al. 1997). Other aspects of operational monitoring have proven less technically challenging and methods are described in operating plans (e.g., Alyeska Pipeline Service Company 1995). This section focuses mainly on effectiveness monitoring.

Effectiveness Monitoring

The purpose of effectiveness monitoring is to assess whether the patch of oil that is being sprayed is dispersing more quickly with dispersants than without. This type of monitoring is necessary because, even though a slick may be amenable to dispersion early in the spill, it may become completely resistant to dispersion within a matter of hours or days through the processes of weathering and emulsification. Monitoring determines whether the target patch of oil continues to be dispersible over time. When a patch of oil has clearly become resistant to chemical treatment, it is pointless to spend further time and product trying to disperse it, and the operation moves on to target another patch of oil or to change spill control strategies. There are two approaches to effectiveness monitoring: (1) monitoring the rate of disappearance of the treated slick, and (2) monitoring the behavior of the oil that has been dispersed into the water.

Monitoring the disappearance of the treated slick involves observing it to determine whether or not it is disappearing more quickly than a similar, untreated one. This can be done by observing the treated slick from the air, either visually or by remote sensing. At present, there does not appear to be an accepted, documented approach for this kind of monitoring. In the U.K., where effectiveness monitoring by aircraft observers and instruments is regularly performed, the key to success is said to be the judgement of a thoroughly trained and experienced observer (MacLeod 1995).

The second approach to effectiveness monitoring involves observing and/or measuring oil in the water under slicks. This is done either through visual observation from the air or by direct measurement of oil in the water using in-situ fluorometry. The simplest method is through visual observation (Lunel et al. 1997). This involves looking for a “coffee-with-cream”-colored cloud of dispersed oil droplets in the water in the vicinity of the treated slick. This approach is not always reliable because the plume may or may not be visible depending on a variety of factors (Lunel et al. 1977, IMO 1995). The more rigorous method involves directly measuring the concentration of oil under slicks before and during treatment. This method is based on the fact that physically dispersed oil behaves differently from chemically dispersed oil. In the former case, the dispersed oil is present in the water in the form of large droplets which, because of their buoyancy and large size, float very quickly to the sea surface and seldom mix deeper into the water column than one meter. In the chemically dispersed case, the oil is in the form of very small droplets. The droplets do not resurface, but remain in the water and are mixed quickly down to a depth of several meters. Measurements of the concentration and distribution of oil in the water column are conducted using flow-through fluorometry, with on-site calibration, and post-event verification by means of gas chromatographic analysis (Lunel 1998, these proceedings). This approach to monitoring is the basis for the NOAA - U.S. Coast Guard Gulf Strike Team monitoring plan, “Special Response Operations Monitoring Plan (SROMP)” (NOAA-GST 1994), as well as the next generation of monitoring plans currently under development.

Other Operational Monitoring

Other aspects of operational monitoring involve ensuring that the equipment and operators are performing effectively. Two important aspects to be monitored are the quality and accuracy of the spray. The dispersant droplets must be of appropriate size and the spray must be distributed evenly across the swath in order to achieve effective mixing of the dispersant droplets with the slick and accurate dosage control. Most importantly in aircraft operations, the spray must fall on the desired target. The effects of winddrift and overspray must be minimized to avoid wasting dispersant product. These factors are monitored visually.

Environmental Effects Monitoring

Environmental effects monitoring involves assessing the impact of the spilled oil on specified biological targets. Monitoring is conducted for a variety of purposes using a variety of methods as described below. Although effects monitoring is required or recommended in a number of jurisdictions, very little specific guidance is currently available. Within the U.S., the RRT guidelines provide some direction (Table 1), but this guidance is very general and lacks details of purpose, methods and uses of the output data. Internationally, the situation is the same, in that even jurisdictions that actively use dispersants or are active in dispersant research, such as the U.K. and Norway, have not yet developed dispersant-specific monitoring plans (R. Law, pers. comm., P. Daling, pers. comm.). As mentioned above, in Alaska , state regulations require that an environmental monitoring plan be prepared when cleanup methods other than mechanical recovery are used. However, there are no standards or guidelines to guide the monitoring effort. This lack of a clear, well thought out vision of the purpose of monitoring will handicap operators in their efforts to address the concerns of stakeholders and government regulators at spill time.

On the other hand, there is a considerable literature on the subject of marine environmental monitoring in general (NRC 1990, ICES 1996), as well as on monitoring of pollution incidents (e.g., natural resources damage assessment). In addition, there is considerable, well documented experience with the environmental effects monitoring of oil spills (e.g., *Amoco Cadiz*, *Exxon Valdez*, *North Cape*, *Braer*) and there is now at least one example where dispersants were heavily used (*Sea Empress*). This section summarizes the guidance concerning the purposes and methods of effects monitoring for dispersants. It also considers whether there are any unique objectives or approaches to monitoring that might be required for dispersant operations.

Purposes of Effects Monitoring

Dispersant operations could be monitored for the same reasons as conventionally-treated spills, but there are unique reasons as well. The purposes that are common to all spills regardless of treatment include:

1. providing information upon which to make decisions concerning secondary spill countermeasures such as closing and opening fisheries;

2. providing information to stakeholders on impact on important ecosystem components or economic resources (e.g., coral reefs, herring eggs/larvae); and

3. providing information for post-event activities such as natural resources damage assessment and planning restoration.

Although the purpose and general approach to these monitoring activities might be the same in both dispersant treated and untreated spills, in dispersed spills the sampling plans are greatly altered to take into account the altered fate of the oil.

However, dispersed spills are monitored for at least two unique purposes, as specified in the dispersant use guidelines for the U.S. Regional Response Team Region II. These are:

1. to assist natural resource trustees by providing them with information crucial to their impact trade-off decisions; and

2. to provide responsible officials with support in post-incident assessments of their decisions.

Monitoring is necessary because of the uncertainty surrounding the potential fate and short-and long-term impact of dispersed oil. In short, dispersants alter the fate the oil, driving it into the water column, and increasing risks to species in the water column that would be at little risk from an untreated spill. It is believed, based on scientific evidence, that the risks from dispersant use are modest. However, we have very little practical experience with full-scale dispersant use on actual spills and there is therefore considerable uncertainty surrounding their actual impacts. Until experience is gained in using dispersants in real spills, monitoring will be needed to verify that the impact of dispersed oil is as predicted and that there are no unanticipated environmental complications.

Many responders and regulators agree that effects monitoring is not conducted for purposes of managing the cleanup operation, but rather for other spill-related and policy-related purposes. This has two important implications. First, from a spill management perspective, the simple appearance of toxic effects should not cause regulators to suspend dispersant operations. Rather, the potential for some toxic effects has been anticipated by regulators and has been taken into account in assessing the environmental trade-offs in the spill in question. Second, the fact that effects monitoring may not be used to control the dispersant operation has important implications for the monitoring methods. Because data concerning effects are not required on an immediate basis to control the operation, as are effectiveness data, monitoring techniques need not provide immediate results in the same way that effectiveness monitoring methods do. Rather it is sufficient for methods to produce results within days or even weeks after the spraying activity itself.

Methods of Effects Monitoring

The methods of effects monitoring must be appropriate for the purpose and target. The purposes are described above. The targets vary somewhat from region to region, but generally the target species reflect the concerns that have been voiced by stakeholders for decades and include:

1. species and habitats in shallower nearshore waters;

2. benthic species and habitats in deeper nearshore waters; and

3. pelagic species in surface waters.

The approaches to monitoring described in the various dispersant use guidelines are of three types:

1. observing effects and contamination;

2. measuring exposure; and

3. conducting bioassays.

The available guidance for each of these methods is described below.
Direct Monitoring of Effects and Contamination. Direct monitoring involves measuring the actual effects of the dispersant operation on the target biota. Various RRT guidelines call for observing pre-selected indicator species and habitats, analyzing them for mortality, sub-lethal effects, indices of exposure to hydrocarbons, and hydrocarbon contamination of tissues. In future spills, monitoring conducted for routine purposes (e.g., closing and re-opening of fisheries) can make use of traditional methods for which there is already considerable guidance and experience (e.g., Law et al. 1998, this volume). For example, for monitoring activities conducted to support the closure and reopening of fisheries, the objectives and methods are well documented (e.g., ASTM 1968, Law et al.1988, Mauseth et al. 1997, Mearns and Yender 1997, Poste et al. 1991, Shaw et al. no date) and there is considerable practical experience (ESGOSS 1994, Goodlad 1996, Law et al. 1998 this volume). These methods are used routinely for monitoring impact on benthic and pelagic species and habitats in both deep and shallow waters and should be appropriate for many dispersant-related needs.

However, there is little guidance available for monitoring the unique targets of dispersed oil, such as species in the upper water column. Impacts on the water-column community, particularly pelagic eggs and larvae of commercial fish species, have concerned stakeholders in the past. However, impacts on this community in deeper offshore waters have been largely disregarded on the assumption that they would not be significant and would be impossible to detect. However, such effects might not insignificant in semi-enclosed systems, such as Prince William Sound, especially when the potential targets are the ecologically important seasonal blooms of plankton or eggs/larvae of economically important fishery species. Monitoring for effects on these species poses challenging technical problems since organisms are small, challenging to work with, and sensitive to handling. In addition, evidence of effects on this community is ephemeral. Several authors have approached this problem in the past with some success (Lee and Nichol 1977, Crippen and Perrier 1974). However, in the absence of proven techniques for dealing with certain of these problems, planners appear to be looking to alternative methods, such as exposure monitoring and bioassays for assessing potential effects. These methods though indirect, pose fewer technical challenges than direct monitoring in the water column.

Exposure Monitoring. Exposure monitoring for dispersed spills involves monitoring the ambient hydrocarbon levels in water and sediments near the dispersed slicks in order to infer whether effects might have occurred. The procedure involves three steps:

1. measuring concentrations and persistence of dispersed oil in the water and seabed sediments at and near the locations where dispersants are applied;

2. determining the species at these locations at the time of the exposure; and

3. comparing the exposure conditions for each species/lifestage with information on its sensitivity to dispersed oil in order to infer whether effects might have occurred.

This approach is technically challenging because it requires making large numbers of measurements of oil concentrations at many locations within a short span of time. The approach appears to be feasible, however, through the use of flow-through fluorescence methods calibrated against gas chromatography. This approach has at least two important limitations at present. First, although the toxicity of dispersed oil has been determined for a variety of species over the past decades, there remains a very wide variety of species for which specific toxicity information is not available. Second, chemically dispersed oil is a complex mixture of hydrocarbon compounds present in both particulate and dissolved form, whose composition changes with time as the oil weathers. The toxicity of the dispersed oil will vary somewhat with the composition of the oil. Fluorescence methods yield only a crude approximation of the level of hydrocarbons present, but provides no information concerning the chemical composition or its changes. Therefore, there is uncertainty associated with the inference of toxicity from fluorescence data. Overall, however, the method appears to be adequate for making crude assessments of the potential presence, absence and spatial extent of effects. In-situ fluorescence has one decided advantage in that the technique is already being used during chemically dispersed spills for both effectiveness monitoring and to monitor the spatial movement of dispersed oil in order to support other effects monitoring activities.

Additional reasons for monitoring the behavior of dispersed oil are: to verify the existing model of the behavior of dispersed oil upon which our current appreciation of risk is based; and to establish a cause-effect linkage between any observed environmental effect and the dispersant operation. Flow-through fluorescence methods augmented by gas chromatography appear to be adequate for monitoring the rapidly changing conditions within the water-column for these purposes. Monitoring hydrocarbon contamination in the seabed pose unique challenges. However, when sediments become contaminated with spill-derived hydrocarbons through sedimentation, the contamination is less ephemeral than in the water column and can therefore be monitored using existing methods for measuring hydrocarbons in seabed sediments.

Bioassays. Bioassays are standardized tests in which specific organisms are exposed to samples of environmental media to assess their potential for causing effects. This approach is suggested in at least one RRT Region (Region II), for contaminated water and sediments. However, guidelines offer few details of purpose or methods. Bioassays appear not to be used to estimate the effects of conventionally treated oil spills, but a variety of methods are being considered for assessing the effectiveness of shoreline cleanup methods (Mearns et al. 1995, 1997). In dispersant operations, bioassays might serve as a supplement to exposure monitoring by providing verification that exposure media may be toxic. Bioassays would address, to some degree, the uncertainties in inferring effects from measurements of hydrocarbon concentrations alone. Their usefulness for this purpose requires knowledge of the sensitivities of the target species/life stage and the bioassay test organism to dispersed oil. At present, an almost complete lack of data in this area is a major handicap. Some work has been devoted to developing and testing certain methods such as the Rototox M test, Microtox test, oyster embryo development test and copepod lethality test (Coelho et al. in press, Dunn et al.1994). The Microtox test appears to be one of the more useful candidate tests in terms of sensitivity operational feasibility and cost.

Summary

In general, in the U.S. the Regional Response Teams' dispersant use guidelines call for three types of monitoring in dispersant operations: compliance monitoring; operational monitoring; and environmental effects monitoring. The purposes and methods of the former two types are becoming well understood, but there appears to be uncertainty concerning effects monitoring and at present there is little specific guidance to assist the practitioner. The available guidance for these types of monitoring regarding purpose, methods and uses of the output data were reviewed.

1. Compliance monitoring is intended to ensure that dispersant operations are conducted according accepted standards of practice and within regulatory restrictions. These standards address the type of dispersant used, how and where it is applied, and the physical environmental conditions under which is used.

2. Operational monitoring is intended to assist in making the dispersant operation as effective and efficient as possible. The spraying operation is observed to ensure that spraying equipment is performing properly and that the spray is on target. The behavior of the treated oil is observed by aerial and in-situ methods to verify that the oil is dispersing more quickly with chemical dispersion than without treatment. A variety of methods are available, but monitoring of the behavior of oil in the water under slicks using in-situ fluorescence appears to be the most reliable.

3. Environmental effects monitoring assesses the presence or absence of effects on specific biological targets for a variety of purposes. When effects occur monitoring determines the magnitude and duration of effects. Effects monitoring is performed during spills whether dispersants are used or not, for reasons that range from controlling the closure/reopening of fisheries to conducting a natural resource damage assessment. However, monitoring of dispersant operations is conducted for at least one unique reason. That is that there is a high level of uncertainty surrounding the environmental fate and effects of chemically dispersed spills because we have little experience with dispersant in real spills. Monitoring verifies that the effects are as predicted and that there are no unanticipated impacts.

RRT dispersant use guidelines mention three different approaches to effects monitoring. In most cases little guidance is provided concerning the specific purpose or method of monitoring or of the use of the resulting data.

Direct observation involves observing pre-selected target species for evidence of effects or contamination. Effects on certain target species, such as shellfish, finfish or habitat species (e.g., seagrasses) might be monitored using a variety of well established methods. Other targets, such as water column species, are more challenging to monitor. New methods must be developed in order to monitor these species directly or the following two indirect methods might be used.

Exposure monitoring has been suggested for use in inferring the occurrence of effects where the effects themselves cannot be observed directly for whatever reason. This approach involves first measuring the level and duration of exposure to dispersed oil in the environment and then inferring possible impacts based on the sensitivity of species as determined in laboratory toxicity tests. The proposed approach for measuring exposure levels, continuous flow fluorometry supported with gas chromatography appears to be feasible, but the approach has two important potential drawbacks.

Bioassays are a second alternative for inferring the occurrence of effects when direct observation is not possible. To date, the Microtox bioassay method appears to be the most promising. However, although the approach appears to be operationally feasible, there is an almost complete lack of data correlating the sensitivity of the test to the sensitivity of important biological targets.

Table 1. Dispersant Monitoring Requirements in the U.S. as per RRT Regional Dispersant Guidelines				
Jurisdiction	Compliance Monitoring	Effectiveness Monitoring	Effects Monitoring	Ref.
RRT Region I - ME, NH	- no formal plan in place	- no formal plan in place	- no formal plan in place	1
RRT Region I - MA, RI	- no formal plan in place	- no formal plan in place	- no formal plan in place	2
RRT Region II - NY, NJ	- yes - visual - responsibility - responding party, USCG, states	- yes - trial application - method - visual, airborne and surface - responsibility, USCG, NOAA	- yes - exposure monitoring, measuring exposure concentrations in water - observe pre-selected indicator organisms or habitats for effects when organisms are known to be exposed to injurious concentrations - monitoring for contamination: conduct analysis of oil concentrations in biota and/or habitat; - conduct bioassays of dispersed oil in water and sediment - minimum monitoring effort includes: a. measurement of dispersed oil with fluorometer b. concurrent recording of physiochemical measurements - responsibility not specified	3
RRT Region II - Caribbean	-no	-yes - based on SROMP(7) - visual - in-situ metering (e.g., fluorescence)	- yes - exposure monitoring, measuring exposure concentrations in water	4

Table 1. Dispersant Monitoring Requirements in the U.S. as per RRT Regional Dispersant Guidelines

Jurisdiction	Compliance Monitoring	Effectiveness Monitoring	Effects Monitoring	Ref.
RRT Region III DE, MD, VA	-yes	- yes - visual - tube test on oil - trial application in authorized zones	- yes - exposure monitoring , using the "6-point protocol" - measurements include: fluorimetry, grab samples of water, physio-chemical parameters in water column - sediment grab samples in nearshore areas for assessment of hydrocarbon contamination - benthic biota sampled in nearshore areas for hydrocarbon contamination	5
RRT Region IV - NC, SC, GA, FL, AL, MS	-no	- yes, SROMP (7) - visual - fluorometry, at depth of 1 meter - sampling pattern described - grab samples of water collected for confirmation	- yes - exposure monitoring in water	6
RRT Region VI - MS, LA, TX	-no	- yes, SROMP (7) - visual - fluorometry, at depth of 1 meter - sampling pattern described - grab samples of water collected for confirmation	- exposure monitoring	8

Table 1. Dispersant Monitoring Requirements in the U.S. as per RRT Regional Dispersant Guidelines				
Jurisdiction	Compliance Monitoring	Effectiveness Monitoring	Effects Monitoring	Ref.
RRT Region IX CA	- yes - no specific guidance (Dec. 31, 1997)	- yes - no specific guidance (Dec 31, 1997)	-no	9
RRT Region X HI	-no	- visual, airborne visual assessment by qualified observers	- exposure monitoring in water column; concentrations of dispersed oil in water column measured using grab samples -in-situ measurement of dispersed oil concentrations by fluroescence - exposure monitoring, exposure conditions in water and sediments; - monitoring for tissue contamination, tissue burdens of hydrocarbons in benthic organisms.	10
RRT Region X WA	- no.	- no	- no	11
RRT Region X OR	-no	-no	-no	11
RRT Region X AK	-no	-no	-no	12

Table 1. Dispersant Monitoring Requirements in the U.S. as per RRT Regional Dispersant Guidelines

Jurisdiction	Compliance Monitoring	Effectiveness Monitoring	Effects Monitoring	Ref.

1. Anonymous.1995 Maine/New Hampshire Preauthorization for Dispersant Use.
2.Anonymous.1995. Massachusetts/Rhode Island Dispersant Pre-authorization Policy.
3. Memorandum of Understanding Among U.S. Coast Guard Distr. 1., U.S. EPA Reg II, U.S. Dept. Int., U.S. Dept. Comm., New Jersey, New York Concerning Chemical Countermeasure Preauthorization in COTP NY and COTP LIS Zones.1994. And RRT II Dispersant Use Monitoring Concepts. November 1995.
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5. Memorandum of Understanding between U.S. Coast Guard District 5, U.S. EPA Region III, U.S. Dept. Comm., U.S. Dept. Int., Delaware, Maryland, Virginia. 1997. and Annex iv Dispersant Monitoring Protocol
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9. California Department of Fish and Game. 1997. "Quick Approval Zone" Plan.
10. Letter of Agreement between U.S. Coast Guard, EPA and the State of Hawaii Concerning the Preauthorized Use of Dispersants. Appendix II. Monitoring Plan.1991.
11. Northwest Area Committees.1996. Northwest Area Contingency Plan. Section 7.1 Dispersants.
12. The Alaska Federal/State Preparedness Plan for Response to Oil and Hazardous Substance Discharges/Release. Unified Plan. May 1994. Annex F. Appendix I. RRT Oil Dispersant Guidelines for Alaska.

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PANEL DISCUSSIONS

Introduction to Panel Discussions

The second day of the conference was devoted to five, one-hour panel discussion sessions. Four of these sessions addressed technical subjects and the fifth session, the “Stakeholder Panel,” addressed the positions and concerns of five stakeholder groups.

The four technical panels addressed the subjects: a) dispersant effectiveness; b) fate of dispersed oil; c) environmental risks associated with dispersant use; and d) environmental effects monitoring of dispersant operations. Each panel was made up of from four to six technical experts and the purpose of the discussion was to allow participants to state their concerns about the subject and question the technical experts. The role of the technical experts was to respond to questions and to provide information, where possible, to address the concerns of the participants.

The Stakeholder Panel was composed of one representative of each of five important stakeholder groups, including: industry, government, the response community, the fishing community and the Native Community. The purpose of the session was to allow the panelists to state and discuss the position and concerns of the their respective groups.

In order to document the results of the panel discussions, the sessions were recorded electronically and a verbatim transcript was prepared. The transcript was then edited in the interest of brevity and readability.

Panel #1: Potential Effectiveness of Dispersants in Prince William Sound

Chair: Dennis Maguire

Panel Members: Per Daling, Merv Fingas, Carl Lautenberger, Alun Lewis, Sy Ross

DENNIS MAGUIRE: In many ways we saw this as the big question, "Do dispersants work?" There are a lot of issues surrounding this question. So think about the questions that you want addressed. We have here the distinguished body of experts needed to address them.

What we would like to do is this. Those members of the panel who did not have an opportunity to make a formal presentation will have a few minutes to speak now. So Merv Fingas and Carl Lautenberger will make presentations. Then we will open up the discussion and take comments from the floor.

CARL LAUTENBERGER: The term "effectiveness" means different things to different people and it is important to be specific about what we mean. Effectiveness can be measured in the laboratory or in the field. When dealing with field trials or real spills, are we specifically talking about the intrinsic ability of the chemical to the dispersed oil, and if so, what are we comparing that against? Are we comparing that against the whole volume of the spill or the targeted amount of oil that was intended to be dispersed? The different measurements are used for different purposes, so it is important to be clear about the definitions.

MERV FINGAS: This discussion relates to laboratory effectiveness testing. If you do not take anything else home from this, I want you just to remember one thing. If somebody gives you an effectiveness value, make sure to specify the test conditions (e.g., energy, temperature). Effectiveness is a function of a many factors. They're grouped into two sets as summarized in Table 1. One set is called fundamental factors, such as oil composition, energy, and temperature. The second group is application factors, such as oil viscosity, hitting the target and dosage (Table 3).

Effectiveness is influenced by a variety of factors and the effectiveness always is the combined effect of many influences. Energy is the single most important factor in determining dispersant effectiveness. Some energy is required for effective dispersion and within limits the greater the energy, the greater the effectiveness. Oil composition is also important. For example, some oils like Bunker C are not dispersible. From the perspective of dispersant effectiveness, composition can be characterized by the relative proportion of saturates in the oil (Table 2). Salinity also has a major effect on effectiveness. Products that are formulated for saltwater are not effective at low salinities. Effectiveness increases with the amount of dispersant present, but declines with temperature.

SY ROSS: ANS oil has been tested extensively by many researchers, but for a long time it was believed that ANS was not a good candidate for dispersion because it appeared that it emulsified quickly and became resistant to chemical dispersion. However, the results of the emulsification tests showed that there is a substantial time window for effective use of dispersants with Alaska North slope (ANS) when spilled. For large spills our models predict that the time window could be two to

Table 1. Factors Controlling Effectiveness

- **Fundamental Relationships**
  1. Oil composition - see Table 2
  2. Sea energy - single most important factor after oil composition
  3. Salinity - each dispersant is effective over only a range of salinities
  4. Temperature

- **Application Factors**
  1. Oil viscosity
  2. Hitting the target
  3. Dosage
  4. Herding

Table 2. Effect of Oil Composition

- **Dictates the amount that disperses at a given energy**
- **Some oils will never disperse (e.g., Bunker C)**
- **Composition effect can be viewed as "Saturates minus Everything Else", where Everything Else includes aromatics, asphaltenes, resins and waxes**

Table 3. Application Factors

- **Hitting the target**
  - tests show about 50% good
- **Dosage**
  - generally between 1:50 and 1:25
- **Herding**
  - major problem
- **Oil Viscosity**
  - causes poor mixing with dispersant and possibly herding

three days. So there is a general view that the ANS is really quite a good candidate for dispersant use.

You have an advantage here in Prince William Sound (PWS) in that you only have one oil to worry about. This is in contrast to Britain which has dozens and perhaps hundreds of different oils that they have to worry about. You can focus on one oil and understand it very, very well.

QUESTION: By the time the oil gets to Valdez through the pipeline, it's pretty well mixed, but there's a whole bunch of different fields. I think somebody needs to take a look at the changes in the pipeline oil over time to see if it's dispersibility changes over time.

SY ROSS: We've been tracking the properties of North Slope oils, individually and blended stock, for a long period of time. There is a change in the properties in the oil over time. As it turns out, the change is for the better. The oil seems to be getting slightly lighter in properties and not heavier. That's just a function of the new fields that are coming on stream and the particular properties of their oils.

MERV FINGAS: I don't fully agree. We've tested several hundreds of oils for dispersability and ANS is certainly below average, but it doesn't necessarily mean that it's a bad candidate. We've also test the whole variety of the North Slope mixes all the time. There isn't that much difference among them with respect to dispersibility. They're sister oils anyhow. Over time we've actually seen the dispersability go down. That's the usual way a reservoir goes.

BRUCE MACKENZIE: We now inject a chemical called drag reducing agent (DRA), into the oil before it goes into the pipeline. This has an effect on the dispensability of that oil, and that's what Sy is referring to. We haven't verified that that's the cause of the oil being a little bit more amenable for dispersion. I also think that the oil doesn't emulsify as rapidly as the oil that was coming down that pipeline five years ago.

PER DALING: We also have tested batches of ANS from different years. There are some changes and I'm seeing the same trend that Sy Ross has seen that the recent samples of oil seem to be lighter, but that's only based on three samples from three different years.

ALUN LEWIS: Our offshore test spill was done very recently on ANS. In that test ANS was shown to be a good candidate for dispersion. However, there are some factors which were not realistic in the Alaskan context. We were operating at a higher sea temperature than you have here, but that actually causes the oil to weather faster so it would not actually make much difference to the window of opportunity for effective dispersion.

DENNIS MAGUIRE: In a low energy environment, what do you do with dispersants?

TIM LUNEL: There are two things to bear in mind when considering dispersant use under low energy conditions. First, although you must have at least some energy for dispersants to work, you do not need breaking waves. Dispersants do increase the rate of dispersion even at low energy levels, but the absolute rate of dispersion will not be as great as at higher energy levels. The second consideration, is that even at low sea states, dispersants will prevent the formation of water-in-oil emulsion. This effect will only work however, as long as the surfactants remain with the oil and the length of time that the dispersant stays with the oil is not well understood.

DENNIS MAGUIRE: I am not sure logistics is an aspect of effectiveness that we want to address. In Alaska we are fortunate in that the logistics capability that Alyeska maintains is excellent. We have two C-130's, we have over 60,000 gallons of dispersants here in Anchorage. We have a barrelling capacity, we have two ADDS pack units that are well maintained, well exercised.

In terms of tools that are available in the Aleutians, dispersants are about one of the only tools that can efficiently and quickly get out there to deal with spill situation. Dispersants are a tool for Alaska because Alaska has many remote areas and the threat of oil spills is not just from tankers. With dispersants in aircraft we can respond to spills from passenger and freight vessels which seem to go aground often in far flung regions of Alaska.

GEOF MERRELL: As far as the Aleutians are concerned, Alyeska maintains a memorandum of understanding with the Coast Guard, so if we have an event that is outside the Alyeska realm of activity, we have a cooperative relationship with Coast Guard to use their planes to respond. That kind of cooperative arrangement also extends to training and exercising.

QUESTION: When you start talking about working out on the Aleutians, an awful lot of your fuel is going to be burned in the aircraft in just getting there before you can begin to spray dispersant. I wonder what sort of contingencies you have for getting large quantities of dispersants out to the Aleutians and what sort of facilities are available out there for reloading the tankers? I don't think it's practical to think that you can load a tanker here and fly off to the Aleutians somewhere and do one quick run and then turn around and then have come all the way back and reload.

GEOF MERRELL: The question of logistics depends on geography. To begin with, all of our dispersant and spray equipment are in Anchorage. There is a point beyond which one cannot fly the chemical in the plane because of the fuel limitations. So you have to fly the plane there empty, load the chemical, spray, reload, etc. Obviously this kind of operation requires more than one aircraft. With the Coast Guard's six C-130s in Kodiak, this multiple aircraft scenario is not too much of a problem. We have two C-130s under commercial contract. If we have to fly, load and then spray, we will fly to either Dutch Harbor or Adak and stage from there. You double your material handling problem but neither handling nor fuel are problems at these locations.

BRAD HAHN: When working in the Aleutians, logistics is only one issue. The other consideration is we will be dealing with a different oil, namely heavy fuel oil. My question is, how did the field trials conducted last summer indicate how well dispersants work on heavy fuel oil?

TIM LUNEL: Yes, from the field trials heavy fuel oil was dispersible when the oil was treated on the first day. The window of opportunity was shorter than with ANS however, about four hours. In that way you can say it was less of a candidate than the Alaska North Slope crude, but it is dispersible.

DENNIS MAGUIRE: Does temperature impact dispersants?

SY ROSS: Of course there is an effect of temperature on dispersant effectiveness. There is going to be an effect on dispersant effectiveness because lowering the temperature increases the viscosity which in turn lowers effectiveness. But the question is for a particular oil spilled in a given environment, does the temperature change create a large effect? The question really relates to the interaction of temperature, viscosity and dispersant effectiveness.

ALUN LEWIS: The whole question of viscosity limits for dispersants has gone on for years because people want to have one number as the standard, whether it be 2000 centipoise, 3,000 centipoise or whatever. I am just going to review quickly what we see when oil weathers.

When ANS oil weathers, it's viscosity goes up. The viscosity goes up because it loses its light ends by evaporation and it incorporates water by emulsification. As a consequence you get a rapid increase in viscosity that comes to a very big number at the end. Dispersants are restricted by viscosity, but they're not restricted in a linear way. So an ANS oil with a viscosity of 100 centipoise, it will disperse at about the same rate as a 200, 500 and 1000 centipoise oils. However, once you start moving into very high numbers, the dispersant effectiveness drops off rapidly. So with a low viscosity oil, like ANS when you raise its viscosity slightly by weathering it or cooling it, moving up in viscosity causes very little change in dispersant effectiveness (moving from A to B in Figure 1). However, with a heavy viscous oil like a heavy fuel oil, when you weather it or lower its temperature slightly this causes a huge effect on viscosity and on effectiveness (moving from C to D in Figure 1).

There is no absolute viscosity limit for dispersant effectiveness. We were dispersing samples of weathered ANS crude oil with viscosities of 20,000 centipoise, because the dispersant was breaking the water-in-oil emulsion. However, a 20,000 centipoise fuel oil would be undispersible.

DENNIS MAGUIRE: Can dispersants be effective in fresh water?

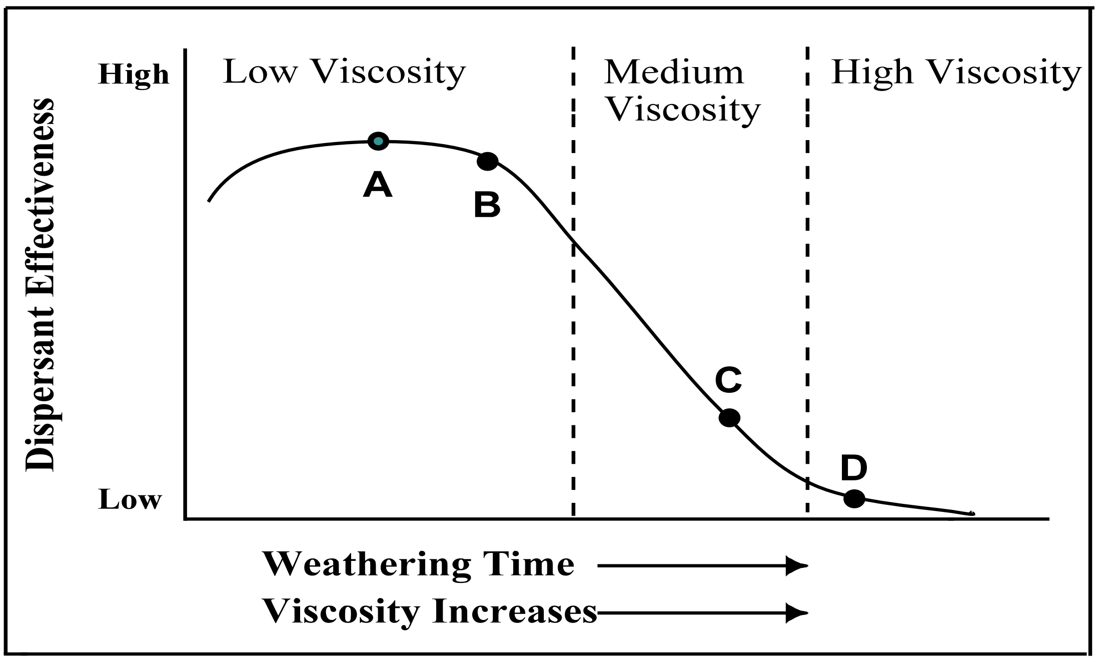
PER DALING: The effectiveness of most dispersants is strongly influenced by the salinity of the water. Their effectiveness is greatest at the salinity of full strength sea water and it declines at lower and higher salinities, so they work poorly in fresh water. However, there are dispersant products which are specifically designed for fresh water and these are highly effective.

Summary

SY ROSS: We did not answer the question of whether waiting or delaying the application of dispersants in order to allow the lighter ends to be lost by evaporation, was a good idea overall. The short answer is no. The time window is short, so don’t delay for any reason. That is why preapproval is very important, it avoids unnecessary delays.

TIM LUNEL: ANS is a good candidate for chemical dispersion. It is dispersible when fresh and even when somewhat weathered.

Figure 1. Dispersibility vs Viscosity



MERV FINGAS: Every time you consider a value from a laboratory effectiveness test, insist that worker report all the important information concerning testing conditions.

CARL LAUTENBERGER: It is essential to carefully define terms when dealing with laboratory and field effectiveness.

PER DALING: There are two comments. First, ANS is a good candidate for chemical dispersion. Second, the properties of the oil in the pipeline will change from time to time for a number of reasons, so it is important to check the properties, including dispersability on a regular basis.

Alun Lewis had no summary remarks.

Panel #2: Fate of Dispersed Oil in Prince William Sound

Chair: Ron Morris

Panel Members: Per Daling, Alan Mearns, Charles Henry, Tim Lunel

RON MORRIS: We are going to be discussing the fate of dispersed oil in Prince William Sound. This is a good lead into the subject of dispersant use. We have heard that ANS is a good candidate for dispersion. What we are dealing with here is, "What happens to the oil once it is dispersed?" As a lead into the subject, we will have brief presentations from Per Daling, Charlie Henry and Alan Mearns. Then we will open the floor for discussion.

PER DALING: I would like to present some material coming out of our group at SINTEF, concerning the short-term fate of dispersed oil and the exposure conditions for organisms in the upper part of the water column right under chemically dispersed and untreated slicks. Specifically, this presentation addresses concentrations and composition of dispersed oil in the water under slicks, as well as the rate of dilution of dispersed oil and the vertical distribution of oil under dispersing slicks.

The fate and exposure conditions can be illustrated by considering one of many experimental spills in the North Sea. In this particular experiment, emulsified Statfjord crude oil was treated with Corexit 9527 applied by aircraft. At 15 minutes after treatment, it is visibly evident that the emulsion is breaking and there is a visible cloud of dispersed oil in the water. At 2 hours after treatment, some oil is still left on the surface and there is still a visible cohesive cloud of dispersed oil in the water. After 2 hours the concentration of dispersed oil in the dispersed cloud has reduced to approximately 10 ppm from the approximately 50 ppm that it had been at 5 minutes after spraying. This is a dilution factor of approximately 3 to 4 per hour.

Let us look at the vertical distribution of hydrocarbons in the water under the slick. Under a chemically dispersed slick, we found a fairly homogeneous and stable distribution of dispersed oil down to 8 metres. Below this there is a rapid decline down to 10 metres and there was no oil observed at 15 metres depth. Under an untreated slick there can be fluctuations up to 200 ppm of oil in the water upper 1 metre of the water column due to temporary natural dispersion. However, this is limited to the upper metre or two of the water column. Below this, concentrations are very low, generally less than 1 ppm.

I want now to consider the fate of the BTX compounds [benzene, toluene, xylene] compounds in crude oil during dispersion. This addresses the question of whether we should wait or how long might we delay the start of dispersant application. The behavior of BTX is important because these compounds are important contributors to the toxicity of chemically-dispersed oil and the water-soluble fraction of untreated oil. The behavior of these compounds can be illustrated through the modeled behavior of BTX in the water under slicks with and without dispersion. The model considers a slick which is treated after 2 hours and the output shows the concentrations of BTX in the water from the time of release up to half a day later. The output shows that the highest concentrations of BTX occurs immediately after the spill before the dispersant was applied and when the slick is still fresh. When the dispersant is applied at 2 hours after the release of oil, the highest concentrations of BTX have already passed. This theory can be verified by considering measurements taken during an experimental spill, as illustrated in the table below. Consider measurements of oil concentrations and BTX concentrations in the water under an experimental slick. This experiment involved a spill in which dispersant was applied four hours after the release of the oil. BTX concentrations were monitored at a depth of one meter. The data show that at one hour after release, before dispersant was applied, the concentration of total petroleum hydrocarbons (TPH) at one meter depth was 1 ppm and BTX concentrations were 25 to 35 ppb. When dispersants were applied after four hours, the oil concentrations were drastically increased by a factor of 10 to a level of 15 to 20 ppm. However, the concentrations of BTX that were observed in the water (approximately 15 ppb) were actually lower than at the earlier stage in the spill.

Concentrations of Oil and BTX Compounds in Water Under an Experimentally Dispersed Oil Slick (*)

Sample depth (m)	BTX concentrations (ppb)	Dispersed oil concentration (ppm)
Samples at 1 hour after the oil was released, but before dispersant application		
1	25 to 35	1 to 1.2
5	10 to 12	0 to 0-.2
10	1 to 2	0 to 0.04
20 minutes after dispersant application at 4 hours		
1	15	15 to 22
5	9	5 to 6
10	4	0.1 to 1.5

(*) Example from a Norwegian field trial in 1996. A slick was chemically dispersed at 4 hours after the oil was released.

CHARLIE HENRY: This is a very quick presentation on biodegradation of chemically dispersed and untreated oil spills. Biodegradation is a process by which organisms such as bacteria breakdown oil and petroleum to simpler substances like carbon dioxide and water. It is one of the most important processes by which spilled oil is ultimately removed from the marine environment.
What factors limit biodegradation? Just as there are different factors which limit the dispersibility of oil, there are different factors which limit the biodegradation of oil. These are :

1. Presence of oil-degrading bacteria. This is not a limiting factor in Prince William Sound because we know that they are present.

2. Nutrients
3. Oxygen
4. Oil Composition. The composition of oil affects the rate of degradation. Some oils are easily degraded, while some resist degradation. ANS crude oil is not the easiest or the most resistant. It is in the top half in terms of degradability.
5. Bioavailability. The most important factor is in degradation is bioavailability. This refers to the contact or interaction between the bacteria and the oil. The bacteria are the main degraders in the environment. Some of the oil that continues to persist in PWS is oil that is not bioavailable for degradation.

How do dispersants help with bioavailablity? Dispersants help to break oil up into tiny packets or droplets of oil which increases its bioavailability. On the one hand, emulsification [formation of water-in-oil emulsion] reduces the surface area and actually slows down biodegradation. With dispersants the situation is just the opposite. With dispersants you break up the oil into tiny packets or droplets and significantly increase the amount of exposure, bioavailability and biodegradation.

We conducted a small experiment looking at the influence of a number of factors on the rate of degradation of oil in a jar with natural seawater. We found that oil alone degrades to a certain extent, but in our experiment the degree of degradation was limited because of limited nutrients. In the real world nutrients would not be limiting. By adding dispersant alone, we did not greatly increase the amount of degradation, because it is still limited by nutrients. Adding nutrients resulted in some increase in degradation, but with dispersants and nutrients together we found a significant increase in the rate at which the oil was degraded.

Biodegradation reduces the toxicity of the oil.

The bottom line is that an effective dispersant application would result in a significant increase in the rate of natural biodegradation.

ALAN MEARNS: I have several points to make about the potential longer-term fate of oil if dispersants are used or not.

My first point is that there is not much known about the long-term fate of oil spilled on the sea, because few studies have followed oil for long periods. Exceptions to this are a limited number of studies which have followed the long-term fate of oil after major spills (e.g., *Exxon Valdez*, Amoco Cadiz) and field trials (BIOS).

My next point is to consider the potential role of food chain transfer on the fate of oil. There are two pieces of information which suggest that food chain transfer and biological transformation might play a role in the fate of dispersed and untreated oil. The first is that over 20 years ago during the very large spill of Bunker C from the tanker Arrow on the Atlantic Coast, a researcher named Conover showed that copepods actively ingest oil droplets and egest oil-laden fecal pellets. He observed copepods containing 7000 ppm of Bunker C, in their guts, which were still living and producing fecal pellets containing oil droplets. There is no indication of whether ingestion of oil and incorporation of it into fecal pellets affects the overall fate of spilled oil to a significant degree, but if it does occur at a significant level, it would mean that the traditional vision of the dispersed oil spreading and diluting in the water column for may days might be replaced by one in which the droplets are ingested and are transformed into rapidly sedimenting projectiles, which transport the oil droplets to seabed sediments much more quickly that previously thought.

The third point is that there is ample evidence that fish down stream from the epicentre of a spill do receive some exposure to oil. The evidence is that metabolites of oil appear in the bile of these fish. Again it is not clear whether the amount of oil that is transformed in this way by biota is a significant proportion of the oil spilled.

There appears to be a whole area of research related to the question of biological processing of spilled oil. It may be that the bottom line is that the spilled oil ultimately becomes part of the food chain and is ultimately harmlessly processed. However, we do not have the data to confirm this.

The last point related to the long-term fate of oil, is whether the long-term fate of oil dispersed at sea is truly different from oil that is not treated and as a consequence becomes stranded for a time on a shoreline. If you examine aerial photographs taken during the shoreline cleanup activities following the *Exxon Valdez* spill, you will see people washing the stranded oil off the shorelines and picking it up from near shore waters. However, some of these photographs show big brown plumes of fine oil-laden sediments, that were washed off the shorelines, but were not picked up, and passed under the containment boom to become dispersed into the PWS environment. This is also a form of natural dispersion of oil. This suggests that our current spill cleanup policy says implicitly that it is acceptable to disperse oil from shorelines. What it means is that just because you do not use dispersants on the oil at sea, it does not mean that some of it will not ultimately become dispersed while being washed off the shoreline.

QUESTION: I have two questions. In terms of dispersant application timing, I gleaned from the first panel the idea that you should not wait to apply dispersant, but should begin spraying as soon as possible. However, immediately, I thought that the low end organics are going to volatilize very rapidly. So are there any advantages in delaying dispersant application to allow for the volatilization of the organics or is it preferred, for dispersant effectiveness purposes, to apply dispersants immediately driving the potentially toxic volatile organics into the water column? Secondly, looking at the toxic effects of the dispersants, yesterday we heard discussions about toxicity of water accommodated fractions (WAF), dispersant enhanced water accommodated fractions or chemically-dispersed oil (CEWAF), and the dispersants alone. The data coming from the CROSERF program appear to suggest that dispersant has an insignificant toxicity, but the toxicity of the dispersed oil, which is comparable to the WAF, is significantly more toxic. Am I interpreting this information correctly? So in terms of policy guidelines, what are the relative toxicities of dispersants, dispersed oil and WAF?

PER DALING: A lot of things are happening within the first hour with respect to the BTX. Under most operating conditions the first application of dispersants would take place more than one hour after the oil is discharged and under these conditions you would be treating a slick which has been weathered to a certain degree and most BTX would already have been lost. Another question is whether the BTXs are the most toxic components.

CHARLIE HENRY: Toxicity is probably caused by more than one component of the oil and the volatile organics, which include the BTXs, are definitely a contributor. However, there are different types of toxicity and the larger aromatic hydrocarbons may also contribute to the toxicity. Chances are that, except in unusual circumstances, you will lose the BTX fraction and you will end up with the other components that are toxic. We understand, however, that the key question is not toxicity, but trade-offs.

QUESTION: I am looking at some CROSERF (Chemical Response to Oil Spills: Ecological Effects Research Forum) data from the University of South Florida that show that the toxicity of the dispersant alone and that of the CEWAF (dispersed oil) are comparable and that the values for the WAF showed the greatest toxicity. (Editorial note: On a gram per gram basis, comparing total petroleum hydrocarbons (TPH) to TPH, WAF is more toxic than dispersed oil. The reason is that WAF is made up of aromatics, which are some of the more toxic components in crude oil, while dispersed oil includes many less toxic hydrocarbon components. Dispersant toxicity varies widely with both the product and species.)

TIM LUNEL: In the second part of your question you compared the toxicities of WAF and dispersed oil. That is the specific sort of regulatory tests that are being done in the U.K. that Robin Law talked about yesterday. In those tests, in the chemically dispersed run you get higher concentrations of oil in the exposure medium because of the effect of the dispersant. However, the U.K. test specifically compares the toxicity of the dispersed oil run with that of an untreated run with comparable concentrations of oil in the water. The only products that can be licensed for use in the U.K. and in the U.S. are those which do not increase the toxicity of their dispersed oil.

ALAN MEARNS: Does anyone have an approach to the big picture. That is does anyone have a model that can relate the area within which toxic conditions occur in the water with the size of the slick being treated?

SUSAN SAUPE: Are microbial degradation rates related just to the surface area to volume ratio, or is there something inherent in the dispersant/oil mixture that could enhance the microbial degradation rates? When the dilution rate or the amount of available nutrients are limiting, would adding nutrients with the dispersants increase the rate of microbial degradation? In Cook Inlet, where there is a high suspended sediment load of fine sediments and a risk of sedimenting dispersed oil to the seabed, is there any way to augment the natural rate of removal of the oil from the system?

CHARLIE HENRY: There are other factors which limit the rate of degradation, but surface areas is one of the main ones. In the real world nutrients are seldom the limiting factor. In low nutrient areas even when nutrients in one location are depleted, nutrients are replenished from adjacent areas by mixing. In addition, recognize that even in cases where nutrients are limiting, if you increase nutrient concentrations to optimum levels you can increase the rate of degradation, but beyond that you don't increase the degradation rate further. Also adding nutrients to dispersed oil may have negative environmental effects, such as causing algal blooms at the wrong time of year.

With respect to the potential for sedimentation, there are studies that show that dispersants reduce the potential for sedimentation, but I will ask Tim Lunel and Per Daling to address this subject.

TIM LUNEL: Our studies show that the main effect of dispersants in enhancing the biodegradation rate is the surface area effect. There does appear to be a secondary effect which appears to be caused by the components of the surfactant, but this is a small effect. In terms of actual interactions with sediments, it is the surface interaction of the dispersed oil droplet with sediments which determines the sedimentation rate. There are cases in experiments when you get formation of flocs of dispersed oil and bacteria in which you get high levels of degradation. However, these are probably experimental artifacts which are unlikely to occur in the open ocean where the droplets would dilute fairly rapidly.

RON TJEERDEMA: Given the wide variety of oils and dispersant, there may not be any basic trend in relative toxicities of dispersants, dispersed oil and water-accommodated-fractions. Might dispersants interfere with microbial action and microbial degradation?

CHARLIE HENRY: When bacteria attack food sources like oil, they actually secrete their own biosurfactants. The dispersant's surfactant may compete or enhance this process.

MARK REED: We at SINTEF have a model which can predict the concentration of dispersed oil in the water column over time and the water volume where concentrations exceed certain thresholds for both WAF and TPH. You can also model the location of areas to toxic conditions relative to spawning areas or areas of high plankton concentrations. In addition, you can model how this changes if you vary the time at which the dispersant application starts.

ALAN MEARNS: What is the relationship between the size of the slick and the size of the area of toxic effects?

MARK REED: There is a relationship among the size of the area of toxic conditions and the size of the slick, the dispersant application rate, sea state, oil type; all these things have an effect. It is not a single factor.

QUESTION: Dispersants operate on the premise that "the solution to pollution is dilution." If the reservoir available for dilution is adequate this is probably true. As well, it is important that the system can eliminate these pollutants as quickly as they are introduced into it. In a system like the Mississippi River for example we have exceeded the rates at which the system can degrade pollutants. Is there any work looking at the rates at which oil enters the system during dispersant operations versus the rates at which it is degraded?

CHARLIE HENRY: This is a complex question. Bioavailability was one of the most important limiting factors in the degradation of spilled oil. In your Mississippi River analogy, many of the pollutants that you refer to are soluble and are available for degradation. Oil, on the other hand, is poorly soluble and is not available. Dispersants are one way of making it available for more rapid degradation. In that sense dispersants are one way of enabling oil to be removed from the system faster, so the system can recover faster.

TIM LUNEL: In answer to your question about degradation rates versus entrainment into the system, in the *Sea Empress* case, the time needed for degradation was a matter of weeks to months, which is a great deal longer than the time it took to put all the oil into the water.

RON MORRIS: I want to thank the panel members and questioners for this excellent discussion.

Panel #3: Environmental Risks from Dispersed Oil in Prince William Sound

Chair: Peter Armato

Panelists: Don Aurand, Jim Clark, John Goodlad, Robin Law, Stan Rice, Ron Tjeerdema, Ken Trudel

The introductory remarks of the panel chair, Peter Armato, were not recorded due to a technical malfunction. The panel addressed a variety of issues surrounding risk. Jim Clark began the discussion by summarizing the position of the oil industry concerning dispersant risks and methods for their assessment.

JIM CLARK. I do want to give a couple of perspectives that represent the Exxon position and I will try to present the broader industry perspectives as well.

The first point is that in almost all of the research that you have heard about over the last couple of days: field trials in U.K.; the laboratory studies of the CROSERF network; and the Coastal Oil Spill Simulation (COSS) System; industry money has formed part of the support for the work. Industry has been supporting the research to get the kind of data that we need to help to advance our characterization of risk and our perception of the issues. I want to assure you that the perspectives of industry are not greatly different from the rest of the community. We recognize data needs, we want to get the information that will help resolve some of the controversy. We have been a team player in a lot of these issues.

What has happened in the last few years is that people at the state level have come forward to request that issues or species of specific local concern be addressed. Because of this, the CROSERF network has supported and funded by Louisiana, Texas, and Florida. Now Alaska has joined and there are specific Alaskan issues that are being brought to the table.

As Don Aurand said yesterday, one's perception of risk depends on one's history. Industry brings a different perspective to the table. There are a couple of points that I wish to make with this in mind. When we discuss the available toxicity information, it is important to remember that there is a range of sensitivity among species. The laboratory data that we have looked at over the last couple of days is based on the most sensitive species and life stages. By focusing narrowly on data from only these sensitive species and making an effort to include the most sensitive species, we are beginning to bias our perception of those risks. Information concerning sensitive species does need to be represented when we assess the risk, but we must recognize that biota display a wide range of sensitivities so that we don't bias our perception of risk. Not everything will be affected at the levels of toxicity that we are observing with those highly sensitive species.

Next I want to speak about scale. One of our goals is to use the specific information concerning the sensitivities of individuals to extrapolate the potential effects and impacts on populations. We have to consider these impacts on a temporal scale and on a spatial scale. In assessing risk we must consider the size of the spill and the area affected and relate this to the size of the area that is involved with the total target population. It is important to recognize however, that we are not ready to go to the next level and to consider the impact at the ecosystem scale in PWS concerning the fate and effects of chemically-dispersed oil. Science won't help us answer these questions. That subject is at the cutting edge of science right now.

We do know a lot about the recovery of populations after damage has occurred. We know a lot about population dynamics, the rates of recovery and the rates of movement of animals. So we know that when we predict the size and location of possible effects, we also know a lot about the potential speed with which the affected populations might recover. Because when we are assessing trade-offs we want to taken into account that some effects will be long-lasting, while in some recovery will be rapid. In short, its not a question of what can we do to ensure that no effects will occur. If you have a large enough spill then something will be affected.

I want to go back to the point that Tim Lunel made yesterday, quoting the IMO (International Marine Organization). IMO published a flat statement that given sufficient dilution, no toxic effects are observed. From the toxicity data generated so far, people have the perception that dispersed oil has some potential toxicity. The difference in the perception that you arrive at from looking at the specific toxicity information and the position taken by IMO, is that IMO looked at the bigger picture and recognized that the potential effects of chemically dispersed spills would be localized and transient or they chose to make the point that the effects of these spills would be insignificant from the perspective of the larger, longer term picture.

The other point is that in gathering information, we want to move from the laboratory to the field.

We have talked about the laboratory toxicity testing programs. We have heard about the COSS program of meso scale tests. You have also seen data from real spills, the *Sea Empress* and *Braer*. As Ken Trudel pointed out yesterday, the latter are some of the most significant modern data on the effects and impacts of spills, but there is still some information missing from the characterization of effects during the *Sea Empress* and the *Braer* spills. I'm sure if you speak to Lunel, Lewis, or Law they will tell you that there are data from the early stages of these spills that they would like to have obtained, such as the early exposure concentrations. We can go back now to sample for effects in mussels, but we don't know what oil conditions they were actually exposed to. There is still field research that needs to be done. Some longer-term food chain studies can be done in the field. From an industry perspective, these are some of the issues that have not been brought out in the last few days in terms of the data we are generating at present. But these are issues that have been brought to the table and must be addressed in future work. Thank you.

STAN RICE. I was thinking over the last day or so while we have been looking at a lot of short-term toxicity data, what it really comes down to here is: "What is the bottom line?" Having spent the last nine years on the *Exxon Valdez* spill, the perspective that I have is this: "If you use dispersants, do you do more harm than good?" or "Do you do more harm than good if you don't use them?" I don't think of this in terms of a short-term perspective. I think of it rather in the longer term in terms of the productivity of a habitat over ten years or more after the incident. The question is what is the productivity of the habitat that has or has not been damaged after 10 years.

We would all like to have these answers, but it is not always practical to do long-term studies especially when you are only funded for one year at a time. However, you still have to make that determination and often it is a "best guess". I would like to relate examples arising from the *Exxon Valdez* oil spill (*EVOS*).

The first involves pink salmon, the most important species economically in the Sound. There was a decision made up front on the spill that there would be no cleanup of the delta areas where they spawn, at low tide in fresh water. The assumption was made that the mouths of the spawning streams would be naturally protected from the oil, because oil floats and it would not get mixed into the spawning gravels. In part that is true, but the gravels adjacent to the streams did become contaminated during the flood tides and ultimately the spawning beds did unexpectedly become contaminated. Subsequently the Alaska Department of Fish and Game observed elevated levels of mortality of eggs in those beds for four years through 1993 after the spill. As a consequence I have always asked myself if dispersants had been used would this have offered protection to these salmon streams. I don't have an answer to this question. But then I ask myself if we had used dispersants would we have damaged the rockfish. So while you may help one species, the salmon, you may harm another species, the rockfish. If you look at the situation from the perspective of just one species, as you might if you were a pink salmon fisherman, you might arrive at one conclusion, but if you look at the ecosystem as a whole, the situation may look somewhat different.

So that's the trade-off. What impact do you have now and what will you have later? The real question is, "After 10 years, is there more productivity through using dispersants or not using dispersants?" The problem now is how do you get the information to address this question.

QUESTION: Does dispersant reduce the tendency of oil to emulsify? Does dispersant reduce the residence time in sediments? Is this good or bad? Does dispersant treated oil not stick to sea otters as much as untreated oil? Do fish take up dispersed oil to the same degree as untreated oil? Do they retain it as long or longer than untreated oil? Do shellfish depurate dispersed oil more quickly than untreated oil? If smaller species/life stages in the water column are impacted, do they recover quickly?

PETER ARMATO. I want to add another question, that of scale. If we have a 70 million liter spill and we disperse half of this where does the dispersed oil go?

STAN RICE. I think that the first consideration is the potential risk to major habitat structure, and that depends on where the spill occurs. If the spill takes place 50 miles offshore it may affect some individuals but it will not affect the habitat structure. However, once you are within a mile of shore in relatively shallow water, then you may affect some habitat structure and/or cause some more persistent environmental contamination and this raises the question of whether you will be doing more harm than good to the habitat.

JOHN GOODLAD. Just a specific point about the distinction that you draw between the close inshore versus the offshore spills. I am not familiar with the marine biology of the Alaska fishing industry, but in the North Sea there are some very particular distributions of fish occurring 20, 30, 50 miles offshore. I am thinking of two particularly well-defined spawning areas which are well offshore at depths of 70 to 80 fathoms where fish come year after year to spawn. This would also apply to nursery areas where small immature fish congregate, feed and live year after year. If there were a spill in the North Sea in those offshore areas and the oil was dispersed and sank to the seabed, and if it were a spawning area or a nursery area, then it would perhaps have a fairly major impact on the fishery. This means that oil doesn't have to be dispersed nearshore to have an effect.

ROBIN LAW. One of the reasons for limiting dispersant use to water depths greater than 20 meters is that we want to avoid impacting the bottom-dwelling organisms with dispersed oil. We have seen from the field trials that the dispersed oil mixes down to about the 10 meters depth, so that even with water depths of 20 meters, you have a buffer of about 10 meters of water protecting the seabed animals from coming into contact with the oil.

Within the upper10 meters of the water column what happens to the dispersed oil after it is entrained depends on the water transport and mixing in the area. You are effectively taking it away from the influence of tidal currents and winds and mixing it deeper into the water column, where it will be transported, diluted and dispersed just by the water movements. So you need to know something about these water movements.

Does chemically-dispersed oil go into sediments? Following the experience with the *Braer* where the seabed sediments became heavily contaminated, during the *Sea Empress* we tried very hard to determine whether any of the dispersed oil found its way into the sediments. We did show that we could not find any fine-sediments accretion areas of the Bristol Channel that showed measurable quantities of *Sea Empress* oil. The message seems to be that dispersion of the oil takes place in the upper part of the water column and the dispersed oil is not sedimented. Oil is more likely to become sedimented if emulsified oil is left on the surface particularly in turbid areas, where it can pick up sediments and eventually sink.

In terms of bioavailability, during the *Sea Empress* spill the major contamination resulted from bulk emulsified oil which was held in near shore areas. We did not find any additional impact from the chemically-dispersed oil.

In terms of accumulation in fish, you would probably expect that the concentration would be less with the chemically dispersed oil than with the untreated oil, because once the oil is chemically dispersed, the concentrations are reduced quite quickly and that reduces the exposure. Because accumulation of PAH by fish is an equilibrium process that responds to the water concentration, when the water concentration is high you have hydrocarbons moving into the fish, when they are low the concentrations move out of the fish. So if you reduce the exposure the bioavailability is reduced.

JIM CLARK. I want to address the question, "Is the bioaccumulation of dispersed oil different from those of untreated oil?" Our research is showing that once the oil gets into an organism the animal doesn't know whether the oil came originally from a dispersed oil droplet or from solution under an untreated slick. This means that once it has been accumulated, it will depurate at the same rate regardless of whether it was taken up or dispersed or untreated oil. What we are doing by using dispersants is to change the rate of exposure [concentration] and the form of exposure [droplets vs dissolved].

DON AURAND. There are four things that I want to comment on. The first is that dispersants change pathways for the distribution of oil. Oil may ultimately end up in the same place, but you have changed the route by which it gets there. The second is that by changing the pathway you change the exposure and the exposure is a key determinant of what the effect is likely to be. You can change the geographic location of the exposure, the concentration or duration and in doing so you may change the effect. In dealing with this from a risk assessment and decision-making perspective, you can deal with this either on a qualitative or quantitative level. My own opinion is that you start out at a qualitative level and resolve as much as you can at this level and then move to the quantitative level to resolve the rest, because the more quantitative you try to get, the more expensive and time consuming the work becomes. Third, you must take the system view. This is sometimes difficult because different people value different parts of the system more highly than others. Lastly, you really do need to take a long-term look in deciding whether or not to use dispersants. You must recognize that in a large spill no matter what you do you are going to damage something. In making decisions about dispersant use, you are deciding what you are going to damage, by how much and for how long.

RIKI OTT. I have a question regarding the effects of spills on herring. During the *EVOS* the oil had two effects on the herring population. One was that there was no 1989 year class. This is known as the beach effect. We have discovered in retrospect this species is an important forage species at the base of the entire ecosystem. So this class failure had ripple effects. The recovery of the Sound depends on the recovery of this species. The point is that the effect of the spill on both the anadromous fish and species in the water column were system effects, in that the oil affected the adults as well as the eggs in the herring. We are still seeing those effects. That population has not recovered to this day. I question whether dispersing oil would have changed anything.

PETER ARMATO. I will try to restate the question. This is a fate and persistence issue. PWS is a silled fjord system. We are just now beginning to understand its dynamics. I would like to look at it as a closed system. Herring is not the base of the food chain, but it is close to being the base. Much depends on herring. Where does all the oil go? Will it be in PWS forever and what effect will this have on the environment. Does this restate the question properly?

JIM PAYNE. Alan Mearns commented earlier that even if you don't disperse offshore, the oil will become trapped on the beach, interact with glacial till and will be removed by natural removal or by flushing or washing some of it in a dispersed state. This is evidenced by the brown plume of sediment-associated oil which dispersed into the water column, passed under the collection boom and became dispersed into the larger marine system. So even if you don't chemically disperse a spill, at some point at least some of that oil will become dispersed. From a mass balance perspective during a spill 25-30% evaporates and 15% can be collected by mechanical means. That leaves approximately 50% of the oil remaining. At some point that oil will go into the water column and be re-worked by a variety of natural processes (i.e., be ingested by organisms and passed in fecal pellets, be re-worked by bacteria as it falls to the seabed via sedimentation). We have expended a great deal of effort looking for evidence of *EVOS* oil in PWS sediments and you cannot find any in the sediment either in deep or in shallow sub-tidal sediments in the Sound. The oil that persists in PWS today is in the intertidal zone. You made the comment that oil persists in PWS. Well where is the oil coming from? It is coming from being remobilized from the intertidal zone. So the long-term impact on the herring is due to this oil that continues to be remobilized from the intertidal zone. So the question becomes, can you reduce this persistence in the intertidal zone and avoid its longer term impacts?

RIKI OTT. My concern is specifically about impacts in the water column. That is why I separated effects on eggs/larvae from those on adult herring. In 1993-94, we lost 140,000 tonnes of adult herring and we think it was a direct effect of exposure during the 1989 exposure combined with later environmental conditions and that toxic exposure had weakened the fishes' immune system to the point that they were not able to survive the subsequent environmental exposure. So I am specifically talking about exposure of adults to oil in the water column and hence my question is: "Is it going to be worse or better to put more oil in the water column initially?"

JIM PAYNE. The information we have seen so far suggest that when you disperse the oil the impacts will be limited to the upper 10 meters of the water column which is right where your target species is. However, you have to trade that off against 10 years of persistence of these hydrocarbons in the intertidal regions. I cannot make the trade-off for you here. However, those water column impacts are limited to the upper water column and are short-lived. The information presented here suggests that within an hour the concentration will come down by outward diffusion.

QUESTION: If you could mount a five-year program involving field trials, what would you suggest that we study. There appears to be ample information concerning effectiveness, but not a whole lot on long-term environmental impacts.

JIM CLARK. We are about to begin a study in the COSS tank in Texas which a mesocosm facility. We are looking at where the oil goes. We are looking at residues in the species that are exposed and what are the effects of these residues. We are comparing the effects on the shoreline and sub-tidal communities, as well as, with some representative water-column species. We are looking at the fate of the oil. Does it stick to the bottom sediment? But this is still just limited to short-term effects. We are looking at 10 days. If we had more money and resources one of the things that we would be looking at would be to extend the observations to look at benthic communities. I think the studies that were done during the *Braer* and *Sea Empress* spills were important. The only thing that was missing was the exposure correlation, what concentrations of hydrocarbons were organisms exposed to and for how long.

DON AURAND. There has been one good long-term study of dispersant affects in the Arctic, the BIOS Experiment, which looked at effects on benthic communities. It is difficult to do a long-term study of the water column community. There have also been other longer term studies including the Panama study and the Searsport study. Somehow or other the results of these studies don't get used as well as they should.

QUESTION. Related to your question is the implicit assumption that the near shore communities and biota have greater value than those in the offshore? Is this generally accepted to be true? Also, if we had a spill in PWS and we needed to make a decision about dispersant use, what tools do we have to give us information on the real-time distribution of organisms in the water column and in the near shore?

DON AURAND. I can't make any specific comments about PWS, but if you are going to make this kind of decision after the oil is in the water you are too late. You must do this up-front. That doesn't mean that you analysis every possible scenario to the last detail, but you must have broad criteria. You must also have the information already assembled to find those solutions before the spill happens.

KEN TRUDEL. Don Aurand may be a little pessimistic in saying that you can't consider all of the issues in advance. You can consider a range of spill scenarios in advance and it does give you a picture of the issues. This is what the response planners do. They consider in some detail what they would have to do to respond in each of several specific spill scenarios. You do the same thing for the environmental risks and you can very quickly see what the major decision points are. You develop consensus concerning what the risks are if you put the oil into the water column or let it come onshore. You then develop consensus about the trade-offs and decisions. By considering a number of scenarios you begin to see trends in the trade-offs and the decisions. That is what leads to policy and guidelines. I agree with Don, however, that this must be done in advance.

Summary

KEN TRUDEL. I have only three points. First, dispersant decision-making is a matter of trade-offs. You are not going to eliminate risks, you are only trading one set of risks for another set. Second, in order to do a good job of these trade-offs it is essential to plan in advance. Third, we are in an excellent position to do a knowledgeable job of addressing trade-offs now. We know much more about oil fate and behavior and toxicity than we did in the mid-1980s when the Alaska dispersant guidelines were first developed.

JIM CLARK. In characterizing the risks from dispersant use it is important recognize that risk is a function of two things: toxic potency and exposure. We know that the dispersant does not change the toxic potency of the oil. It does change the route by which organisms are exposed, the rate of exposure, the duration and spatial scale. When considering the risks from dispersant use be sure that you are considering the toxic potency in a relevant exposure scenario. What we see now is that when people are trying to assess risk they look to toxicity data generated in experiments with exposures too unrealistically high concentrations for unrealistically long periods and effects are observed. Whereas in real situations what we see are much shorter exposures to lower concentrations and fewer effects. It is important to use the proper exposure scenario in your analysis.

DON AURAND. In PWS and everywhere else, first seek out the best professional advice you can get about the technology and risks. Second, make sure you understand what your advisors are saying and that they communicate to you effectively. Third, make the decisions for your environment based on your values. Last, try to make the decisions based on the technical information as well as on your values.

ROBIN LAW. I want to say that when using dispersants, you can only make a proper decision in real-time because only then do you know the conditions of the resources, the environment and the spill. However, in order to be able to do this you have to do much preparing beforehand in terms of sensitivity mapping, issues and valuations.

JOHN GOODLAD. It has been evident that in the event of another oil spill in Shetland in which dispersants are considered, the fishing community will have to make informal decisions regarding their use. To do this it is essential that we plan for this in advance and take advantage of the best available knowledge on the subject.

STAN RICE. If you protect the habitat structure then you protect the well-being of the ecosystem in the long run.

RON TJEERDEMA. I will just reiterate. We need to estimate risk at the individual and population level in order to understand what might be happening at the ecosystem level. The more information that we put into place now, the better decision we will be able to make at the time a spill.

Panel #4: Environmental Effects Monitoring in Prince William Sound

Chair: Leslie Pearson

Panel Members: Charlie Henry, Robin Law, Alan Mearns, Mike Sowby

LESLIE PEARSON. This panel will discuss environmental effects monitoring in Prince William Sound and the GOA. I think the last presentation that Ken Trudel gave yesterday, was pivotal, because the information that he gathered indicated that while there are operational plans for monitoring for dispersant effectiveness, when you get into the environmental effects you are treading into another arena.

To set the stage, the Alaska Regional Response Team dispersant use guidelines do not require any kind of monitoring, but state law does. If a contingency plan holder wants to use an unconventional technique, the approval criteria reads as follows: "The plan which proposes the use of dispersants, in-situ burning or other non-mechanical response techniques during periods when environmental conditions or other factors limit the use of mechanical spill response techniques, must demonstrate their efficiency and effectiveness and must include a full assessment of potential environmental consequences and provision for continuous monitoring and real-time assessment of environmental effects.". So with that said, I think we will begin discussions here of whether some of the operational monitoring plans that exist will fill the same needs for environmental effects monitoring.

Before we really get started, we have Mike Sowby from the Oil Spill Response Office of the California Department of Fish and Game to speak briefly about environmental effects monitoring in California.

MIKE SOWBY: I work with the California Department of Fish and Game and we wear two hats in California. One is response; we work with the Coast Guard and the Responsible Party as far as taking care of response. The other hat is to do damage assessment. We are the state trustee for the State of California. Overall, this means that we have some in-fighting among ourselves as we progress with the spill.

Once we had put our dispersant decision process together, the next step was to put together an effects monitoring process. If we use dispersants, we have to have in place a plan to monitor the effects because we are the state trustee. We must quantify those effects and arrive at an injury determination. That is part of our mandate. So the State of California is tracking what you are doing now and I hope to get as much out of these sessions as you do.

CHARLIE HENRY. In our current approach to monitoring for dispersant operations we sometimes try to take the monitoring data, which in many cases is chemistry data, to try to make assessments about exposure, potential environmental effects and damage. There is a lot that must be kept in mind when you do this and this is something that is being addressed in the CROSERF committee. In this presentation, I will talk about how we do monitoring in the Gulf, and how we have used it in the last incident and in the pipeline incident off Galveston. I will also address some of the changes that the Coast Guard is planning.

In the Gulf Region the primary objective of operational monitoring is to provide proof of efficacy or proof of effectiveness. We consider monitoring with in-situ fluorescence to be an extension of the aerial observer, which is the primary tool that we use to determine whether the dispersant is working or not. We consider our field monitoring group to be a ground-truthing group, which verifies the observations made by the aerial observer. This is our primary function, to provide a yes/no answer concerning whether or not the dispersant is working. Secondarily, from a scientific perspective, we are also interested to some degree in the fate and transport of the oil, even if it is not a truly operational issue. A few basics about the plan which is called Special Response Operations Monitoring Program (SROMP).

1. Must be deployed quickly. One of the ways to do this was to use the Gulf Strike Team (USCG).
2. Use a vessel of opportunity.
3. Turner Design Fluorometer.
4. Continuous Monitoring. Currently the plan stipulates monitoring at a single depth; 1 m but the revised plan SMART, will require two depth, probably 1 and 10 m.
5. Aim is to collect data including: i) background levels of oil; ii) pre-application levels of oil; and iii) concentration of oil in the dispersed oil plume.

We practiced the plan in late January during a pipeline spill off Galveston in which 3000 gallons of Corexit 9527 was applied. The first point to be made about this operation was that during this incident we demonstrated that we could get the SROMP Team into the field quickly and coordinate with the dispersant spraying aircraft, and using modern technology such as Geographic Position Systems (GPS) we know where we are and know what we are doing.

In the field the machine output (UV/fluorescence) is in terms of relative response values, rather than concentration values. But this is adequate because we are doing efficacy testing only. We calibrate the instrument after the event. My second major point is that if you wish to convert these relative response factor values gathered during monitoring to terms of concentrations of dispersed oil it is important to recognize that many factors influence the values. It is a fuzzy number. The factors which influence the relationship between dispersant concentrations and the level of fluorescence include:

1. Concentration of oil (including composition of the parent oil, dissolved vs particulate oil, droplet size, weathering);
2. Temperature;
3. Salinity;
4. pH;
5. Dissolved oxygen concentration.

Therefore if you wish to compare the apparent dispersed concentrations measured in the field against effect thresholds observed in the laboratory, it is important to recognize that: all analytical data are method dependent, that is, if [concentration] measurements are made using two different methods they cannot be compared. This has lead us in the Gulf to conclude that in-situ dispersed oil concentrations, as measured by real-time fluorometer readings, may not be directly comparable to standard laboratory values. For this reason, in the Gulf we use these in-situ fluorescence methods for efficacy determination only and take the data no further.

QUESTION: This is a question about correlating fluorescence results with GC (gas chromatography) data. You said that you cannot convert in-situ fluorescence values measured in the field directly to oil concentration values as they might have been measured by GC methods, because other variables affect the fluorometric measurements. What I am questioning is the standard for the quality of the comparison. There is one standard for the purpose of publication in a peer reviewed journal and another standard for rule-of-thumb decision-making in the field. In Alaska there have been concerns about whether fluorescence data is useful for our purposes even though it may not be of an acceptable standard for use in a peer reviewed journal. What are your comments on that?

CHARLIE HENRY. I believe you can [use fluorescence data]. I believe that the fluorescence data gives you lots of information that is adequate for considering the fate and transport processes that are going on. However, if you are going to use the data to estimate exposures you must analyze the field verification samples using the exact same methods that were used in analyzing exposure condition in laboratory toxicity tests so that the data are directly comparable.

TIM LUNEL: You can actually use fluorescence to provide at least a semi-quantitative measure of oil concentration. Something you can easily do at sea is to prepare a crude reference standard using pre-mixed oil and dispersant. Put a drop of that into a known volume of water and pump it through the continuous flow system and then calibrate the fluorometer to [that reference concentration]. It may not be a precise calibration, but it will be accurate plus or minus 10%. You don't need anything more precise than that in order to determine whether the operation is being effective or not. It does mean that when you are measuring concentrations under slicks you can tell whether the readings that you are getting are sensible.

I have a problem with hearing people say that they don't calibrate the instrument at all. I agree that the instrumental response will vary with temperature and other factors, but if you don't do any calibration before hand, you have no fixed baseline that allows you to make that initial judgement. The other thing that you can do to improve the process of your calibration in the long run is to take the sample for post-calibration directly from the outflow from the fluorometer, rather than taking grab samples, which may be from other parts of the slick or the dispersed oil cloud. If you take your post-calibration samples from the effluent of the fluorometer, then you mark the point at which you took this sample on your data logger and then you can relate the content of a specific sample to a specific instrument reading. That is your final calibration.

ROBIN LAW: Just a comment on the differences that you saw in the calibration between the crude oils and the diesels. By setting up the instrument at fixed pairs of wavelengths you have already made some decisions about the types of oil that you are trying to measure.

CHARLIE HENRY. That was a conscious decision. Our aim with the monitoring plan is to keep it simple, because we want it deployed quickly to be in the field within a matter of hours. We decided that most often we are going to disperse crude oils and not diesel.

NANCY BIRD: When I think of environmental monitoring I think of the Sound Ecosystem Assessment (SEA), which has been funded by the *Exxon Valdez* Trustee Council and along with the two other programs that the Trustee Council has funded I think we are in a much better position to respond to an oil spill today and make decisions where dispersant may or may not be used.

The second point is that the SEA Program began with strong emphasis on planning, which involved the residents of PWS region; fishermen, environmentalists, as well as scientists. It seems that we are moving ahead with a new program addressing dispersant decision-making. I believe it will be just as important to include the stakeholders, like the fishing community, in this program. I wonder if anyone on the panel has had thoughts about how to include a broader segment of the community in the decision-making process, particularly in the San Francisco Bay area which is similar to PWS.

MIKE SOWBY. We have a pre-planning process for dispersant decision-making in which we talk to many of the stakeholders. Then again, the offshore is a different animal and it is easier to make a decision for that environment. Certainly within San Francisco Bay it is likely to be a longer and more drawn out process. Perhaps a gathering like what we have here is one way to bring everybody into it. Certainly planning is going to be a very important part of this process because you want to know what you are going to do before the spill happens. When you make a decision to use dispersants, it is important that you have some justification that it will cause the least impact on the environment, but you have to recognize that you will have some impacts in the environment and that is when the damage assessment comes in. At some point further down the line you will be called upon to quantify the impact. However, you have to recognize in advance that there will be some damage resulting from the dispersant use and that the decision to use them is a trade-off.

CHARLIE HENRY. One of the reasons that, in the current plan in [USCG] District 8, that concentration [of dispersed oil in the water column] was not a factor in decision-making, because the environmental risks and trade-offs are recognized in advance and are the basis of the trade-offs. The decision makers felt that they were not going to second guess themselves as soon as the real-time exposure numbers come in.

BRUCE MCKENZIE. Leslie, I found it very interesting that there are no monitoring requirements in the RRT guidelines, but that the State laws do require monitoring. It was very interesting to hear about the Gulf of Mexico. But I am really interested in hearing what the plan is for PWS.

SHARON HILLMAN. The monitoring process that we have [at Alyeska/SERVS] is based on in-situ fluorometry, supported with water samples. We developed this program in conjunction with the State of Alaska, the U.S. Coast Guard, EMCON, our consultants, with comments from the RCAC. We also received input from Tim Lunel [of AEA] and Per Brandvik [of SINTEF]. We use at least two fluorometers, so that we now can sample at two depths simultaneously and can take water samples at the same time. The fluorometer units and the chemical bottles are maintained here in Anchorage and we have vessel support out of Valdez to implement the plans.

MIKE SOWBY. Sharon, what is the purpose of the monitoring program?

SHARON HILLMAN. Ours is a multi-purpose program. The immediate purpose is to give us information about the success of the operation, although aerial and visual observation are also important in our program. Secondly, we do intend to take water samples to provide information on fate, to be used in reflecting the long-term consequences of the spill and the trade-offs that have been made.

MIKE SOWBY. My concern here is that in some places they propose to take the water samples and then they try to infer what the impact was. My personal opinion is that if you take only water samples and you try to make some sort of damage assessment based on them the result will not be particularly meaningful. I think that you must sample the organisms that are out there too. I guess what I am saying is that you can't collect the chemistry without the biological data.

SHARON HILLMAN. The question of field biological assessments involves field bioassays. Field bioassays are not easy and the potential usefulness of results from them is controversial. I would like to hear the panelists opinions about the potential uses and usefulness of field bioassays.

MIKE BRONSON: My questions is, "Do you feel that rigorous mass balance estimates are a possible outcome of the kind of fluorometry that Charlie Henry has been talking about?"

CHARLIE HENRY. If I was asked to determine how much oil was dispersed, I would not use the fluorometry data in particular, I would use other mechanisms. The kind of monitoring that I do in the field to get at whether it is working or not won't get us to an estimate of how much oil was dispersed.

KEN TRUDEL. In doing the research for my presentation on monitoring yesterday afternoon, it looked like there are several purposes for doing environmental effects monitoring ranging from doing things that could feedback and control the immediate operation all the way to doing it for the sake of science. Could I ask Mike Sowby, in developing a state environmental effects monitoring plan for the State of California, what are your objectives and what will the information generated in the field going to be used for?

MIKE SOWBY. The first thing that you talked about was feedback, I am not sure that that is necessary, because I think that you have made a decision. Any decision that is made is made based on pre-planning. Because of pre-planning, when you choose to use dispersants you have accepted the risks of putting that in the water, so I would hate to see someone 30 minutes into the response say, "Whoops, we have some toxicity in the water. Let's stop." You pre-plan, you discuss with the stakeholders, and you make the decision that under these circumstances the trade-offs favor dispersant use. You have recognized and accepted the risks and impacts that go along with this because it is the lesser of the two evils.

The other part of the answer is that there is always a damage assessment that goes along with any oil spill. For political and other reasons, I think that you need the good database in order to go forward to determine whether there was no impact, minimal impact or significant impact on fisheries or on birds. In order to make that finding, you need the best database possible. I appreciate that the sampling and the water chemistry are important, but the question is that if you don't know what is there in the water column coming in contact with the dispersed oil, you really can't say much. In addition, when we are looking at impacts we should be looking at population impacts not impacts on individuals. If only one individual out of a population is affected, it is significant to the individual affected but from the perspective of the population as a whole the impact is insignificant.

QUESTION: I would like to expand on an earlier mention of the Sound Ecosystem Assessment Program. The ecosystem assessment program is a large, well-funded program which is approaching the point where its results will be published. In addition, the SEA made use of the traditional knowledge of the Natives and fishermen, important elements that must be considered.

RIKI OTT. What does the State of California do to verify the amount of oil spilled?

MIKE SOWBY. The OSPR has an investigation team whose sole responsibility at spill time is to determine how much oil was spilled, through calculation of what was on board, how much was recovered, and then trying to determine the mass balance. It is a difficult job.

JIM PAYNE. Charlie Henry asked me to comment on the two monitoring operations that we have done. We deployed field monitoring operations during two spills in the lower 48: the Pac Baroness in 1987, and the Mega Borg off Galveston in 1990. We did this because of the lack of any planned field experience with dispersants here in the U.S. One of the recommendations of the NAS Panel was to take advantage of spills of opportunity to obtain information on effectiveness and other questions. I was very gratified to hear that Alyeska has a system and equipment in place to amount one of these monitoring efforts. However, it is important to recognize that this kind of field activity is complicated and it is important that the spraying operation not be held up until the monitoring capability is in place. I was concerned that, in Alaska, state law demands that you must have this capability and I would like to know whether the law requires that you have this in place even before you go out and do your first pass or is it just part of the overall approach.

LESLIE PEARSON. It is part of the overall approach and the role doesn't specify the approach to be taken. It is a broad brush approach. It does bring in the question of doing real-time monitoring of environmental effects. What does this mean? How do you do it?

KEN TRUDEL. Since your state regulations demand some environmental effects monitoring, but you have said that no standards or criteria are specified; what do you think the objective or the purpose of the monitoring is? What do you think the information will be used for?

BRAD HAHN. The regulations are very general. They state that if you decide to use an alternative response method, i.e., dispersants, you have to be able to assess what the impact to the environment is.

How do I see the monitoring program? I see it from two ends. One is determining effectiveness and the other is determining fate of the oil. I would not delay a dispersant operation until I have the mechanism in place to gather these data. However, you need to have a detailed plan in place and the resources to deploy it so that it can happen as soon as possible.

What am I going to use the data for? I will use it to determine whether or not the dispersant application has been effective, to confirm or backup the visual observations. I am also going to use that information to determine what the fate of the oil is and then extrapolate to determine what the effects might be. To know what the effects are, you have to know what the fate is. I am hoping that we can then take that information and correlate back to the good information that CROSERF is getting.

In short, I am looking at this information from two ends. One is the effectiveness, and the other is the fate with extrapolation to effects.

SHARON HILLMAN. Leslie Pearson mentioned the Microtox test as having a potential role in monitoring. Although it is feasible to run it in the field, it is not clear to me what its usefulness or relevance is in reflecting the biological effects. My question is, " How is its relevance established?"

ALAN MEARNS. Regarding Microtox. We had an opportunity several years ago to conduct a trial spill of oil on a beach in Delaware. This may have been the only trial spill in the U.S. in the past decade. One of the things that we wanted to do was to test the use of a number of bioassay techniques to examine the effectiveness of bioremediation in reducing the toxic potential of the oil. Microtox assessment of pore-water was one of the effects tests. The sea urchin bioassay test was also used. The results from the Microtox experiment were favorable. They showed that toxicity could be measured for several weeks on the beach. I think there are several data sets available to show that Microtox can be used for near-real-time monitoring. None of this answers the question of what this means in terms of ecological significance. It is just a biological hit measurement, but you have a problem with calibration.

Summary

MIKE SOWBY: I have two points. First, don't predicate the use of dispersants on the presence of the monitoring team on station in the field. There are just too many things that can go wrong and can delay them getting into place. Second, I think this important to know what exposures are but it is equally important to know what is out there being exposed.

ROBIN LAW: One of the earlier questions said that it is important to have a detailed plan ready to make sure that the water sampling would be done and that all of the platforms, equipment and people who would execute the plan were identified. I think that it is also important that you have plans in place that will allow you to begin taking biological samples very soon after the incident. These samples are very important in providing some kind of ground-truth background to operate from. You don't necessarily have to analyze those samples right away, you can freeze them. But you can't go back and collect them at a later time. You therefore need to make sure that those are collected as soon as possible.

Charlie Henry and Alan Mearns had no summary remarks.

Panel #5: The Stakeholder Panel: Where Do We Go From Here?

Chair: Buzz Rome

Panel Members:

John Allen	**Native Subsistence Community**
Brad Hahn	**Alaska Department of Environmental Conservation**
Dennis Maguire	**Alyeska Pipeline Service Company/SERVS**
Ron Morris	**U.S. Coast Guard**
Riki Ott	**Commercial Fishing Community**
Stan Stephens	**Prince William Sound Regional Citizens'`Advisory Council**

In this discussion, each of the panelists made opening presentations and these were followed by questions from the floor. The full opening presentations of the stakeholders have been included, with the exception that the jokes have been left out. The questions from the floor and the ensuing discussions have been summarized for the sake of brevity.

BUZZ ROME: The last panel is a group of people who have been sitting patiently for the last two days listening to, absorbing and evaluating the information presented. They represent the stakeholders that we identified at this point in time to examine the issues surrounding dispersant use in Prince William Sound. Each panelist will make a five minute presentation and we will go in the order listed the program. I will ask Dennis Maguire to start.

DENNIS MAGUIRE: I've formed several questions over the last two days. Do dispersants work? The answer is yes. Are dispersants a viable response tool? The answer is yes. Will the Federal On-Scene-Coordinator (FOSC) and State On-Scene-Coordinator (SOSC) want dispersants at their disposal during a spill? Again, the answer is yes. The answer to all these questions is yes. Then why have two of the oil spill response organizations in the State of Alaska disposed of their dispersant capability. Why are a third and fourth willing to sell their dispersant capabilities, leaving only one company willing to maintain dispersant capability? I think there are two factors. First is an unwillingness to accept the risk associated with using dispersants. The second is the ability to support the expense associated with dispersants with so much uncertainty associated with it. As I stated in my opening remarks, in order to stay competitive, industry must shape its spill response inventory to provide the best response capabilities at the best efficiency. This is given regulatory concerns, response capability and cost. If we continue down our present path, Alaska will soon have only one organization left with dispersant capability. This trend applies not just in Prince William Sound. Similar concerns exist in the Southeast and in the Aleutians. Dispersants are a viable response capability, yet we're creating environments where the risk associated with having and utilizing dispersants are serving to reduce the availability of the technology, taking it away from those who have the responsibility (particularly the Federal On Scene Coordinator, and the State On Scene Coordinator) of overseeing the public's interest in response. Where do we go from here? We can go in several directions to build a world-class response capability. This conference is the first step. It is providing those of us who need it the information on where the new baseline is for dispersants. The last time that we got together in Alaska was five to six years ago and much has changed. I think we've established a new base line. I think that from here we need to move forward in small steps, setting short-term goals. We should be working with the Alaska RRT to re-examine the dispersant guidelines. I think that this should be a priority for them and for industries working with them. I've already said to several members that Alyeska will commit to supporting endeavors to update these guidelines. We need also to take a look at the operational aspects of dispersants.

I see in many ways a double standard. You know that we at Alyeska have started talking about a monitoring program and are committed to getting together and working with a number of folks in the monitoring program. I'm not seeing that happening with other people. Alaska North Slope Crude is not the only oil or product being moved in Alaska. We don't represent the only risk in Alaska. Dispersants are also a viable tool for the freight vessels moving through the Aleutians and for the Unimak Pass. They are also a viable tool for the passenger vessels spending more and more time in the State. So if we want to keep this as a viable tool, there has to be more of a commitment not by just industry, but also State and Federal Government and other organizations who have the potential to benefit from this. Thank you.

STAN STEPHENS: Well first, on behalf of RCAC in the Prince William Sound, I really want to thank everyone here for addressing such a complex issue. It is very important to the citizens that we address this issue and that we try to come up with a solution.

We from RCAC, need to consider and try to sort out what's been said here in the last couple of days. Our job is to advise industries in these kinds of areas. Many of you have brought up new ideas, new thoughts and directions that we need to look at. We may be settled in our ways and we need to reconsider what's been said here. The stakeholders need to be heard. It's the stakeholders and citizens of the State that are really important. The bottom line for oil spill planning is not what it costs the oil industry to clean up oil on the shoreline, or what it cost the tourist industry or fishing industry. Rather it is the health and well-being of the people in the community that is important. We get kind of into a dilemma and I hope that you here today won't take what I'm going to say wrong; but for a few years when we first started RCAC, we became involved with dueling scientists over air quality in Port Valdez. We have very good scientists with excellent credentials on both sides, but they were 180 degrees apart.

The reason that I bring this up is that it's hard, hard to know what science is about sometimes. Because they present both sides of the argument and we must figure out which is the right solution. We hire people to advise us and we have to listen. We will be getting back to many of you soon to try to sort out what did happen here the last couple of days.

I want to talk about the *Braer* because before that vessel had actually hit the shoreline, a number of us were on our way to Shetland. I didn't go because I had knowledge of oil. I went there because I had knowledge of tourism and that was one resource that was damage in the *Exxon Valdez* Spill and I was hit hard by it as were many others. I went to Shetland to help advise the tourist industry. There's a couple of things I learned. One was that the ship was as tough a vessel as you could imagine. I couldn't in my wildest dreams think that any vessel could hold out under those conditions. When it did, it made me realize that it really wasn't the ship's fault that we're getting beaten to death, but it was major human error that we had to contend with. The other thing that was different was that you would see the oil roll out of the ship and hit the shoreline and I went down to the rocks where it hit the rocks. I would run my hand over the rock and I couldn't even get enough oil to put on my fingers to get it to stick, and yet a little oil was hitting the rocks. If I had done that with the *Exxon Valdez* oil, I'd be trying to pull my fingers apart. With hurricane force winds, the oil was dispersed quite easily, but even with that they still were finding oil amongst the sands offshore at Shetland. Whether it is doing any damage or not, I don't know.

In Prince William Sound I get a little bit concerned about using dispersants because it is a very complicated system. The Sound is not all the same and I thought I understood currents in the Sound, until I got a hold of the study done by Prince William Sound Science Center. I was amazed to see that every month the currents and temperature are different. At Hinchinbrook entrance there's sometimes one current that's going one way and another strong current going the other. I think it's going to be very hard for us to successfully use dispersants until we better understand the areas we're going to use them. Some comments were made today suggesting that we have to decide whether we want oil on the shore or whether we want oil in the water column. These are decisions that none of us want to make, and I'm hoping that we never will. I think we need to remember that everything spreads and nothing disappears. I just want to leave you with three words: prevention, prevention, prevention. Thank you.

BRAD HAHN: I am one of three State On-Scene-Coordinators and it is a very difficult job. I've got to represent the interests of all stakeholders. As Stan mentioned, this includes fishermen, local residents, subsistence users, recreational users, land owners and the list goes on. Not always will all these groups have the same opinions concerning response tools. The goal is balance. We have to consider what the trade-offs are. I think we have to look at balancing them taking a system-wide view. This conference has helped me a lot to understand these trade-offs and I hope it has helped others. That was my goal in working with the other sponsors in bringing this conference together.

So where do we go from here? I have gleaned two points. First, I think we need to evaluate and update our guidelines. Second, I want to ensure we have a capability for good environmental monitoring.

If we have a significant spill tomorrow, I hope we can clean it all up using the mechanical equipment that we have. We probably have the best capability in the world in Prince William Sound from a mechanical clean up perspective, but do we think that we can still clean it all up? Mother Nature and Murphy are going to intervene and I think it's going to be a difficult task. We may be faced with the decision of whether or not to use dispersants. The decision tool is our guidelines. I want to make sure that we have the best tool possible.

Our guidelines are about 10 years old. Since that time we've got a lot of new information and we've heard a lot of that today. We have new research, the CROSERF work and work that's been done in other countries. We also have case histories to look back on. The *Sea Empress* is a great one. It's one of the key things that I wanted to bring out here. We have to learn from our past experience and past failures. We were the first in the United States to institute guidelines, but since that time there have been numerous other guidelines brought in. I think we can learn from what they have done and are doing. Last but not least, we have conducted million of dollars worth of research in Prince William Sound since1989 as a result of the spill. I think we need to utilize this research and knowledge in our guidelines.

Can or should we update the guidelines? I think that answer is "yes", but the issue is with resources, time and money. It is not an easy task as we have heard here. The scientists who wrestle with it, tell us we must assemble all kinds of information, different scenarios must be played out, and trade-offs must be made. I've got to have the resource agencies tied in to the process, as well as the Coast Guard, fishermen and other stakeholders. I would just say at this point that we might not be able to do it tomorrow, but I think we have to put it on a list of priorities. I think we need to look at it from a stand point of net environmental benefits and trade-offs.

The second point is to ensure capabilities for field monitoring. I've already addressed that earlier and made most of the points. I'm very pleased to be working with Sharon [Hillman] and the progress that we've made to date. I would like to move back a little bit to touch on CROSERF data because it is the CROSERF data that we plan to compare our field monitoring results against. Why? Because as we heard earlier, this data is based upon the most sensitive life in stages, so it is like a worse case scenario. Even though we may not know what is out there at the time of the spill, if we are receiving real-time data back and we can compare it to reliable toxicity data, it gives us a level of understanding of what potential impact that the spill can cause. We need to know whether our analysis of net environmental benefit was reasonable, so we can learn and move forward. Up-front planning is necessary to make it happen.

RIKI OTT: I was involved with the RRT when the zonation plan was established in Prince William Sound. I'm not saying that I would like to be part of the next go around, but I do think that there should be another go around and I do think that the RRT is overdue. We need to incorporate the data from the *Exxon Valdez* oil spill, including: the acute data; the chronic toxicity data, and the data on chronic toxicity of acute exposures in species like the herring. Since things seem to get so trifling and political in this State, I would like to see, as part of the process, the RRT peer review the revised guidelines and go to states like California and get input before we finalize. In the revised guidelines I would also like to see the following.

1. I would like to see a standardized mechanism for verifying the amount of oil spilled.
2. I would like to see a meaningful standard for human to oil in the Native Community. I was appalled when the government came in and said, "Don't worry according to our calculations....." and there was no mention that these calculations were based on only edible portions of flesh, which include only the muscle tissue. Here the Natives consume all parts of the animal. The standards were not relevant at all in the Native community. Thank God those people had common sense. They took a look at the mussels dying and said, “ I don't think we should eat that even though the government decided it was safe".
3. I would like to see the RRT recognize some toxicity end-points that are less old fashioned. I'd like to see more state-of-the-art chronic toxicity data incorporated. That goes for oil as well as for dispersed oil. The RCAC did not exist when the first RRT standards were set in 1988. We would really like to see them involved in a major outreach to all user groups as part of the

process. A very good effort was made in 1988 to get out and reach people and I would like to see that continued this next go around.

I'd like to make two final points here. I have a slightly different spin on the answer that Dennis gave to his question about yes, yes, yes and yes, and then is curious as to why we don't use dispersants. I would like to say that the reason we have problems with dispersants in this State is because the public lost a great deal of faith in the government's ability to regulate the dispersant use. For example, EPA has a set of guidelines and dispersants which do not meet these standards are not supposed to be used. The EPA standard for acceptance as far as effectiveness is concerned is 50% effectiveness in a standard test. According to the EPA's test the effectiveness of Corexit 9527 is 38%. It does not meet the guidelines. Furthermore, EPA's guidelines also ban carcinogenic, reprogenic and teratogenic dispersants. Corexit 9527 has all those compounds yet we have over 60,000 gallons of it in a warehouse here in Anchorage. So, it's a little disheartening to the public when we compromise and say, "Yes you can use dispersants in Zone One". Then we go to the EPA to figure out which dispersant they will approve and the guidelines bend. They bend in favor of industry at the cost of increasing public risk. I equate this with the EPA looking the other way when hazardous waste is being mixed with the fertilizer and spread all over farms; the next thing you have is kids and crops all having some problems. As far as I'm concern, we have 60,000 gallons of hazardous waste sitting in Anchorage right now and I would like to hear how EPA is going to dispose of it. I would personally ask for an injunction if there's another oil spill. There has got to be some mechanism for industry to improve. When the public agencies who are responsible for public health and safety in the environment allow this kind of thing to happen, it is not in anybody's best interest. This does not give the industry any incentive to improve and approach the state of the art capability, which I believe we're entitled to. So.... fair warning, I really hope that something is done with this stockpile of hazardous substances. I think that's all I have to say.

JOHN ALLEN: I want to start by saying that I appreciate the opportunity to be here, whoever is responsible for having this. I represent some subsistence users, who are the fishermen. We appreciate the opportunity to have a voice in these proceedings. It's kind of a first for me, I've never had an opportunity to comment like this. I would like to make an analogy of what it's like to live with the threat of another oil spill. We've experienced one and there's always the threat of another one. Let's just imagine that I'm mean and ugly, but it's just an analogy. Let's also say that there's something wrong with me mentally and at times I pick up chairs and beat people over the head with them. If these guys don't know me, they don't know whether or not this is true. But what do they do? They say, "Give us some protection, we want to go dress up like a goalie, we want helmets. We want to be protected." That's where we are in the subsistence community. That's where we are as commercial fishermen living in Prince William Sound. We want a measure of protection just in case. We see the dangers lurking out there. We come today and I can say, "Well, over the last 20 years I only picked up one chair and actually hit somebody with it". We are going to adopt a state of complacency. Not only me, but the people sitting here. They may say, "Well there's no danger". Even after the first time I picked a chair up and hit somebody, they became very aware of me. When I stood, they said, "He's standing up". When I take the chair up they'd say, "He has the chair in the air, we're concerned and I want protection". That's where we are today, we're saying we want protection. We see a danger of me saying to these guys, "It's all right, now don't worry about protection". I say, "I've got this salve, and I'm going to put it on you after I hit you. I'm going to apply it to wherever your wounds are and everything will be all right". I know I'm concerned. I don't have much faith in the stuff. It's just an analogy.

But we deal with unknowns in Prince William Sound. The oil industry has been there for 20 years, that's 20 years experience in the Port Valdez, and I challenge them to accurately predict the surface currents. I don't think they can do it; much less if they looked under the surface. I am always amazed by conditions in the Sound. I fished at Port Valdez and waited all day for the tide to change so I could catch the fish. It never happened. We don't know how the tides operate, much less what happens below the surface of the Sound. There are places in the Sound where we fish day after day, year after year. We know what's happening on the surface, but what's going on down below? No one can make the prediction and say, "I am going to disperse oil in the water columns and I'm going to tell you where it's going to go", because you can't do it. I'm afraid that once this oil is in the water column we're going to contaminate the whole Sound. That's an unknown we'll deal with.

Exxon Valdez proved to us that once untreated oil is introduced into the environment, it's basically there for life time. RCAC has done studies, a mussel study in particular and said that hundreds of miles from the point of exposure you're going to get contaminated mussels. Those are the things that concern me. We heard yesterday from the people from the Shetland who told us that 100% of the salmon that were exposed with dispersed oil, there was a mortality rate of 100%. We believe that if we lose two years of our pink salmon run, it will be 10 - 20 years before they even begin to recover. The natural stock, I don't think has ever recovered from the 1989 spill. The hatchery stock had survived and we were able to make a living off of that, but we haven't seen the natural stock. It's a fragile environment, particularly the salmon are hard to predict. There's so many variables. Our fear first of all is that we can't equate dispersing with removal. By law, federal and state, I understand that if you spill oil, you have to clean it up. It says removal it doesn't say spread it around. I might be wrong about that. Our fear is that with preapproval of the use of dispersants, they will not only be the primary response, they will become the only response. Thank you.

RON MORRIS: I am fortunate as the Federal On Scene Coordinator that we have an agreement within the Prince William Sound to assist me in making that go or no go decision for dispersants. From an operational perspective, I have a short window of opportunity for dispersant use. I have the need to make an informed decision that will fundamentally do more good than harm. I submit that the guidelines that we have now are inconsistent with the material and information that we have seen today. We should be able to see if changes could improve our ability to respond and reduce the impact of the spilled oil. During the examination of the issues, we can review our current agreements, validate what we have, or add options that will enhance efforts. Now I will talk about some about minor adjustments that we could make to our current dispersant application procedures, i.e. putting the State's signature on there. It seems like a small thing, but it is part of the documentation for the approval process. The more difficult challenge, though, is with our current application forms for dispersant use, in having the resource agencies that are responsible for completing the "resources-at-risk" portions (the habitats, the biological resources and human resources), identify which sections they are responsible for, and possibly address the trade off issues. I listened with great interest yesterday to the description of the efforts that will soon get under way in Washington and Oregon as they begin to work on their ecological risk assessments. Is that something that we could explore here in Alaska? The idea certainly has merit for our area. Not too long ago we were engaged in the Prince William Sound Risk Assessment for the shipping of oil in and out of the port there. It was a great effort several years in the making, lot of dollars, lots of research was taken into that. The key to that was that was that it was a stake holder effort; a lot of people were involved, a lot of the stake holders were involved. Through that, we've built a consensus on what the results were and the recommendations that came out of it. I looked at the ecological risk assessments and the three steps indicated, i.e. problem formulation, the analysis and the risk characterization. With the stakeholder involvement, it certainly is a sound method for pursuing such an issue here in Alaska.

How do we get there? I believe we have to get there through the Region Response Team, Science and Technology Committee. Members of that committee are probably cringing right about now, but working with the RRT provides a mechanism to involve the resource agencies and pull together all the interests of stakeholders as we explore the best way to approach the issue. I started out yesterday morning with a kind of thought. I'll just echo what Stan [Stephens] had to say that prevention is really the key. We've got a system of transportation up there and if we can keep it inside the envelope, that's the best way. However, when it gets out of there, we've got to have a plan. We have to have a method to make informed decisions. I hope that we can make some more progress in this direction with our existing agreements.

BRAD HAHN: The monitoring plan should not become a hindrance to the use of dispersants. That's exactly the position we take and I want to be clear on it. From the State's prospective, our top priority is getting the oil off the water, not putting the oil into the water. Dispersants are our last ditch effort.

STAN STEPHENS: I agree with what you're saying and I think we do need to listen to what you have to say but I also think that you need to listen to us a little bit, even though we are not the scientists. The area around the U.K. is quite different that which we deal with in the Prince William Sound.

CARL LAUTENBERGER: Corexit 9527 is on the National Contingency Product Schedule. The regulation is 50% effectiveness of test oils averaged together. One test oil is Alaskan North Slope Crude, one test oil is Louisiana Crude. The whole idea behind those tests were to ensure that chemicals that were formulated as dispersants were listed, and others weren't, were not.

COMMENT: My concern is that we use every tool we've got in the tool box to get rid of that oil and to take care of it just as quickly as we can with the greatest safety to the people, the least damage to the environment, the wildlife and the fish.

BRUCE MACKENZIE: “Is Alyeska considering relinquishing their dispersant capability. A question for the rest of the panel members is, would anybody on the panel be concerned if Alyeska said, "Okay we're getting out of the dispersant business"?

DENNIS MAGUIRE: At this time Alyeska is not considering relinquishing or giving up it's dispersant capability.

RON MORRIS: That would concern Coast Guard. I'd hate to see the ability diminished down to what we couldn't even consider. If they don't have capability, it's not in the area, then you don't lose your window of opportunity. Even if we can't decide if it's the right thing to do, we wouldn't have an opportunity.

QUESTION: We know what we know about the limitations and the capabilities of mechanical recovery, but in spill after spill, experiment after experiment, we've encountered the limitations of that approach. It's apparent in this conference that we have additional things to learn, and not just about dispersants. We need to learn more or at least address where the questions are about the environment into which we might propose to put dispersants. I guess the philosophical question to the panel is this: "The problem is not the effectiveness. The problem is that they're not sufficiently punitive. If the object of law and regulation is not to try to do what is effective, but instead to ensure that sufficient penance is done and sufficient retribution is exacted, then dispersants and burning don't meet the test."

JOHN ALLEN: I would like to make one comment on that. The thing that I see with dispersants and burning is that it is not the removal of oil that's required, but it's a chemical change, as it were. Burning takes the oil from the sea surface and puts it into the air as soot. Dispersing shifts the oil down into the water. Neither removes the oil from the environment. Those are the things we have problems with.

RIKI OTT: I'd like to add that the industry and perhaps the people who are looking at dispersant use, are not really totally honest with the effects of dispersants and that's part of the problem. You see what you want to see and you're not seeing everything that's there. For example, the chronic effects of your acute exposure.

DENNIS MAGUIRE: When you look at what Alyeska and the oil companies are doing, you have to look at dispersants as a small part of our response capability. The whole story's part is prevention. Prevention in terms of the design of the tankers, the training of the crews. The Coast Guard's vessel tracking system. The escort system, the tethered tugs, the acquisition of new tugs, the "Voice Snider" (sic) tracker tugs. As soon as we recognized there was a potential hazard at Hinchinbrook Entrance, a very large rescue tug was added. That's literally more than half of what we're talking about here. That's the prevention component of this system. The other component is the response component. We have, and our major focus is mechanical collection, mechanical clean up. It is the most significant collection of response equipment in the world, and it's mechanical. Beyond the mechanical (and that's all that we're required to have is mechanical), but we have recognized that you need a diversity of tools. If you build a house, you don't just stock up on the saw or a hammer say, "I'm going to build some things with one tool", you need a number of tools to construct something worthwhile.

QUESTION: Yes, I'd actually like to direct this mostly to John and Riki. I understand that the topic is use of dispersants, but we are here to listen to one another and we're looking for the best solution. If dispersants aren't the best solution in some cases, what would you see as a better tool. Also, what type of testing would you be willing to use or look at to give you more confidence in the use of dispersants?

RIKI OTT: Common sense where you don't have to average your standards with Louisiana crude. I mean if we're going to have put it on, put it on something that's going to be effective, and effective in terms of EPA standard test not in terms of industry test which are going to try to make it look as effective as possible. I do recognize dispersants as a potential tool. I'd like to see some kind of effectiveness monitoring afterward and not just a year after it, or just two years after it, but over life cycles of pink salmon, over life cycles of herring so that we get the answers to chronic exposure.

JOHN ALLEN: I would like to see the fate of dispersed oil studied and the flushing time for the Sound. That's a concern. There's been much said about short term contamination in the water column beneath the slick. That might be true if you spilled 100 gallons of oil out there and put dispersants on it, but with larger spills that is not going to happen. The oil will cover a large portion of the Sound. That's what I'm concerned about. It's going to settle out to lower areas of the Sound and to the trenches where fish live.

RIKI OTT: The public tends to look at the oil industry as kind of a lump. There's a promise by industry to have some better idea on currents in nine months. Well I'm willing to bet in nine months we don't have it. We've waited a year and a half. DEC has asked the industry to get the deadlines. But if it's something that industry wants, we all have to hustle to get it.

JIM PAYNE: I think John's point about the currents and Riki's point about the currents is well taken and more information needs to be obtained and talk about the fate of dispersed oil if it should get down below the upper mixed layer where all of they suggest so far to where it's been. Riki in regard to your comment with the different laboratory methods, I'm sorry that you weren't here yesterday because there was a great deal of time that was taking to talk about the different lab methods and the problems associated with them.

RIKI OTT: I acknowledge that a laboratory test can vary, and my concern is that if we add on human error and we add on these uncertainty in the field, we better be working with the most conservative methods, not the least conservative.

SY ROSS: I resent being called dishonest. There are scores of years of experience here in the area of dispersants. Some research has involved the oil industry, but most has involved government scientists. There's a genuine dishonesty here and that's the big lie about the capability of mechanical recovery. There was tremendous pressure to tell the industry after *Exxon Valdez* that they have to pick up all the oil. Their answer was that they had the capability. That's what the public probably believes and that's why there's a lack of interest in looking at other methods.

LYNDA HYCE: Well, I just wanted to mention that getting from science to policy is what this is all about. We came here and heard a lot of the scientific reports and learned how that related to policy. I think what these stakeholders are saying here today is that we can take the scientific information from these folks who don't live in Prince William Sound and don't rely on its resource for a living and we respect all of their input. However, when it comes down to placing a value on intertidal and water column resources and habitat, we have to trust local opinion and accept their decision making process. That is as valid as the scientific decisions are at the other end.

Summary

RIKI OTT: Prevention. Prevention. Prevention.

JOHN ALLEN: Our view here needs to be geared toward, "Can dispersants work / do they work?" They do work. You've all agreed on that. We should also address the question, "Can we use it or may we use it?" The question, "Can we use it?", I think has an answer. The question, "May we use it?", I hope will be considered.

BRAD HAHN: Prevention is the key. We must not allow the oil to get out. However, if it does, we have to be ready. I think that we have excellent mechanical capabilities in the State, but there are situations where mechanical may not work for us. We have to have alternatives and I want to have the best plan in place in terms of guidelines on how to use those alternative tools.

RON MORRIS: You can do whatever you can on the prevention side, but are you never going to prevent every casualty? So in the event that you do have your next event, you've got to be ready. I look forward to exploring the guideline changes, even though it's going to be a big task. I think it's something that's going to be well worthwhile once we get done.

Stan Stephens had no summary remarks.

DENNIS MAGUIRE: What I've heard here are the words "common sense". That's what we need.

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