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Use of Chemical Dispersants for Marine Oil Spills

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USE OF CHEMICAL DISPERSANTS FOR MARINE OIL SPILLS

by

IT Corporation
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Project Officer

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FOREWORD

Today's rapidly developing technologies, industrial products, and practices frequently carry with them generation of materials that, if improperly dealt with, may threaten both human health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural resources to support and nurture life. These laws direct the EPA to conduct research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs. These programs provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication presents information on current research efforts and provides a vital communication link between the researcher and the user community.

An area of major concern to the Risk Reduction Engineering Laboratory is the impacts associated with oil spills in both marine and freshwater systems. This document is intended to bring together all pertinent information on the use of chemical dispersants as a tool in controlling oil spills in marine waters. It is meant to be a neutral presentation, referencing existing literature to the extent practicable, on the advantages and disadvantages of using dispersants.

Further information relative to this document may be obtained by writing to Daniel Sullivan, P.E., U.S. EPA (MS-106), Releases Control Branch, 2890 Woodbridge Avenue, Edison, New Jersey 08837-3679.

E. Timothy Oppelt, Director
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ABSTRACT

Chemical dispersants are one of the tools available to oil spill response personnel during a spill incident in marine waters. This document presents information from the literature relative to dispersant effectiveness, toxicity, and other environmental factors, regulatory and administrative considerations, application methods, the dispersant use decision process, and practical considerations for dispersant use. It is meant to be a neutral presentation on the benefits and disadvantages associated with dispersant use in marine waters.

Numerous documents have been published on the fate and effects of chemically dispersed oil, the effectiveness of chemical dispersants, application techniques for dispersants, and criteria for deciding whether to use dispersants. Most of these documents have appeared in the proceedings of the biennial Oil Spill Conferences or have been published by the American Society for Testing and Materials (ASTM), the American Petroleum Institute (API), and various other U.S. and foreign sources. Because these documents were produced by a wide variety of sources over a period of years, this document compiles relevant information from these sources into a concise format for the use of planners, responders to oil spills, and the lay public. The document has been reviewed by a group of 20 technical advisors and reviewers who are listed in the Acknowledgements. The document contains four appendices that provide information on vessel and aircraft application equipment, conversion factors and calculation tables, example decision trees, and a bibliography.

This report was submitted in fulfillment of Contract No. 68-C2-0108 by IT Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 1992 to September 1993, and work was completed as of September 1993.

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ABBREVIATIONS AND ACRONYMS

ACP	Area Contingency Plan
ADDS	Airborne Dispersant Delivery System
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
COTP	Captain of the Port
CWA	Clean Water Act
EPA	Environmental Protection Agency
ERT	Environmental Response Team
FOSC	Federal On Scene Coordinator
HV	High Volume
IMO	International Maritime Organization
ITOPF	International Tanker Owners Pollution Federation
LV	Low Volume
MASS	Modular Aerial Spray System
MMS	Minerals Management Service
NCP	National Contingency Plan
NCPPS	National Contingency Plan Product Schedule
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OPA	Oil Pollution Act of 1990
OSC	On Scene Coordinator
RCP	Regional Contingency Plan
RREL	Risk Reduction Engineering Laboratory
RRT	Regional Response Team
SLAR	Side Looking Airborne Radar
SSC	Scientific Support Coordinator
STP	Special Technical Publication
ULV	Ultra Low Volume
UNEP	United Nations Environmental Program
USAF	United States Air Force
VMD	Volume Mean Diameter

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This document was prepared by IT Corporation under contract to the Risk Reduction Engineering Laboratory of the U.S. Environmental Protection Agency. A group of technical advisors and reviewers was established at the beginning of the effort to comment on the document as it was being written; however, their participation does not imply concurrence with all conclusions in this document. That group is acknowledged below. Further, comments on the completed draft document were solicited from members of the National Response Team. Parts of the document were extracted from draft dispersant use documents being produced by the Region II Regional Response Team.

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SECTION 1

INTRODUCTION

The literature contains a great deal of technical information regarding responses to oil spills as well as the fate and effects of oil in the marine environment. This document provides an overview of the general concepts and conclusions of previous research and observations pertaining to one type of oil spill countermeasure--oil dispersing chemicals. The material presented in this document is intended for use by regional response teams (RRTs), areawide committee members, other planners and responders to oil spills, state and local officials, and the general public. This document is intended to provide a basic understanding of oil dispersant use as a spill response measure and the trade-offs that may be involved in the decision to use dispersants or to follow other response actions. Technical details on the application of dispersants are included to assist response personnel in preparing for and carrying out a spill response involving the use of dispersants.

Although oil spills can occur in several environments, including on land and in rivers, lakes, and shores, this document focuses solely on use of chemical dispersants for oil spills occurring in the marine environment. Details of the concepts presented here cannot be extended to the freshwater environment because not only do dispersants perform differently in freshwater, but the fate of dispersed oil in a river or lake may be very different from that in the marine environment.

Dispersants do not provide a direct cleanup method for oil spills because they do not remove the oil from the environment. Instead, dispersants promote the distribution of oil throughout the water column and, as such, represent an oil spill control method. Dispersants can also be used in conjunction with other oil spill control methods when properly coordinated. The appropriate use of dispersants may provide an increased measure of control in affecting the fate of spilled oil. In any event, the decision to use dispersants must be weighed against the relative risks of allowing the oil to reach possibly sensitive shoreline areas vs. mixing and diluting it into the water column.

In practice, only rarely is any countermeasure completely effective in removing floating oil. Just as mechanical recovery operations rarely collect more than 10 to 15 percent of the oil in open-sea conditions, dispersants usually remove as much as 30 percent of a large spill from the surface under good conditions (Moller, et al., 1987; Nichols, 1993). Because environmental and economic impacts will occur regardless of the type of response, the best spill response is one that minimizes the overall impacts.

1.1 Characteristics of Oil and Oil Spills

Oil is composed of thousands of hydrocarbon compounds whose relative proportions vary, depending on its reservoir of origin, date of production, and subsequent processing, transportation, and storage history. Oil consists mostly of low molecular weight compounds (aliphatics and aromatics) that allow it to remain in a liquid state at ambient conditions. These compounds act as solvents for the higher molecular weight compounds (asphaltenes, resins, waxes).

Although a considerable amount of oil enters the environment from natural seeps, significant amounts are also accidentally spilled or discharged. The vast majority of spills are small, under 1000 gallons. In 1990, for example, the following oil spills occurred:

- 12,892 oil spills of less than 1,000 gallons (24 barrels)
- 980 oil spills of between 1,000 and 10,000 gallons (24-238 barrels)
- 208 oil spills of greater than 10,000 gallons (over 238 barrels)

Although the largest spills (usually from supertankers) are most often associated with coastal marine waters, many large spills have occurred on inland freshwater systems. Figure 1-1 shows the number of large marine spills for the past 22 years.

The detrimental effects of oil spills are most dramatic when oil is seen smothering small animals or inducing hypothermia (by nullifying thermal insulation) in ocean mammals and wild fowl. Components of oil can also be toxic to specific organisms by causing

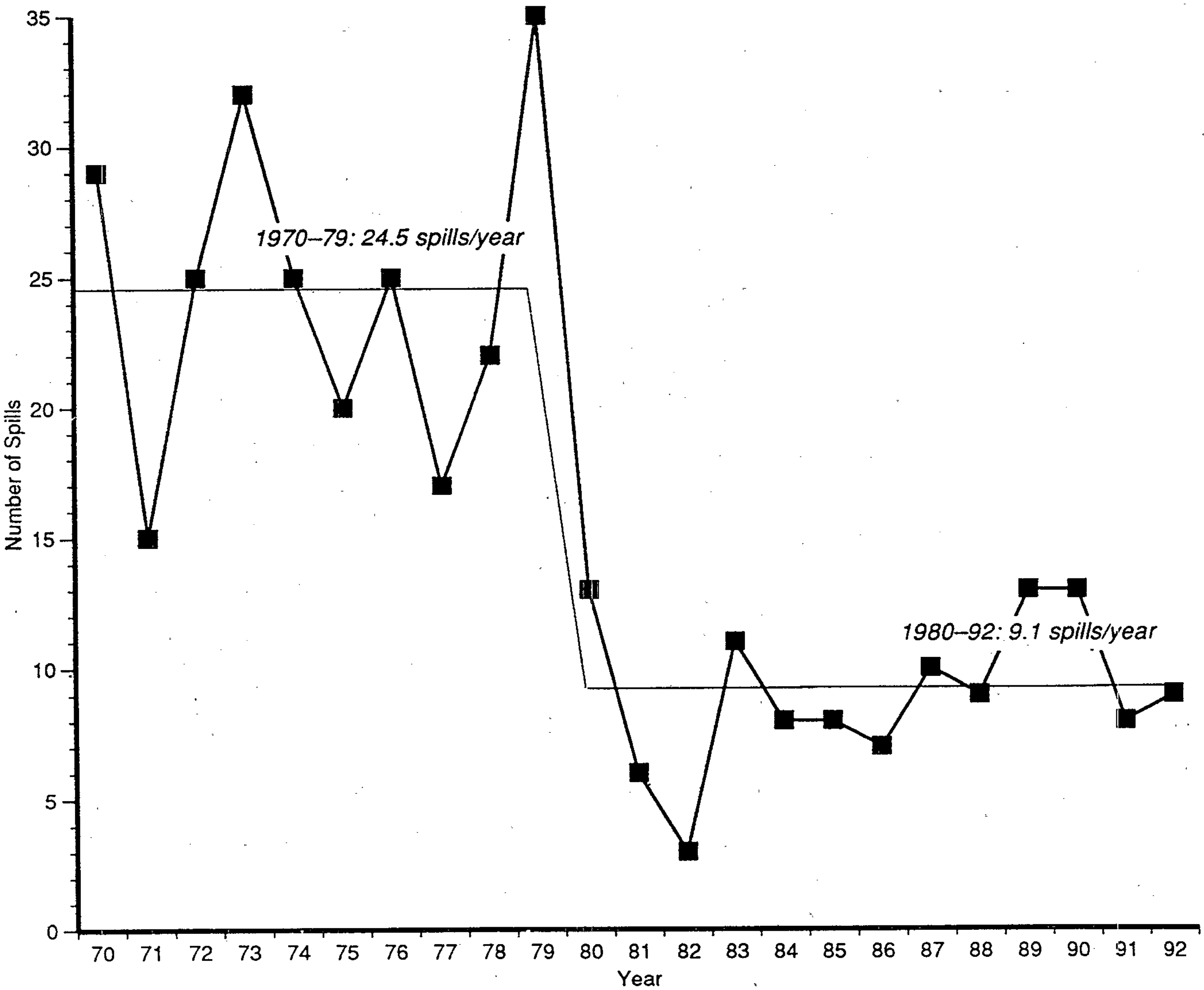

Figure 1-1. Major tanker spills*, 1970–1992.
(ITOPF, 1993)

*greater than 215,000 gal (700 metric tons or 5,130 bbl) fatal injury or alteration of behavior so as to greatly shorten lifespan. Spilled oil can also render ecological niches incapable of life support for a season or for a longer period. Under proper conditions, however, oil can provide a food source for some microorganisms, thereby affecting the degradation and fate of oil in the ecosystem.

1.2 Response to Oil Spills

In 1968, the Federal Government began oil pollution response efforts in the areas of prevention and cleanup. In addition, current laws and regulations require a number of safeguards. For example, regulations were developed to provide added protection when oil is transferred between ships and shore terminals, and spill prevention regulations were designed for onshore and offshore facilities. Accidents still occur despite these precautions, however, primarily because of human error or equipment failure.

In cases where oil spill prevention has been ineffective, the preferred response has been to contain the floating spill and to physically remove as much of the oil as possible from the marine environment. An oil slick is typically contained with booms to prevent further spreading and to reduce the movement and contamination of sensitive environments. The oil is subsequently skimmed and either recycled or disposed of at a land-based disposal site. Unfortunately, collection efforts only account for approximately 10 to 15 percent of the oil spilled in the open sea. Inclement weather and logistical problems (such as the lack of timely access to sufficient boom/skimming equipment) often account for these low removal rates. Mechanical skimming generally can be attempted if winds are under 20 miles per hour (30 kilometers per hour), but it is more effective at lower wind speeds. When winds are greater than 30 mph (50 km/h), skimming is not effective.

If physical oil removal is ineffective or unable to be implemented, the next choice has been to try to keep the spilled oil from contaminating the most biologically or culturally significant resource areas, such as the shallow benthic zone and the shoreline. This approach usually entails the use of booms or other barriers between the oil slick and the resource. Other possible alternatives include the following:

- Using dispersants to transfer oil from the surface into the upper water column.
- Burning oil in place.
- Accelerating biological treatment of the oil in place.
- Using sinking agents to move oil to the ocean bottom.
- Doing nothing.

Of these, the only direct prohibition by EPA has been on the use of sinking agents.

1.3 Oil Burning

Oil burning has been used with limited success in test spills to remove a substantial portion (90%) of spilled oil. Although it has only been used once in the United States (Exxon Valdez), burning has been used successfully in certain limited applications in Canada and Norway. Burning is restricted to an oil slick that has specific properties, and the physical and environmental conditions must be within fairly narrow limits for burning to be successful. Such conditions are not present in most spill situations; when all conditions are favorable, however, burning has the greatest potential for rapidly removing the bulk of the oil from the water and leaving only a viscous tarry residue.

The trade-off in the use of burning is the generation of smoke plumes (particulates) and potential air pollutants. Also, the heat and flames generated can be quite substantial, up to 300 feet (90 meters) into the atmosphere. This may be an acceptable trade-off, however, for a short period of time in the open sea. Certainly, the issue warrants further attention. Federal research on oil burning is being conducted primarily by the National Institute of Standards and Technology (NIST) and the Minerals Management Service (MMS) of the Department of the Interior.

1.4 Accelerated Biological Treatment

Biological treatment has often been suggested as a tool in responding to oil spills. This treatment, however, has two major drawbacks: (1) its natural processes are slow when compared with required response times for open water oil spill cleanup; and (2) the elements needed for biological degradation (i.e., sufficient nutrients) are difficult to maintain in correct proportions on open water spills. The addition of nutrients may also pose a toxicological hazard to marine organisms. Further, a typical slick moving toward a shoreline or other sensitive area is likely to impact it before effective biodegradation can occur.

Over a period of weeks or months, however, biological processes can have substantial beneficial effects. In addition, organisms that can degrade various hydrocarbons abound. Given proper environmental conditions, sufficient nutrients, and time, these natural processes are probably the paramount activity for cleansing ecologically sensitive areas of oil pollution. Further, bioremediation systems can be used to treat recovered oil and oil-contaminated debris.

1.5 Sinking the Oil

Sinking the oil has been prohibited in this country because the impacts on productive benthic aquatic ecosystems would be greater than leaving the oil on the surface. Further, much more time is usually required for biological degradation because less oxygen is available in the bottom sediments.

Considerable laboratory and field data have been generated concerning the effects of petroleum hydrocarbons on marine benthic communities. Long-term exposure to concentrations in the 1- to 100-ppm range results in acute toxicity for some benthic species. Such long-term exposures are not typical of dispersant use. If, however, the oil is trapped in sediment and is slowly released over time, chronic toxicity problems can arise for benthic species. The exposure of benthic species under these conditions is similar to laboratory toxicity test exposures in which chronic toxicity tests have demonstrated numerous lethal, developmental, and behavioral effects. Thus, the risk of adverse ecological effects is extremely high if oil is incorporated into bottom sediments following the sinking of an oil slick.

1.6 Planning and Regional Contingency Plans

Advance planning and preparation are essential for any successful response. The procedures to be followed must be decided upon in advance instead of during the crisis situations that occur during a spill. The planning document developed by the RRT is a regional contingency plan (RCP) that outlines a spill response policy. Many regions of the country will address marine dispersant use in updated RCPs and in Area Contingency Plans (ACPs) developed for each Captain of the Port (COTP) zone. Each plan committee is requested to formulate expedited decision-making procedures governing the use of dispersants and other chemical countermeasures in their area.

This document presents a foundation for the dispersant planning process. Planning for all contingencies, however, is not possible. An oil spill is usually accidental, and response to the spill depends on numerous unpredictable variables. Certain planning actions can be put in place that will improve the response and thus lessen adverse impacts. Proper planning should address not only the decision process (Section 7) and the type of dispersant and equipment to use (Section 6), but also the availability of the dispersant and equipment. Unforeseen events may still occur, however, that have unplanned consequences. Oil spill response planners, who have a basic understanding of available response options, can address these unplanned events.

Immediate decisive action in the event of an oil spill can appreciably reduce the impact of the spill. In addition, a spill response must be flexible enough to address the changing events by applying alternative technologies and/or conventional methodologies in concert, as appropriate. Two responses that have had extensive application in the United States are off-shore recovery and shoreline cleanup. This document focuses on the use of oil spill dispersants. The material in this document provides much of the information needed for a planner to evaluate conditions and implement dispersant use when circumstances are favorable.

1.7 Stages of An Oil Spill Response

The response to a typical oil spill involves three stages. The first stage is characterized by confusion resulting from a lack of information, the second stage by initial countermeasure implementation, and the final stage by stabilized response. Oil spill dispersants are most likely to be useful during the first two stages.

The first stage of a spill, when the lack of accurate information generates confusion concerning an appropriate response, is the time to begin to mobilize dispersant equipment and make preparations to start dispersant application if further reconnaissance indicates conditions are appropriate. Preparation for dispersant application during this stage is one of the critical factors in an effective oil spill response. Dispersants are more effective on fresh crude oil compared with weathered crude oil that is several days old. Thus, even if it is unknown whether the use of dispersants will be the response method of choice, it is prudent to begin mobilization of the dispersant, application equipment, and supplies until sufficient information is obtained to make the decision. This course of action should be followed unless dispersant use in the area has been precluded during preplanning.

The second stage of a spill response involves the actual countermeasure activity. At this stage, there should be sufficient information and resources to initiate the response actions best able to address the current situation. This second stage involves experimentation and evaluation. Although a response may have already been initiated, the effectiveness of the response will only be known after observation and feedback from the field. In addition, adjustments will be required as part of the recovery or dispersant operation. Changes may be required because of equipment availability, weather conditions, storage capacity, or changes in the character of the oil. In this stage, the response is organized in the field and the best techniques for the particular conditions developed.

The third stage of a response is characterized by a more stable approach involving routine activities. For a large spill, the third stage may not begin for days. By this time in the life of an oil spill response, the organization should be in place, equipment on site, and personnel responding to the situation. In this stage, the dispersant's effectiveness is declining, and more emphasis is placed on recovery or shoreline cleanup. Unless the spill is from an ongoing source, the oil may be too weathered for dispersants to be effective.

Throughout all three stages, the overall objective of an oil spill response is to reduce the environmental and economic impact (both short- and long-term) of the spill. The evaluation of the potential environmental and economic impacts is a complex undertaking that must be accomplished under less-than-ideal conditions. The interrelationship between environmental and economic impacts involves both technical uncertainties and policy concerns. Opposing external pressures are often placed on an oil spill responder concerning the potential impacts and how best to avoid them.

There are four major options that may be combined when responding to a spill. These options are the no-action (natural degradation) approach, shoreline cleanup, mechanical containment and recovery, and the use of chemical dispersants (NRC, 1989). A fifth option, in-situ burning, also shows promise. Countermeasures that are less widely used or have major limitations include gelling and enhanced biodegradation.

In some cases, the no-action alternative is the only choice because of stormy weather, lack of equipment, lack of qualified response personnel, or the lack of a bona fide contingency plan. The no-action approach sometimes may be used in cases where the spill can disperse naturally, where the shoreline impact is expected to be small, or where shoreline removal is appropriate. This approach is ideal in many ways when the spill location away from sensitive areas allows such an approach and the oil is of the type that will disperse naturally. Also, safety risks to response personnel are minimized, and the environmental impacts to the open sea are thought to be minor relative to the environmental impact at the coast. If this option is selected, there should be some certainty that the spill will naturally disperse before it reaches the shoreline.

The second option is to allow the spill to come ashore and then to conduct cleanup operations along the coast. This course of action is often involuntary when spill countermeasures off shore are unsuccessful and coastal areas become oiled. Such a cleaning operation can often cause significant environmental impacts and economic loss.

Recovery off shore has the greatest potential for minimizing environmental harm. Such recovery operations, however, have historically been only marginally effective (approximately 10 to 15 percent recovery) on major spills. Weather, equipment, storage capacity, and area coverage have combined to prevent recovery operations from significantly limiting shoreline impacts.

The fourth approach available is the use of chemicals, including dispersants, while the oil is still on the water. This approach does not preclude the use of other responses. Dispersant chemicals are the primary response mechanism in some European countries, even though they are infrequently used in the United States. Dispersants, however, do not represent a panacea for oil spills. The effectiveness of dispersant countermeasures can be increased with greater understanding of their proper use and limitations, and with better preparation and planning.

Before any of these spill response approaches is implemented, certain information is necessary to ensure the optimum combination of countermeasures. Minimum information needed to determine a suitable countermeasure option includes:

- Spill location (including geographic location and habitat type)
- Oil type
- Quantity released
- Weather and sea conditions
- Probable spill path
- Potential consequences of coastal impact.

As mentioned, all of the information will not be available in the initial portion of the response. The above information nevertheless can be used to identify the optimal response mechanism. Actual implementation of the response, however, depends on other factors such as resource availability and approval for dispersant use. In some instances, best response methods may be identified but a lack of planning may still result in the equipment, personnel, or approvals being unavailable within the time frame needed to provide an optimal response. Therefore, proper preplanning prior to an oil spill is essential to maximize the number of options available during a spill.

Surface slicks are not easily biodegraded because they have a relatively smaller water oil interface area compared with an oil-in-water dispersion. Oil on the surface is also subject to emulsification, which increases the slick volume by forming degradation-resistant emulsions that can contain up to 80 percent water. These emulsions are difficult to treat by either mechanical or chemical means.

"Weathering" of the slick begins to occur almost immediately. In this natural process, the low molecular weight hydrocarbons evaporate and dissolve, leaving behind the larger petroleum resin and wax molecules. The bulk of evaporation occurs within the first 24 hours, and, although the process continues, the residue remaining after this period becomes more viscous and difficult to skim. This residue becomes increasingly more difficult to handle with time.

In the rough seas, emulsification usually occurs. In this process, water mixes with the oil to form an oil-water "mousse." This mousse (water-in-oil emulsion) is viscous and has a volume up to five times greater than the oil alone. These characteristics make the mousse difficult to remove or to otherwise be effectively handled for all cleanup methods including skimming, burning, and dispersant application.

A mass balance performed on a typical spilled oil would yield the following results within the first few days:

- A substantial quantity (up to 30 to 40 percent) would be removed through evaporation.
- Some oil would be transferred into the water column, depending on sea conditions.
- Very little would be biologically removed.
- Very little would be removed by photooxidation.
- Very little would sink.

If oil remains in the open sea, as much as 30 to 40 percent could evaporate, 50 percent could be biologically metabolized, and approximately 10 to 20 percent of the heaviest compounds would form tar balls or sink to mid-depths or the bottom of the sea. In most cases as long as the slick does not move shoreward, its impact would be minimized by the minimal exposure to humans or sensitive ecological areas. Unfortunately, not all slicks stay at sea; they often reach land where the impact can be dramatic. Of course,

SECTION 2

OIL SPILL RESPONSE CHEMICALS

Oil spill response chemicals are one of the countermeasures available to control the spread of oil. Only chemicals that are listed with the U.S. Environmental Protection Agency (EPA) may be used in U.S. waters. These chemicals are on the Product Schedule of the National Contingency Plan (NCP - 40 CFR 300). Approximately 100 chemicals were listed in 1993 in the following four categories:

- dispersants - 48 products
- surface collecting agents - 2 products
- biological additives - 42 products
- miscellaneous oil spill control agents - 10 products

Definitions of these categories may be found in the NCP; they are discussed further at the end of this section.

When large quantities of oil are released onto or into a body of water over a short time, a slick forms and begins to spread rapidly in an uneven film. The extent of the spread in the marine environment depends on sea conditions, especially wind, wave, and current conditions. The degree of oil thinning depends on the types of oil, size of spill, and other physical factors. In the absence of wind and waves, the film thickness depends on the surface tension and oil viscosity. Wind and wave action can cause thick patches of oil to form. The thickness of freshly-spilled oil can rapidly approach an average of 0.1 millimeter (mm) or less within a matter of a few hours except in areas where wind and wave action form thicker patches that can exceed 1.0 mm (NRC, 1989). Slick thickness also increases to over 0.1 mm in areas where a natural barrier is encountered (e.g., a shoreline).

there may be instances where an oil slick at sea can also have significant impacts on sensitive ecological areas.

2.1 Chemical Dispersants

Dispersants are defined as "those chemicals that emulsify, disperse, or solubilize oil into the water column or promote the surface spreading of oil slicks that facilitate dispersal of the oil into the water column" (U.S. EPA, 1990). The purpose of chemical dispersants is to enhance the natural dispersion process by facilitating the formation of small (less than 20 μm) oil droplets. Oil droplets on the order of 20 μm rarely coalesce and are carried away both vertically and horizontally from the oil slick by wave action. Dispersion also removes the oil from the action of the wind that may bring a slick ashore. The dispersed oil becomes rapidly diluted in the sea water. Studies have shown that the transient concentration of oil under a dispersed slick can range from as high as 50 ppm to as little as 1 ppm (Cormack and Nichols, 1977). The dispersion induced by chemicals occurs rapidly, with the oil concentration ranging from 16 to 48 ppm within the first 2 minutes, 5 to 18 ppm after 5 to 10 minutes, and 1 to 2 ppm after 1 hour and 40 minutes (Cormack and Nichols, 1977). More detailed testing relating oil concentrations to water-column depth over time was performed by McAuliffe, et al., and was summarized by NRC (McAuliffe et al., 1980; McAuliffe, et al., 1981; NRC, 1989). The key finding of all of the studies is that although transient concentration in the water column goes up significantly, the effect is on the order of a few hours.

In the dispersion process, two dissimilar substances coexist to form a mixture that resists separation into its components under ordinarily encountered conditions. In a dispersion, unlike a solution, the two substances retain many of the physical properties of the separate substances.

Chemical dispersants are surfactant formulations that generally include a solvent carrier to reduce viscosity. The active ingredients are often a blend of surfactant esters with both water-compatible (hydrophilic) and oil-compatible (lipophilic) properties. Sulfosuccinate, sorbitan monooleate, and polyethylene glycol esters are the more common surfactant bases. The dispersant formulation is usually a blend of nonionic and anionic surfactants. Nonionic surfactants generally constitute the bulk of the active ingredient in most dispersants (NRC, 1989).

Water-miscible hydroxy compounds and hydrocarbons are used as the solvent carriers. All solvents are selected so as to minimize the toxicity within the solvent group. Hydrocarbon solvents are specifically selected on the basis of their low aromaticity.

With a minimum amount of mixing, the surfactant in the chemical dispersant can diminish the tension at the oil-water interface and promote the breakup of the slick into small oil droplets. Figure 2-1 illustrates the mechanism of chemical dispersion. When optimally applied, the surfactant travels to the oil/water interface. The surface tension is lowered as a result of the natural orientation of the dispersant molecules (i.e., lypophilic toward the oil and hydrophilic toward the water). The amount of energy required to disperse the oil depends on the quantity of dispersant applied, the composition of the oil and water, and the extent to which the dispersant surfactants lower the interfacial tension. Even a low amount of energy from wave action and currents can be sufficient to distribute the dispersant and encourage droplet formation; breaking waves or mechanical mixing is not required.

Chemical dispersants can break up an oil slick into small oil droplets. Through the mixing energy provided by the sea, the droplets will rapidly disperse into the upper one to ten meters of the water column. Chemically dispersed oil resembles a colloidal suspension such as milk with finely divided droplets distributed throughout the water column. These droplets increase the surface area of the oil and may aid in natural degradation; however, surfactant molecules at the interface of these droplets may compete for surface sites with microorganisms that could degrade the oil (NRC, 1989).

Dispersants can be used in the initial response to an oil spill and, unlike mechanical methods, can rapidly respond over a large area when applied by aircraft. Application of chemical dispersants to an oil slick can reduce the amount of oil reaching the shoreline. Dispersion of oil at sea generally will reduce the overall impact and particularly the chronic impact of oil on many habitats (NRC, 1989). Oil, if successfully dispersed chemically offshore, has a much less persistent impact than does oil allowed to come ashore without dispersal. Such dispersion is particularly important in the case of mangrove communities that can survive dispersed oil impact but not the impact of crude oil slicks, which kill the mangrove trees and destroy the habitat (Baker, 1993).

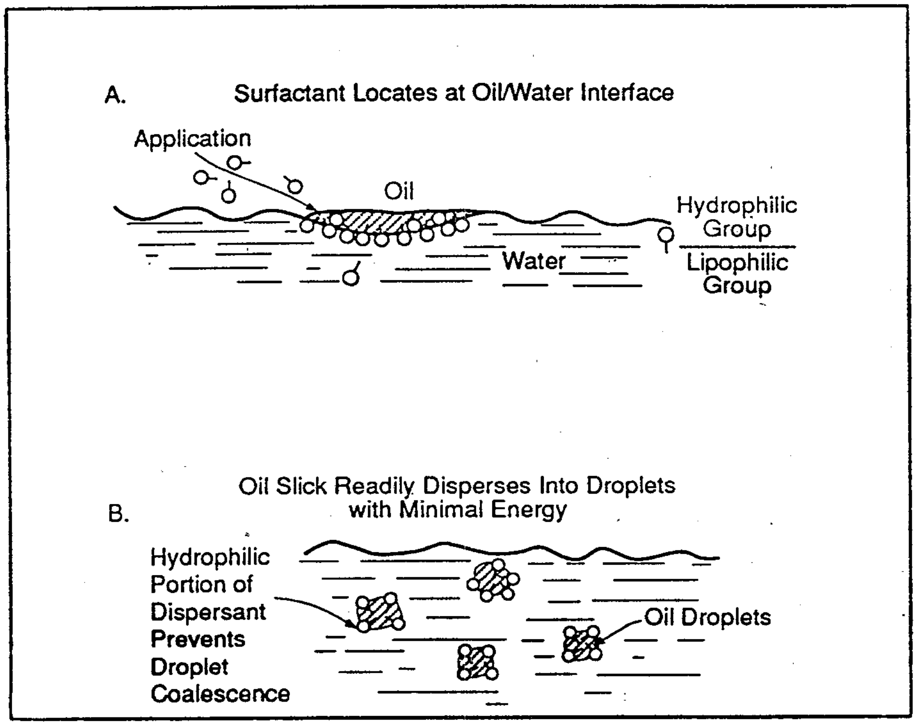

Figure 2-1. Mechanism of chemical dispersion (Canevari, 1969).

In the late 1960s, degreasing solvents containing aromatic hydrocarbons such as toluene and benzene were used as the first chemical dispersants (Gilfillan, 1992). The experience with the *Torrey Canyon* (a tanker responsible for a major oil spill on the English coast line of Cornwall in 1967) put an end to such solvent use because of its toxicity. Today, most surfactant formulations are much less toxic both with respect to the active agents and the solvent carrier. These new formulations have a nonaromatic solvent carrier and a blend of surfactants designed to reduce surface tension.

Chemical dispersants do not dissolve oil; dissolution is a completely different process that uniformly blends two or more substances into a third new substance that has unique chemical and physical properties. In a dispersion, the dispersed substance retains the identity and chemical properties of its components. The surface area of the oil is increased, however, because droplets are formed and distributed throughout the water column. The dispersion results in a transient localized increase of oil in the water column. Low-molecular-weight hydrocarbons in the oil can more easily dissolve in the water and are less susceptible to evaporation, which could cause increased localized toxicity.

Large droplets can return to the water surface because oil drops are generally less dense than sea water; therefore, dispersed oil droplets should have a small volume mean diameter (VMD) of 1 to 20 μm in order to avoid resurfacing (NRC, 1989). VMD is defined as the droplet size in or above which is contained half the volume of a given dispersion (Fingas, et al, 1991a). Measurements at sea during test spills have shown that dispersants produce oil droplets with average diameters in the range of 15 to 25 μm and VMDs between 35 and 50 μm (Lunel, 1993). Oil droplets 20 μm and smaller tend to remain suspended in the water column because of turbulent diffusion. These oil droplets will remain dispersed in the water column as a result of natural water currents or Brownian motion (Clayton et al., 1992).

2.2 Other Oil Response Chemicals

The following are examples of other types of spill-treating agents:

Surface-Washing Agents

Surface-washing agents or surface-active washing agents are used to clean up contaminated surfaces. These agents hold oil removed from a solid surface such as rocks, seawalls, and beaches in a stable emulsion.

Surface-Collecting Agents

Surface-collecting agents (herding agents) act like a "chemical boom" to keep the spill from spreading. Herding agents are most effective for small, thin oil slicks in calm, enclosed waters and have a limited "action" time.

Biological Additives

These microbiological cultures, enzymes, or nutrient additives are deliberately introduced into an oil spill for the specific purpose of encouraging biodegradation in order to mitigate the effects of the spill.

Miscellaneous Oil Spill Control Agents

These are any products, other than a dispersant, sinking agent, surface-collecting agent, or biological additive, that can be used to enhance oil spill cleanup, removal, treatment, or mitigation. The following are examples of such products:

- Recovery agents such as elastomeric agents to condition the spilled oil and improve the recovery efficiency of skimmers These include viscoelastic enhancing agents that reduce the spreading rate and also make it easier for skimmers to recover very light fuel oils. These chemicals are only applicable in restricted circumstances because of the necessity to recover the viscous fluid after application.

- Demulsifiers to break formations of water-in-oil emulsions Demulsifier formulations are usually surfactants or other polymeric materials that tend to break oil-in-water emulsions. Some recent products do not contain surfactants, but instead contain other polymeric materials that serve a similar function. Oil spills in rough seas often become emulsions, particularly if the oil contains paraffins and/or asphaltenes that act as stabilizing agents.

- Solidification or gelling agents used for oil collection and slick control These gelling agents consist of polymerization catalysts and cross-linking agents that change the oil into a solid. Solidification of oil requires both mechanical mixing and time for setting. Large amounts of gelling agents are usually required.

Oil spill response chemicals other than dispersants are not covered in this document.

SECTION 3

DISPERSANT EFFECTIVENESS

There remains controversy over the best means to quantitatively measure dispersant effectiveness. Measuring the decrease in interfacial tension between water and oil upon the addition of dispersant provides the most reproducible and theoretically based test, but it is difficult to translate the laboratory measurement into actual field effectiveness. Although many dispersants are shown in the laboratory to reduce interfacial tension to near zero (NRC 1989), closely monitored test spills have shown that only two-thirds of a slick may be transferred to the water column (McAuliffe et al., 1987). In addition to problems of reproducibility, test methods other than interfacial tension measurement suffer similar problems in relating the laboratory data to use in the field. Realistically, only about 30 percent removal can be expected in most open sea cases (Moller, et al., 1987; Nichols, 1993). Currently, the effectiveness of a dispersant in a particular response situation can only be determined by visual observation. One option being considered by RRTs is to allow only small applications of dispersants (on the order of one drum over an acre) for a test of their effectiveness prior to full-scale use. Even direct observations, however, often result in conflicting opinions on the effectiveness of oil removal or the reduction in adverse impacts. The final test of effectiveness is the degree of success achieved in either removing oil from the sea surface in a particular situation or reducing environmental and economic impacts.

Each of these factors are discussed in this section of the document. Laboratory tests are routinely used to evaluate the relative effectiveness of chemical dispersants. At least six laboratory tests (over 35 have been developed) are currently used throughout the world. Five simplified field tests are also available. Each laboratory test follows the general approach of establishing an oil slick on water, applying a dispersant to the slick (either directly or by premixing the oil and dispersant), applying energy to mix the oil-dispersant-water system, and measuring the amount of oil dispersed into the water column. Because chemical dispersion of oil in water involves complex interactions of many variables, it is unlikely that any single laboratory test will ever be completely suitable for quantifying the performance of chemical dispersing agents for all possible environmental scenarios (Clayton et al., 1992). Nonetheless, the tests have been a useful tool for government agencies to use to screen and compare dispersant products prior to granting approval for field use.

Several investigators have compared laboratory tests and concluded that results of the different tests do not correlate well; generally, the more different the types of oil tested, the less the results correlate (Fingas and Tennyson, 1992). Further, although laboratory tests are useful for screening purposes, the laboratory results may not correlate well with actual field performance because many variables affect dispersant performance (e.g., adequacy of mixing, mixing energy, and oil-to-dispersant ratio). The field effectiveness tests are rapid and simple, but their results are of a very qualitative nature rather than quantitative.

Before the decision is made to respond with dispersants to a particular spill, laboratory data describing the effectiveness of dispersants for use with various oil types should be evaluated in combination with dispersant properties such as low toxicity and biodegradability. As a practical matter, however, it is unlikely that a wide selection of dispersants will be available from which to conveniently choose. Therefore, unless there is a direct contra-indication of dispersant effectiveness with the specific oil involved in a spill, laboratory data must be considered only second to observation.

Quantitative field measurement systems that can be used to determine the effectiveness of dispersants on site are not yet widely available and tested. Such systems are needed to supplement visual observations. The fluorescent properties of certain components of crude or refined oil can be used to quantitatively determine the amount of oil dispersed or dissolved in water. Under field conditions, fluorometry is useful for determining the increased transfer of oil to the water column upon the application of dispersants. The use of fluorometry in a spill response presents two major difficulties: (1) A vessel equipped with the appropriate instrumentation is needed at the oil spill site; and (2) The instrument must be calibrated with the specific weathered oil under field conditions. Despite these difficulties, fluorometry has the potential to be the most definitive measure of dispersant effectiveness in the field.

The following physical and chemical factors greatly influence the effectiveness of dispersants in removing oil from the sea surface:

- type of oil, including chemical composition viscosity
- weathering of oil
- nature of oil spill
- sea state
- sea characteristics, including salinity
- type of dispersant
- dispersant application method.

3.1 Types of Oil, Viscosity

The hundreds of different types of oils, which are composed of thousands of hydrocarbon compounds, have different dispersibility characteristics. Some are easily dispersed, and others will not disperse despite all efforts.

The American Petroleum Institute (API) gravity scale is used to classify crude oils. As the density of the material decreases, the API gravity increases as follows:

$$API\ gravity = \frac{141.5}{specific\ gravity\ (60/60^{\circ}F)} - 131.5$$

where: Specific gravity (60/60°F) is the oil density at 60°F divided by the density of water at 60°F.

API gravities for crude oils generally fall within the range of 5 to 50; oils with API gravities below 5 are not dispersible (Gilfillan, 1992). An increase in API gravity generally means a more dispersible crude oil.

Viscosity has a loose inverse relationship to API gravity, with high API gravity crudes generally having lower viscosity. Viscosity alone can be a good indicator of dispersant effectiveness (Clayton, et al., 1992). Dispersants generally are most effective for oil viscosities of less than 2,000 centistokes (cSt), and almost no dispersion occurs over 10,000 cSt; sufficient data has not been published, however, to determine the usefulness with such viscous oil. Some new dispersant formulations may be effective on particular oil types above 10,000 cSt. Several references are available that give API gravities and viscosities for many crude oils transported by sea in U.S. waters (API, monthly; Whiticar, et al., 1993; NOAA, 1993).

Dispersant effectiveness is also affected by oil composition. The main hydrocarbon components of crude oil can be classified as saturates, aromatics, polars, and asphaltenes. There is a strong correlation between the saturate content of oil and the effectiveness of present dispersant formulations. The greater the saturated hydrocarbon content (especially the saturates with less than 19 carbon atoms), the greater is the dispersant effectiveness. As the asphaltene content of crude oil increases, however, the tendency to form water-in-oil emulsions also generally increases. Water-in-oil emulsions are not easily dispersible.

3.2 Weathering of Oil

During the first 24 to 48 hours of an oil spill, the oil undergoes several substantial changes as it is "weathered." Even though weathering continues beyond 48 hours, the initial changes are generally the most dramatic. The term "weathering" includes the following processes: evaporation, dissolution, photooxidation, and emulsion formation. The major influences on the weathering process are the composition of the oil and environmental factors such as water temperature, sea state, and wind speed. The dispersibility of the slick is reduced by weathering and may in extreme incidences result in a 50 percent decrease in dispersant effectiveness in a matter of two to four hours.

The loss of volatiles from an oil slick through evaporation increases the concentration of nonvolatiles, which causes an increase in oil density, viscosity, and surface tension. Some lower-weight aromatics with high solubilities will dissolve in the water column or quickly evaporate at the slick interfaces (Mackay and Chau, 1984). The oil-aging process decreases API gravity and increases viscosity, which leads to reduced dispersibility. Within 48 to 72 hours, oil floating on the sea will have lost nearly all aromatic hydrocarbons that are lighter than naphthalene (Gilfillan, 1992).

Photooxidation, another natural-aging process, generally occurs too slowly to be a factor to be considered during spill response decision making. Crudes with higher wax content tend to be affected by photooxidation more rapidly than other crudes. This exposure to air and sunlight may increase the tendency to form water-in-oil emulsions (mousse).

Mousse will form with many oils in turbulent seas. Mousses generally are easily formed if the oil contains waxes and asphaltenes. Emulsification results in a tremendous increase in viscosity and reduces dispersibility because the dispersant will not effectively penetrate the emulsion.

3.3 Nature of Oil Spill

The nature of the oil spill can influence the dispersibility of the slick, as occurred during the Ixtoc well blowout in the Gulf of Mexico. In this situation, oil coming out at high pressure under water became emulsified before it reached the surface. Because emulsified oil is more difficult or impossible to disperse, an underwater release can severely reduce the effectiveness of the dispersants.

Fire can also reduce the effectiveness of dispersants because it results in the removal of the lighter fractions of the crude. The residual oil thus becomes more viscous and depleted of the components amenable to dispersion. These dispersible components are necessary to form droplets of the more viscous fractions. The end result of a crude oil fire at sea is a less-dispersible slick.

3.4 Sea State and Characteristics

The motion of the open sea provides the natural energy for dispersing treated oil droplets into the water column. Wind, waves, and tide redistribute the oil slick and cause changes in concentration. Mechanical dispersion occurs with wind speeds great enough to cause breaking waves. Advection from daily tidal currents, wind-induced currents from sea breezes, and frontal mesoscale eddies redistribute the oil droplets horizontally, while turbulent diffusion causes vertical movement as well.

During dispersant application, high winds require careful spray alignment so that the dispersant is not blown away from the target. However, breaking waves from these winds can hasten the dispersion process. High winds will also cause the slick to spread quickly, thus reducing the response time for the use of dispersants. Untreated dispersed oil may reappear on the surface after high winds have ceased because untreated oil tends to form larger drops. Oil droplets formed by chemical dispersion are of approximately the same composition as the oil slick, but smaller. Therefore, while the dispersant does not appreciably change the density of the oil, the oil remains lighter than water, but with decreased surface tension, and a minimum amount of energy will mix the oil droplets into the water column.

Visual observation and the Beaufort Wind Scale can be used to correlate wind speed and resultant wave actions. For example, if small floating material is in constant motion or if wave crests at sea have scattered whitecaps, this gentle breeze is assigned a Beaufort number of "3." A Beaufort code number of 3 correlates to a wind speed of 7 to 10 knots (Bates, et al., 1984). If the Beaufort number is above 5, dispersants probably should not be applied since they will do little to enhance the natural dispersion already occurring (CONCAWE, 1988). The Beaufort wind scale is presented in Table B-8, Appendix B.

Properties of the water, such as temperature and salinity, will also affect dispersibility. Many of the current dispersant formulations increase in effectiveness with increased salinity, up to a point. Dispersibility can decrease at salinities above 40 parts per thousand or as the salinity decreases toward fresh water levels. Increased salinity can lower the solubility of certain surfactants; thus, the correlation between effectiveness and salinity will vary for different dispersant formulations. Decreased water temperatures could increase viscosity of the once dispersible crude oil to such an extent that it could not be effectively dispersed (NRC, 1989).

3.5 Type of Dispersant

Current dispersant formulations contain 15 to 75 percent nonionic surfactants and 5 to 25 percent anionic surfactants. Nonionic surfactants used may include sorbitan esters of oleic or lauric acid, ethoxylated sorbitan esters of oleic or lauric acid, polyethylene glycol esters of oleic acid, ethoxylated and propoxylated fatty alcohols, and ethoxylated octylphenol (NRC, 1989). Anionic surfactants may include sodium dioctyl sulfosuccinate and sodium ditridecanoyl sulfosuccinate. The main classes of solvents used in current dispersant formulations are water-miscible hydroxy compounds and hydrocarbons. Hydrocarbon solvents such as low-aromatic-content kerosene enhance the penetration of the dispersant into more viscous oils.

3.6 Dispersant Application Method

Chemical dispersants may be applied by boat or aerial spray but, in any case, the dispersant must contact the slick in order to be effective. Any dispersant falling outside the oil slick is ineffective. Wind drift can reduce the effectiveness of the application by drifting the dispersant away from the target.

The droplet size of the dispersant influences the effectiveness. To achieve proper mixing, dispersant droplet size should be of the same order of magnitude or smaller than the oil film thickness. Large dispersant droplets can penetrate the slick without dispersing in the oil. Physical properties of dispersants that influence dispersant droplet size during application are viscosity, volatility, density, and surface tension (Fingas, et al., 1992b). Application equipment must be compatible with the physical properties of the dispersant in order to achieve proper droplet sizing.

The dispersant-to-oil application rate directly impacts the effectiveness of a dispersant. For planning purposes, manufacturers generally recommend dispersant-to-oil ratios ranging from 1:10 to 1:20 parts dispersant to oil. As discussed later in Section 6, the ratio should be determined through preplanning and observation. The dosage of dispersant must be sufficient to reduce interfacial tension. Thick areas of the oil slick require more dispersant than the thinner areas; thus, dispersant effectiveness may vary over a slick if the dispersant is applied at a constant rate per unit area. The rate of application ratios over different parts of the oil slick may need to be changed to achieve optimal effectiveness.

SECTION 4

ENVIRONMENTAL FACTORS

Factors to be considered in evaluating the decision to employ chemical dispersants for oil spill control include the potential to obtain a balance between ecological benefits and any adverse impact to marine organisms, wildlife, or plant habitats and the potential, based on the factors discussed in Section 3, that an application of dispersants will successfully disperse a significant fraction of the oil. Unless a successful recovery operation can be mounted against an oil slick that is moving toward a biologically sensitive area, an adverse environmental impact will result. Although dispersants can reduce the severity of impact to fragile habitats, they may impose temporary stresses in other offshore areas because of higher short-term exposure to the toxic components of oil. When deciding whether to use dispersants, one must weigh the tradeoffs between the potential impact to the intertidal and shoreline communities by the untreated oil and the potential adverse impact to water-column and benthic organisms by chemically dispersed oil.

Some environments are more vulnerable to longer lasting impacts of spilled oil than are others such as mangroves, salt marshes, and exposed corals. Although chemical dispersants can increase short-term toxicity in the upper water column, their use may be the most appropriate response to certain oil spills. The use of dispersants does not preclude the use of other recovery techniques. For example, dispersants can be applied at the source and recovery can take place at the leading edge.

The American Society for Testing and Materials (ASTM) developed ecologically based guidelines governing the use of dispersants in marine environments. These guidelines describe habitats in relation to possible dispersant applications. ASTM developed these guidelines for the following areas: 1) bird habitats (ASTM F 1010, 1986),

2) marine mammal habitats (ASTM F 929, 1986), 3) rocky shores (ASTM F 930, 1986), 4) sandy beaches (ASTM F 990, 1986), 5) gravel and cobble beaches (ASTM F 999, 1989), 6) coral reefs (ASTM F 932, 1986), 7) seagrass beds (ASTM F 931, 1986), 8) mangrove swamps (ASTM F 971, 1986), 9) tidal flats (ASTM F 973, 1986), 10) near-shore subtidal habitats (ASTM F 972, 1986), 11) offshore habitats (ASTM F 1002, 1986), 12) salt marshes (ASTM F 1008, 1986), and 13) arctic habitats (ASTM F 1012, 1986).

In addition to ASTM guidelines, the American Petroleum Institute (API) published recommended site-specific planning procedures pertaining to the use of dispersants (API, 1985). These procedures are based on physical factors rather than habitat considerations. Table B-10 in Appendix B presents dispersant and other cleanup methods recommended by API for various habitats. Recommendations for dispersant use are based upon the following zone characteristics:

- Zone 1, Dispersant use recommended
  - Sufficient mixing energy to allow dispersed oil droplets to be diluted and distributed throughout a large volume of water.
  - Ample distance from sensitive areas (e.g., bird nesting areas) so that dispersant use will not cause a disturbance.
  - Significant reason to believe that the oil spill will reach and adversely affect sensitive areas.
- Zone 2, Dispersant use acceptable
  - Same characteristics as Zone 1, but oil is not expected to affect sensitive areas (i.e., trajectory of the spill is not directed toward sensitive areas).
- Zone 3, Dispersant use conditional
  - Shallow or low-energy habitats.
  - Located very near sensitive areas.

This third zone requires identification and evaluation of alternatives. In some cases, chemical dispersants may be the best solution, particularly if stranding oil in sensitive areas along the shore is likely to develop (Lindstedt-Siva et al., 1984). Even in shallow waters, the use of dispersants may be an advantage. Studies have indicated that treated oil is less likely to be incorporated into benthic sediments (MacKay and Hossain, 1982; API, 1986; NRC, 1989). Dispersants may have decreased effectiveness in shallow areas, however, if less-than-adequate mixing energy is available. Thus, the assessment of trade-offs becomes more complex, and a thorough knowledge of the specific ecosystem and water circulation is important.

4.1 Concerns About Toxicity of Dispersants

After the tanker *Torrey Canyon* caused a major oil spill on the English coastline of Cornwall in 1967, much effort was directed toward developing dispersants with low toxicity. The dispersants used to control the nearly 1 million barrels of crude oil that spilled from the *Torrey Canyon* consisted of high-aromatic-content degreasing agents that were developed to clean tanks. The results were an ecological disaster: extensive mortalities of animals and algae occurred immediately, and the natural recovery was severely slowed and was still incomplete in some areas after 10 years. Because the biological impacts along the shoreline were highly visible, dispersant response was not highly regarded (NRC, 1989). Many environmental studies on newer-generation dispersants have been published since the late 1960s; a good bibliography is contained in "Using Oil Spill Dispersants on the Sea" (NRC, 1989).

Dispersants change the rate at which volatile hydrocarbons are incorporated into the water column (McDonald, et al., 1984). Chemically dispersed oil potentially releases toxic water-soluble hydrocarbons to the water column more rapidly than a slick does; this increased transient exposure should be considered when dispersants are used near sensitive areas. The increased transient exposure is balanced by the more rapid dilution of dispersed oil compared with a slick, however, and the net effect tends to be positive. Although researchers have used very high concentrations of oil- and water-soluble hydrocarbons in laboratory testing of dispersed oil on marine life in the field, natural dispersion and aging of oil reduce the concentration and remove the toxic components (Anderson, et al., 1987). Extrapolation from laboratory tests to conditions at sea and in the complex ecosystems of intertidal zones has been unsatisfactory; yet it is clear that weathering reduces the toxicity of oil and that both natural and chemical dispersion increase surface area and reduce the potential shallow water and shoreline exposure of organisms to the oil.

Knowledge of the seasonal habits of marine populations in the response regions provides information about the distribution of that population near the oil spill. Available data on seasonal habits (spawning and breeding) and migratory patterns of key animal species need to be considered. The seasonal ecology of a specific location can be extremely complex and varied. Fish, shrimp, mammals, and birds have different responses to surface oil and dispersed oil, and competing factors such as fish and bird breeding habits often will complicate the decision-making process regarding the use of dispersants. Dispersants that remove oil from the water surface may provide effective protection for marine birds and mammals while increasing the negative effect on larval fish and shrimp populations. The least-controversial use of dispersants is on an oil slick in deep water (greater than 10 meters) that is heading toward an ecologically sensitive coastal area (Trudel, 1984). Other cases do not lend themselves to such easy evaluation of the trade-offs.

With respect to dispersants alone, laboratory studies indicate that the acute lethal toxicity of most dispersants to biota is low compared with the constituents and fractions of crude oils and refined products. Although a wide range of sublethal responses in biota has been observed, usually at high exposure concentrations, the sublethal effects of dispersants at concentrations that may be expected to occur during a spill are only partially understood. At recommended application rates, dispersants should not increase significantly the lethal or sublethal toxicities of dispersed oils (Wells, 1989); however, direct application of dispersants to seabirds and marine mammals must be avoided because dispersants destroy the water-repellency and insulating capacity of fur and feathers (NRC, 1989).

With respect to dispersed oil, laboratory bioassays have determined that acute toxicity generally does not reside in the dispersant, but primarily in the oil droplets (for some species) and the low molecular weight and dissolved, aromatic, and aliphatic fractions of the oil (for most species). Dispersed and untreated oil show the same acute toxicity--a conclusion obscured in much of the literature by many studies that quote oil concentration as being the total oil per unit volume of the experimental system, rather than the actual measured, dissolved, and dispersed hydrocarbon concentrations to which organisms are exposed (NRC, 1989).

Scientists have documented a variety of acute effects on organisms and habitats from both chemically dispersed oils and untreated oils. Organisms in the water column, particularly in upper layers, experience greater short-term exposure from dispersed oil compared with nondispersed oil. Long-term harmful effects to shallow water benthic organisms may be better reduced by chemically dispersing oil than by not treating the spill (Wells, 1989). Laboratory research on mollusks, however, shows that high concentrations of dispersed oil can be toxic (NRC, 1989). In areas having restricted water movement, the acute effect of dispersed oil on some organisms or marine plants may be greater than that of oil alone; however, intertidal habitats such as mudflats are less adversely impacted by dispersed oil that is treated before it enters the habitat, and such habitats can recover faster. Intertidal habitats do not benefit from dispersant application after the oil reaches the shore (Wells, 1989). Measurable effects of dispersed or untreated oil on commercial fisheries or their supporting food webs have yet to be fully verified. If such effects do occur, however, they would be difficult to detect and measure effectively because of the mobility of most fish and many invertebrates, the natural variability of their populations, and the effects of overfishing on stocks (NRC, 1989).

Using laboratory studies, scientists have also documented a variety of sublethal effects to biota (e.g., changes in reproductive and feeding behavior) from dispersed and undispersed oil, most at concentrations comparable to or higher than those expected in the water column during treatment (1 to 10 ppm), but seldom at concentrations less than those found several hours after treatment of an oil slick (less than 1 ppm). The times of exposure in the laboratory (24 to 96 hours) are much longer than predicted exposures during slick dispersal in the open sea (1 to 3 hours), and the effects to biota would be expected to be correspondingly less in the field (NRC, 1989). Bioaccumulation and tainting occur to a greater extent in the short term in filter feeders because water column concentrations are elevated. Over the long term, however, more bioaccumulation of oil occurs in deposit feeders when dispersants are not used. Some laboratory studies and all field studies to date have shown that the biodegradation rate of dispersed oil is equal to or greater than that of nondispersed oil (Wells, 1989).

Based on the foregoing, a variety of toxic and sublethal effects to water-column and benthic biota may be anticipated from dispersed oil. Reduction of chronic exposure is believed to be the key to reduction of biological impacts (Wells, 1989). In offshore open water, concentrations of dispersed oil would be much lower than in shallower water, or in waters with poor circulation, with correspondingly lower impacts (NRC, 1989).

Before a decision is made to use dispersants, the following advantages and disadvantages should be considered:

- Advantages
  - A dispersed slick reduces the possibility of some portion of thick patches of oil reaching the shoreline.
  - Dispersant-treated oil will not adhere as readily to structures, sediment, or marine organisms, assuming that the dispersant is successfully applied.
  - Water in oil emulsions (chocolate mousse) that are difficult to clean up mechanically or disperse chemically can be reduced by application of dispersants.
  - Rapid aerial application can cover a large area.
- Disadvantages
  - Because dispersants will never remove all of the oil (approximately 30 percent), shorelines, birds, and fish will still be affected even if dispersants are used properly and effectively.
  - Concentration of dispersed oil (and dispersants) is increased in the first few meters of water.
  - Increased exposure of biota to oil droplets and dissolved oil components can result in toxicity to organisms in the upper (1 to 10 m) water column (McAuliffe et al., 1980; McAuliffe et al., 1981; NRC, 1989).
  - Application requires approvals not needed with recovery methods; sufficient stockpiles of dispersants and application equipment are

expensive to build and maintain; dispersant application is limited to a narrow time window and sea energy.

4.2 Chemical Dispersant Use Around Coral Reefs and in Shallow Waters

A decreased volume of water in the water column means the concentration of dispersed oil per unit volume is increased in shallow water. Another concern is that the oil may become incorporated into the sediments with release to the water column over a period of months. Areas less than 1 meter deep are generally thought to be more sensitive to dispersed oil, and dispersants should be used in this case only when the tradeoffs of leaving untreated oil are known to be highly severe. An example of a sensitive shallow-water environment is a coral reef. Coral reefs are susceptible to oiling by direct contact during low water and breaking wave action. Direct oiling of corals can be deadly, and dispersant use to prevent such an occurrence should be considered. Evidence exists that coral reefs are slightly more susceptible to dispersed oil than to floating oil (LeGore et al., 1989). Increased sensitivity should be weighed against the possibility that other habitats might be affected by the untreated oil, and the final decision should be based on the least overall impact. The ASTM guidelines recommend the following course of action:

- Whenever an oil spill occurs in the vicinity of a coral reef, use of dispersants should be considered to prevent the bulk of the oil from reaching a reef.
- The decision to use dispersants to treat oil that is in direct contact with a reef should be considered carefully and based upon the type of oil and location on the reef.
- Coral reefs in shallow waters are high-priority habitats and should be protected during oil spills; therefore, dispersant use on oil spills over these reefs is not recommended, but oil in the vicinity should be slowed from reaching the reef.
- Dispersant use to treat oil over a reef should be considered only if the water depth is 10 meters or greater.
- Dispersants are not recommended on oil spills over reefs with low water-exchange rates such as lagoons and atolls.

4.3 Dispersant Use in Breeding Areas

Because breeding is a seasonal phenomenon, response plans for dispersant use (as presented later in Section 5) should identify key species, times of year, and areas that could be affected should an oil spill occur. Fish will breed in both shallow and deep seas depending on the species, but usually within the top few meters of the water column. Fish that reproduce only once per year could potentially have a whole generation eliminated in an affected area if spilled oil is present. It is unlikely, however, that all of the breeding areas would be affected by a spill. Biologists are uncertain of the long-term effects of dispersed oil on productivity, but laboratory studies have shown that exposure to total petroleum hydrocarbon concentrations in the range of 0.01 to 1 ppm for more than 7 days can cause abnormal development and decreased survival in larval fish and crustaceans (U.S. EPA, 1991a). The possibility of fish and larvae migrating into the oil spill area should also be considered (NRC, 1989).

4.4 Dispersant Use in Bird Habitats

Bird populations are vulnerable to oil spills, but dispersants can be used to reduce the amount of oil reaching the populations. Adult birds have a high mortality rate even when they are moderately oiled, and birds coated with oil can carry the oil back to their nests where the eggs can be contaminated by the transferred oil. These effects can be reduced by moving the birds, mechanically removing the surface oil from the sea, or chemically dispersing the oil into the upper water column before the oil reaches the birds or their habitat (ASTM F 1010, 1986). Birds should not be sprayed with dispersant, as this will reduce water repellency of their plumage. Dispersant use to prevent oil from reaching bird breeding and nesting areas is generally accepted, but other mitigating factors such as dispersant effects on fish could cause controversy; therefore, all environmental effects must be considered before the decision is made to use any chemical dispersants.

4.5 Intertidal Habitats

Intertidal habitats, which are found worldwide, can have much greater densities of marine organisms and edible marine species than offshore areas. In addition, intertidal habitats serve as nurseries and support sensitive life stages for various species. Recovery and cleanup of oil in an intertidal zone are difficult and likely to cause considerable adverse environmental impact (ASTM F 972, 1986; Hoff et al., 1993).

Some examples of sensitive intertidal habitats are mangroves and salt marshes. Mangroves found in tropical and subtropical areas protect shorelines from storms and currents. They also provide habitats and nurseries for shellfish such as lobsters and prawns. Although this is one of the most vulnerable habitats to spilled oil (Gundlach et. al., 1978), no active cleanup method has been proven effective for oiled mangrove forests (API, 1985). Recent research is conflicting on the ability to clean previously oiled mangroves (Baker, et al., 1993; Teas, et al., 1993), but oil already dispersed is less harmful to mangroves than untreated oil. Dispersant operations should therefore be considered even at the shallow fringe of a mangrove forest (ASTM, F 971, 1986).

Salt marshes are considered to be almost as vulnerable to spilled oil as are mangroves. Because these marshes are located in sheltered areas, any mixing action from the water is limited and dispersant effectiveness is low. Dispersants should be used offshore to protect salt marshes from spilled oil if the oil could potentially enter the area. Because timing is important, dispersants should be applied as far away from the salt marsh as possible and at a time when the tide starts to rise (ASTM F 1008, 1986).

4.6 Dispersant Use in Other Habitats

Dispersants are not generally found to greatly enhance cleanup of rocky, cobble, or sandy beaches (Baker et al., 1993). The wave action on rocky beaches is helpful in removing the oil and dispersing it naturally. API recommends natural cleansing as the best cleanup option for rocky beaches (API, 1985). When these rocky beaches are home to mollusks or barnacles (all very sensitive to oil), however, dispersants may be considered to prevent oil from reaching these sensitive areas (ASTM F 930, 1986); again, timing is important.

Sandy or cobble beaches may contain simple marine communities or complex food sources in the organic-rich sediments. Again, natural cleansing is recommended for these areas (ASTM F990 and F999, 1986). The habitats found there are equally sensitive to disturbances from physical cleanup measures and to the problems created from the presence of spilled oil. Decisions to use dispersants to keep the oil from reaching these areas should be based upon whether these beaches are used by birds, mammals, or spawning fishes (ASTM F 999, 1986). In order to expedite the decision-making process concerning the use of dispersants, preapproval plans for dispersant use (discussed in Section 5) are needed to identify specific shoreline areas where oiling might cause significant harm.

Arctic areas (above 66 degrees north latitude) may not benefit from dispersant use if low temperatures associated with these areas restrict the effectiveness of dispersants. Newer formulations of dispersants may be effective at lower temperatures. Safety of response personnel is of greater concern in arctic areas where mishaps can have more severe consequences due to hyperthermia. Therefore, the "no cleanup option" should be considered in these areas unless a recovery operation can be safely and effectively implemented (ASTM F 1012, 1986).

SECTION 5

REGULATORY AND ADMINISTRATIVE ASPECTS

The Federal law pertaining specifically to oil spill response actions is the Clean Water Act (CWA) as amended by the Oil Pollution Act of 1990 (OPA). The National Oil and Hazardous Substances Pollution Contingency Plan, or simply the National Contingency Plan (NCP), was promulgated pursuant to Section 311 of the CWA to regulate all response activities. The OPA is a comprehensive statute designed to expand oil spill prevention activities, establish new federal authority to direct responses to spills, improve preparedness and response capabilities, ensure that shippers and oil companies are responsible for impacts from spills that do occur, and establish an expanded oil pollution research and development program. This section highlights the scope of these laws and addresses the necessary steps for dispersant use.

5.1 National Contingency Plan

The NCP provides the foundation for the national planning and response system concerning oil spills. According to the NCP, the On Scene Coordinator (OSC) has the authority to direct the removal and cleanup efforts. The OSC, with the concurrence of the Regional Response Team (RRT), determines whether dispersants or other chemical or biological agents will be approved to respond to an oil spill. Where hazards to human life are involved, the OSC has the authority to approve the use of dispersants unilaterally. Coast Guard OSCs are assigned to the coastal and offshore zones, and EPA OSCs are assigned to the inland zones. The boundaries of these zones are determined by EPA and U.S. Coast Guard agreements identified in the Regional Contingency Plans (RCPs).

5.1.1 Scientific Support

The NCP has identified certain organizations that are available to assist OSCs in preparing response strategies. The Environmental Response Team (ERT) established by EPA has expertise in biology, chemistry, hydrology, geology, and engineering and can provide assistance and advice to the OSCs. Information may be obtained from the ERT, U.S. EPA, Edison, New Jersey [Phone (908) 321-6740 or (908) 321-6660 (24 hours)].

Under Section 300.145(c) of the NCP, Scientific Support Coordinators (SSCs) are generally provided by the National Oceanic and Atmospheric Administration (NOAA) in coastal and marine areas and the Great Lakes, and by EPA in inland regions. NOAA has nine regional SSCs and a scientific support team that include expertise in environmental chemistry, oil slick prediction and tracking, pollutant transport modeling, natural resources at risk, environmental trade-offs of countermeasures and cleanup, and information management. During a response, the SSC leads the scientific team that serves under the direction of the OSC and is responsible for providing scientific support for operational decisions and for coordinating on-scene scientific activity. Depending on the nature of the incident, the team integrates expertise from governmental agencies, universities, community representatives, and industry to assist the OSC in evaluating the hazards and potential effects of releases and in developing response strategies. OSC requests for SSC support can be made directly to the SSC assigned to the area, to the NOAA member of the Regional Response Team, or by calling NOAA's Hazardous Materials Response and Assessment Division in Seattle at (206) 526-6317.

5.1.2 NCP Product Schedule

Section 311(d)(2)(G) of the CWA, as amended by the OPA, requires that the NCP include a schedule identifying dispersants, other chemicals, and other spill mitigating devices and substances, if any, that may be used in carrying out the NCP.
The use of dispersants, other chemical agents, and biological additives to respond to oil spills in U.S. waters is governed by Subpart J of the NCP (40 CFR 300.900).

Section 300.910 of Subpart J concerns the authorization of the use of products on the NCP Product Schedule and specifies the conditions under which OSCs may authorize the use of dispersants, other chemicals, and other spill control agents. Under existing Section 300.910(a), OSCs may authorize the use of products on the Product Schedule, with the concurrence of the EPA and state representatives to the RRT and, when practical, in consultation with the Department of Commerce and Department of Interior natural resource trustees.

Sections 300.915 and 300.920 describe the data requirements and the process used for adding a product to the Product Schedule. Currently under Subpart J, to list a product on the Schedule, a manufacturer must submit technical data on the product to EPA. Data on dispersants, surface collecting agents, and miscellaneous oil spill control agents must include the results of the Revised Standard Dispersant Toxicity Test set for these products in Appendix C of the NCP. Data on dispersants must also include the results of the Revised Standard Dispersant Effectiveness Test. Conducted at the expense of the manufacturer, these tests must be performed by a qualified laboratory.

The raw data and a summary of the results from these tests are then submitted to EPA, where they are reviewed to confirm that the data are complete and that the specified procedures were followed. This list is updated as EPA receives additions to the schedule and verifies that the required data were submitted. Generally, EPA does not confirm the data from independent tests. The data requirements for placement of a product on the Product Schedule are designed to provide sufficient data for OSCs to judge whether and in what quantities a product may be used to control a particular discharge.

Inclusion of a product on the Product Schedule means only that the data submission requirements have been satisfied. The listing of a product on the Schedule does <u>not</u> mean that the product is recommended or authorized for use on an oil discharge. In addition, placement of a product on the Product Schedule does not imply that EPA has confirmed the safety or effectiveness of the product or in any other way endorsed the product for the use listed or for other uses. The purpose of the standardized testing procedures is to ensure that OSCs have comparable data regarding the toxicity, effectiveness, and other characteristics of different products.

The standard toxicity test provides data on the relative toxicities of the dispersant products on commonly used test species under standardized conditions. The Revised Standard Dispersant Toxicity Test uses the saltwater mummichog (Fundulus heteroclitus) and the brine shrimp (Artemia salina) as its required test species for fish and invertebrates, respectively. At the end of a specified test period, a median lethal concentration, or LC50, is calculated using the observed mortalities of the organisms from the toxicity tests. The LC50 is the concentration of a particular dispersant that is lethal to 50 percent of the organisms over the course of the test. Using the LC50's, the toxicity of a dispersant can be compared to that of oil and a mixture of the two.

There is concern whether the two test species used in toxicity testing are commercially available and easily cultured. Consequently, EPA is considering a change to the fish species Menidia beryllinia, the silverside, and to the invertebrate species Mysidopsis bahia, the mysid shrimp.

The current listing procedure does not include an effectiveness criterion; however, such a criterion is being considered by EPA (Sullivan et al., 1993). The current list of almost 50 dispersants would be greatly reduced if a laboratory effectiveness threshold of 50 percent (+/-5 percent) were established. A current product schedule can be obtained from the Emergency Response Division (5202G), Oil Pollution Response and Abatement Branch, U.S. Environmental Protection Agency, Washington, D.C. 20460 (Hotline phone: 202-260-2342).

5.2 Oil Pollution Act

The OPA requires that Area and Regional Contingency Plans for oil spill response be developed and that procedures regarding the use of dispersants on oil spills be identified. Areas and regions for oil spill response and planning organizations are designated in the OPA. There are 13 RRTs consisting of 10 regions, 2 territories, and 1 commonwealth.

Section 4202(a)(4) of the OPA, which requires the establishment of Area Committees, states that the Area Committees shall "work with state and local officials to expedite decisions for the use of dispersants and other mitigating substances and devices."

5.2.1 Response Planning

RRTs have been organized to provide regional planning and spill response. RCP's developed by response team members and federal, state, and local officials provide guidance material for a response to oil and hazardous material spills. These plans describe federal and state authority to respond to spills and introduce protocols for chemical dispersant use. Each office of the RRT Co-Chair has a copy of the RCP.

Area Contingency Plans (ACPs), unlike RCPs, are action plans that are specific to oil. An ACP will define worst-case incidents and describe the actions necessary to respond. The plan lists available equipment, location of the equipment, and personnel that can be utilized during emergency situations.

5.2.2 Approval Plans for Dispersant Use

Dispersant use requires preplanning and the development of an approved plan. The procedures to be followed for obtaining permission for the use of dispersants are specified in RCPs. Regional response team members should develop a preapproval plan for specific dispersants and oil types. If preapproval has not been established through a prespill preapproval plan, the OCS may authorize the use of products on the Product Schedule with the concurrence of the EPA and state representatives to the RRT and, when practicable, in consultation with the Department of Commerce and Department of Interior natural resource trustees. Valuable response time can be lost in this situation because the RRT is unlikely to grant approval for dispersant use in less than 6 hours after a spill. Thus, the preapproval plan allows quick decision making and quick action in responding to specific oil spills.

Prespill plans identify acceptable and unacceptable potential dispersant-use zones and seasons and take into consideration variations in state restrictions on dispersant use and authorization for use. Spill models may be incorporated to help predict landfalls and to relate predicted landfalls with sensitivity maps.

Plans developed for dispersant preapproval should include at a minimum the following information:

- Descriptions of the types and volume of oil transported throughout the region.
- Discussion about the dispersibility of the types of oil transported through the region.
- Descriptions of sensitive areas that would be adversely affected should a spill occur.
- Descriptions of seasonal habits of fish and wildlife in the region.
- Descriptions of the following types of information that must be collected before a decision to use the dispersant can be made:
    - Circumstances of the spill and type of oil
    - Properties of the spilled oil
    - Weather conditions and spill trajectory (can be provided by NOAA).
- Descriptions of the dispersants available.
- Descriptions of the equipment to be used to apply the dispersants.
- Descriptions of monitoring to be performed in the dispersant area.

SECTION 6

APPLICATION OF DISPERSANTS

This section describes the application equipment and the logistics involved in applying dispersants. It provides sufficient detail to allow an OSC who has decided that the use of dispersants is warranted to plan and conduct the dispersant spraying operation in a manner that will achieve the maximum effect. This information is not intended as a design guide for dispersant equipment. The application information presupposes that commercially available and calibrated equipment are ready for deployment. Appendix A contains information on equipment that may be available. The basic organizational aspects of a spill response using dispersants are similar to recovery operations and are not discussed in detail here. Specific organizational aspects appropriate to dispersant use will be discussed to supplement existing planning.

Two of the most significant hurdles to overcome in the effective use of dispersants are the lack of a dispersant supply and insufficient availability of application equipment. Proper planning should not only address the decision method for choosing dispersant use, either alone or with other response strategies, but also identify the source for the dispersant and the means to obtain the proper application equipment (USCG, 1993).

6.1 General Principles of Dispersant Application

Techniques used to apply dispersants on an oil slick are generally less controversial than either the effectiveness of the dispersant or its environmental impacts. The application often is not effective, however, because of poor mixing, the use of inadequate application techniques (such as poor targeting and distribution of aerial sprays), the possibility that the oils were not dispersible, or poor formulation of the dispersant (NRC, 1989). Also, a major controversy concerns how to determine the field effectiveness of the dispersant. Guidelines for determining dispersant effectiveness in the field are discussed in Section 7. Once the decision has been made to use dispersants, the technical aspects of application are comparatively straightforward. Yet, there are often a myriad of logistical problems, including getting enough equipment, getting dispersants and other supplies and doing everything within a short (24-48 hour) timeframe.

The following general principles of dispersant application underpin all operational and design considerations:

- Apply dispersant without dilution. Although some boat spray systems may contain equipment for dilution, predilution of the dispersant with sea water appears to reduce its effectiveness. Dilution also requires additional unnecessary mixing equipment.

- Ensure contact of the dispersant with the oil to achieve effectiveness. Dispersant that falls on the sea will be ineffective even if the slick subsequently moves over the treated area.

- Apply dispersant to the leading edge of a spill or the thickest part. The leading edge or the dark windrows of oil in a slick contain the largest concentration of the oil even though their area may only represent a small fraction of the total slick. By many estimates, 90 percent of the oil is generally found in 10 percent of the areal extent of the slick (Audunson, 1984).

- Apply dispersants as soon as practical after the oil spill occurs. The least-controversial aspect of dispersant effectiveness is that oil is less easily dispersed as it ages. Rapid response is the single most significant controllable factor related to effectiveness when oil dispersants are used.

- Apply dispersants as close to a continuing spill source as possible. The dispersant will have the maximum effectiveness near the source, where the oil is the freshest and thickest.

- Do not apply dispersant to oil sheen. The silvery oil or even rainbow-colored oil generally is less than 0.005 mm thick and may be as low as 0.001 mm thick. Sheens have a greater chance for natural dispersion and have a lower efficiency for chemical dispersion since dispersant drops often pass through the sheen without interaction.

- Observe the action of the dispersant from both the air and the surface. The effectiveness of the dispersant in removing oil from the surface must be observed throughout the application. Although visual observation merely provide a subjective opinion of the effectiveness, it is the only guide that is practical on a real-time basis. When the slick does not appear to be affected by dispersant application, it is time to reassess the response (see Section 7 for observation guidelines).

- Adjust application rate to achieve optimum effectiveness. Dispersants have varying degrees of effectiveness depending on the crude oil, its age, and the thickness of the slick. Adjustments in the field can result in the optimum quantity of dispersant being used to achieve satisfactory dispersion.

- Do not apply dispersants in the immediate vicinity of recovery operations. Dispersant spraying near recovery equipment can render some equipment ineffective. Many recovery devices rely on the ability of oil to adhere to certain materials preferentially (e.g., moving belt skimmers). Dispersant overspray landing on such equipment will reduce oil adherence to the skimming device.

The aforementioned general principles may have exceptions in special cases, but such cases are rare.

Similar to the general principles, the following rule of thumb can be used in the planning stage and during the initial response. Dispersant application planning and the initial response should be based on an application ratio of between 1:10 and 1:20 parts of dispersant to oil. This range has been derived from laboratory studies and practical observations and requires field adjustment to achieve optimal performance. In a spill situation, the oil tends to spread rapidly and can achieve a thickness of 0.1 mm in a matter of 1 or 2 hours (NRC, 1989). At this thickness, the 1:10 to 1:20 ratios translate to about 50 to 100 liters per hectare (5 to 11 gallons per acre). Without specific knowledge of slick thickness and dispersant effectiveness on the slick, the initial response effort should first start with a higher application rate and then be reduced until the optimum rate is achieved.

6.2 Marine Vessel Application

The use of marine craft was the only common method of dispersant application until the 1980s. With the success at Bantry Bay of aerial spraying, more effort has been put into the aerial application route (NRC, 1989). Marine vessels offer several advantages over aircraft in the application of dispersants. In planning for spill response, the following advantages should be weighed against the disadvantages inherent in marine craft.

6.2.1 Advantages

Most coastal areas have a large pool of potentially suitable vessels and experienced mariners. Mariners familiar with the vessels and the coastal region are often readily available even in the absence of trained response teams. Vessels can be easily chartered with full crews and necessary insurance in a very short period. The legal documents for chartering have been in place for years and are well known. Chartered vessels of opportunity can be rigged with portable dispersant spraying equipment maintained in the region or flown in from nearby depots. The rigging is not complex and can be done quickly. Marine craft can provide flexibility in dispersant use. Because small vessels can work comparatively closer to the shore, they are able to tackle smaller slicks and patches with precise application. Large vessels containing thousands of gallons of dispersants can be stationed and provisioned near a continuing source for days or even weeks at a time. Support such as fuel, docks, provisions, and repairs for both small and large vessels are common in most coastal areas.

6.2.2 Disadvantages

The major disadvantages of marine craft use are all related to their speed and the inability of a boat captain to see the limits of the spill. Vessels that might be used to spray dispersants generally have a top speed to get to the spill site of less than 25 knots and while on station an application speed of less than 10 knots. These vessels can require 6 to 8 hours to get from port to the site of a spill even though the spill may be only a few miles off shore but not near a port. Once at the spill site, the treatment capacity of marine craft is usually limited to approximately 15 to 60 acres per hour at 10 knots, depending on the equipment (Appendix B). The area that can be treated is often limited by the travel time between thicker patches of oil. As with any vessel spill response, application of dispersants from boats can lead to nausea problems among workers as a result of the combination of the rolling sea and odor of fresh crude. The efficiency of an operation can be severely reduced in such circumstances.

6.2.3 Equipment

Equipment used to apply dispersants from marine craft is relatively simple and consists of four basic components: dispersant storage, delivery pump, metering device, and delivery system. The equipment should be built specifically for dispersant application to ensure compatibility in specifications between components. Thus, the pumps, meters, booms, and nozzles or fans are designed to work as a system. The system is designed for adaptation without modification to a particular set of vessel specifications. The vessels that are suitable mounting platforms must be compatible with the delivery system specifications. The equipment must have clear and concise instructions for installation and operation, especially if portable equipment is to be used on a vessel of opportunity.

Figure 6-1 shows a common dispersant delivery system that utilizes a boom mounting arrangement. The length of the boom depends on the dimensions of the vessel. Booms generally vary in length from 3 to 12 m (10 to 40 ft) long depending on the vessel size. Booms may have nozzles mounted directly on the frame or mounted on extension lines that hang from the boom. Nozzles should be from 2 to 3 m (6 to 9 ft) from the sea surface. Smaller craft can have nozzles located closer to the sea surface, and the nozzles need to be designed for that height. Booms must be short enough so that the nozzles will not hit the sea surface as the vessel rolls during dispersant application. As seas become higher, dispersant operations must be halted and booms brought in and secured.

The nozzles and their mounting must be designed to provide a mean volume dispersant droplet diameter on the order of 500 to 700 μm in a fan-shaped overlapping pattern, as shown in Figure 6-2. Droplets that are smaller tend to blow on deck or away

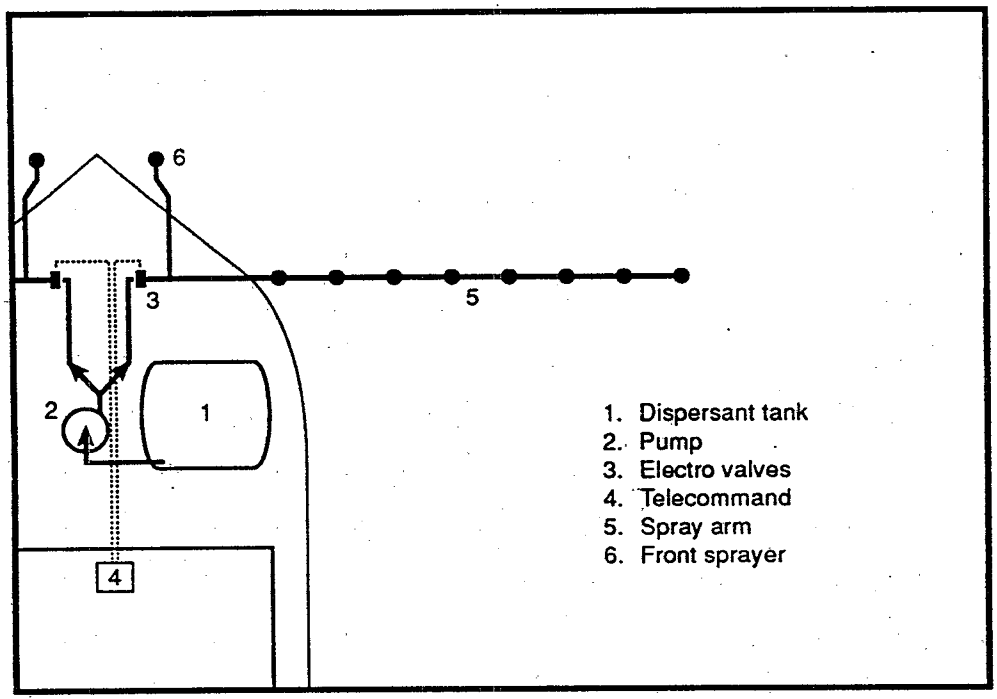

Figure 6-1. Dispersant delivery system using a boom-mounted arrangement (adapted from CONCAWE, 1988).

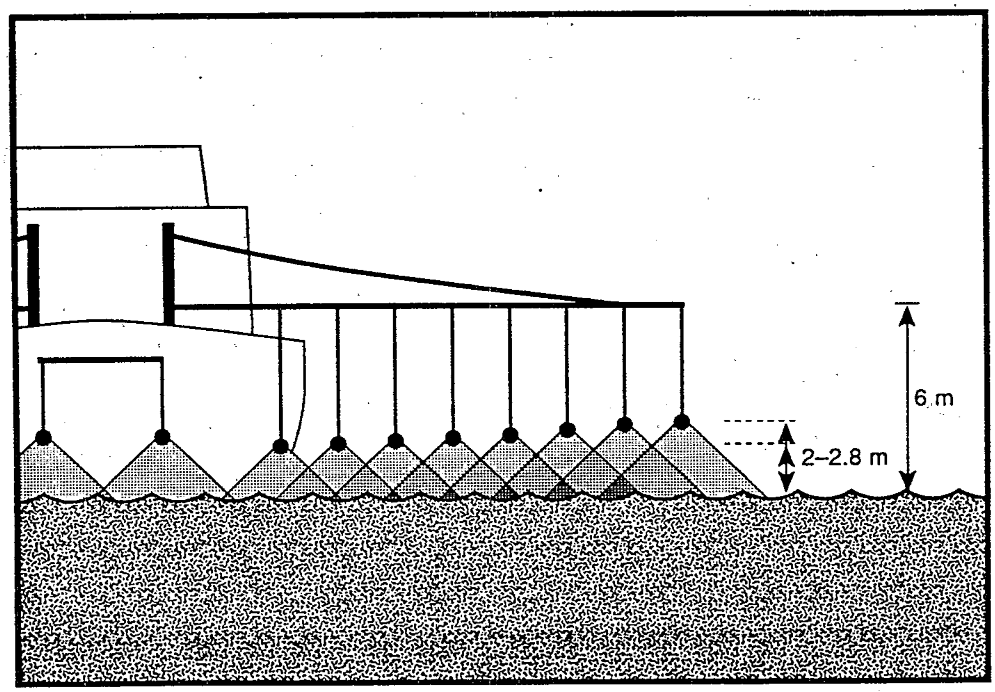

Figure 6-2. Spray arm system with overlapping spray pattern (adapted from CONCAWE, 1988).

from the intended target, and larger droplets penetrate through the slick. The booms on the vessel are placed toward the bow so that the dispersant will strike the slick before being disturbed by the bow wave. The equipment manufacturer may need to supply more than one set of nozzles, depending on the dispersant viscosity or the distance to the water.

An alternative to the boom system is a ducted fan system (Allen, 1985; Barbouteau, 1987). Nozzles spray dispersant into an air stream created by a powerful fan. The resultant spray can accurately distribute the 500- to 700-μm droplets up to 24 meters (80 feet) from the boat. The system requires a higher degree of operational sophistication because of the effects of wind on the spray pattern. The system may not be appropriate for dispersant application if wind speeds exceed 15 knots (CONCAWE, 1988). On both the boom and ducted fan systems, the dispersant flow rate must be calibrated at various meter or pump settings. Since the vessel speed and dispersant flow rate determine the application rate, the vessel master must be able to easily correlate the meter readings to the vessel speed to determine the application rate per unit area. Usually the vessel is maintained at a constant speed between 5 and 10 knots, and the dispersant metering system is to be adjusted to maintain the flow at the desired rate. The calibration for a particular spray system could consist of a set of six plots of dispersant controller settings versus the areal application rate for ship speed at 1-knot intervals between 5 and 10 knots.

6.2.4 Application

Prior to the commencement of a dispersant operation, the quantity of dispersant on each vessel should be inventoried. Daily logs of dispersant use should be maintained to enable a rough approximation of its effectiveness to be determined on a daily basis. Inventory reconciliation can determine dispersant overuse and equipment malfunctions.

Application of dispersants from marine craft requires direction from aircraft in order to achieve the maximum benefit for oil spill control. Communication between the vessel and the aerial observer requires appropriate radio equipment with compatible channels. The aerial observer acts as the coordinator to direct vessels to the thicker patches of the slick and then provides feedback to the vessel on the effectiveness of the operation as seen from the air. The airborne observer needs to provide the vessel master with a description of the slick with respect to alignment and suggest a direction of attack in order to allow the vessel master to make the approach as efficient as possible. If multiple vessels have approached the slick in order to spray in a staggered formation, it is even more important to have clear instructions from the aircraft observer to avoid spraying already treated oil.

Upon instructions from the observer or by direct observation, the vessel master should begin spraying at the preselected rate. On first approach to a spill, the rate may be as high as 90 liters/hectare (10 gallons/acre). This rate may be lowered, based on the results seen by the aerial observer. As experience is gained with a particular slick, adjustments can continue to be made around a narrower application rate as the oil ages or as thicker patches are encountered.

The vessel normally must be kept at speeds of less than 10 knots to avoid having the bow wave push away or submerge the oil before treatment and to avoid wind spray of dispersant onto the deck of the boat. The vessel speed also must be reduced as winds pick up and blow the dispersant on deck. Although dispersants are not toxic, they can cause skin irritations and breathing difficulties if inhaled. Additionally, if decks become coated with dispersants, they become slick and hazardous to movement. Sea conditions resulting from winds measuring over a force of 5 on the Beaufort scale are generally not conducive to dispersant operations. When seas reach this level, there is not only a greater tendency toward natural dispersion but wave action exposes more open water instead of oil.

6.3 Aerial Application

Generally, aerial application of dispersants is preferred to vessel application because it has been found to be an efficient method for treating large areas in a short time. As equipment has become more available around the world, more experience has been gained in large-scale aerial dispersant application that has been translated into more effective techniques and better equipment. Because the logistics of an aerial spray operation are significantly different from other types of response, they are covered in greater detail below. Aerial application appears to have largely replaced marine vessel application as the preferred method for larger spills. Figures 6-3 and 6-4 are photographs of helicopters with suspended buckets. Figures 6-5 and 6-6 show a Fixed Wing Folker F-27 and a C-130 with an ADDS pack respectively applying chemical dispersant.

6.3.1 Advantages

Aircraft have the advantage of speed. They can move from a home base to a spill location staging area in a matter of hours. From staging areas, aircraft can fly to the actual spill site usually in a matter of minutes. This is a significant advantage in a rapid-response application in which the effectiveness of the dispersant is time-dependent.

Dispersant application per unit time is another great advantage of aircraft because of their speed. Appendix A contains tables showing the relationship of carrying capacity of an aerial dispersant system to the area capable of being treated per unit time. These tables show that even a small helicopter-borne spray device can usually outperform the largest vessel. This ability is even more apparent when the slick is broken up in scattered windrows that require significant vessel travel time between thicker patches.

6.3.2 Disadvantages

Only a limited number of aircraft, equipment, and personnel are capable of applying aerial dispersant. Dispersant-equipped aircraft may be located many hours of flight time from a staging base. Compared with marine craft, aircraft of convenience are generally not as available. Although portable equipment can be installed on certain fixed- and rotary-wing equipment, other considerations often restrict its use to specific aircraft. One of the major restrictions involves insurance and contracts. Unless contractual arrangements are made in advance, complications in reviewing the legal instruments can negate all of the speed advantages of aircraft.

Another restriction is the availability of trained pilots and crew. Aerial application requires special training for handling aircraft at low altitudes. Also, the related

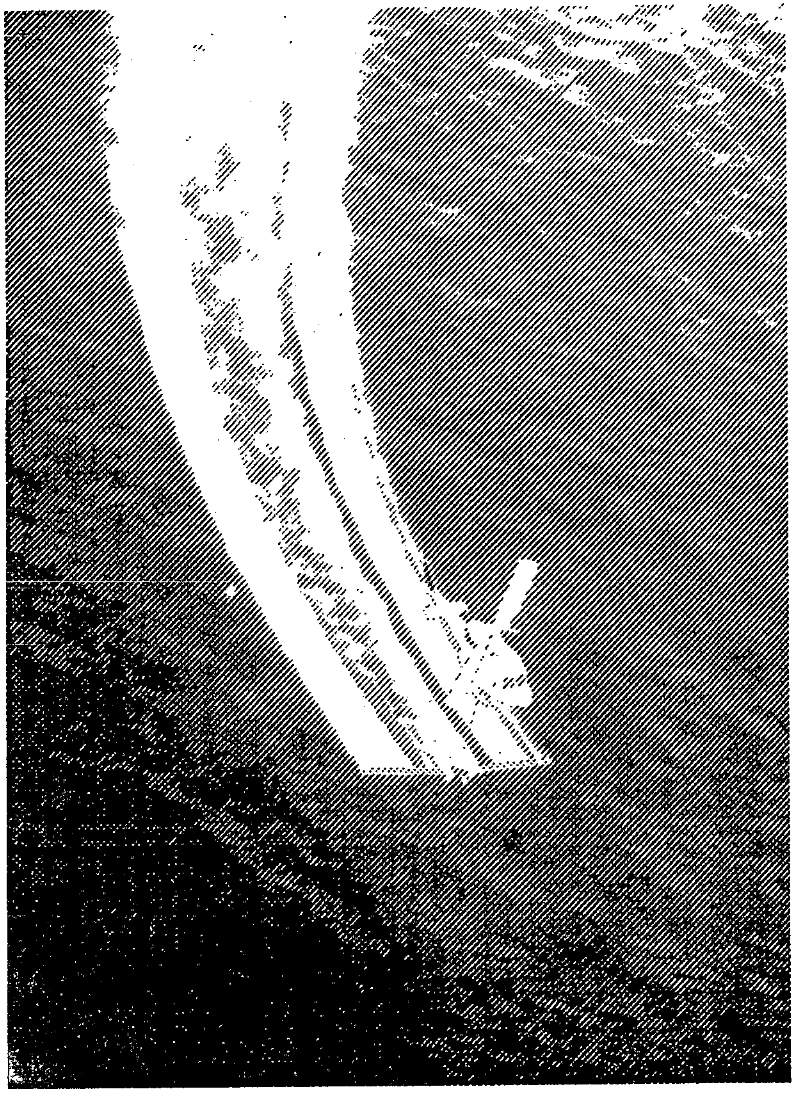

Figure 6-3. Photograph of a helicopter with suspended bucket applying chemical dispersant.

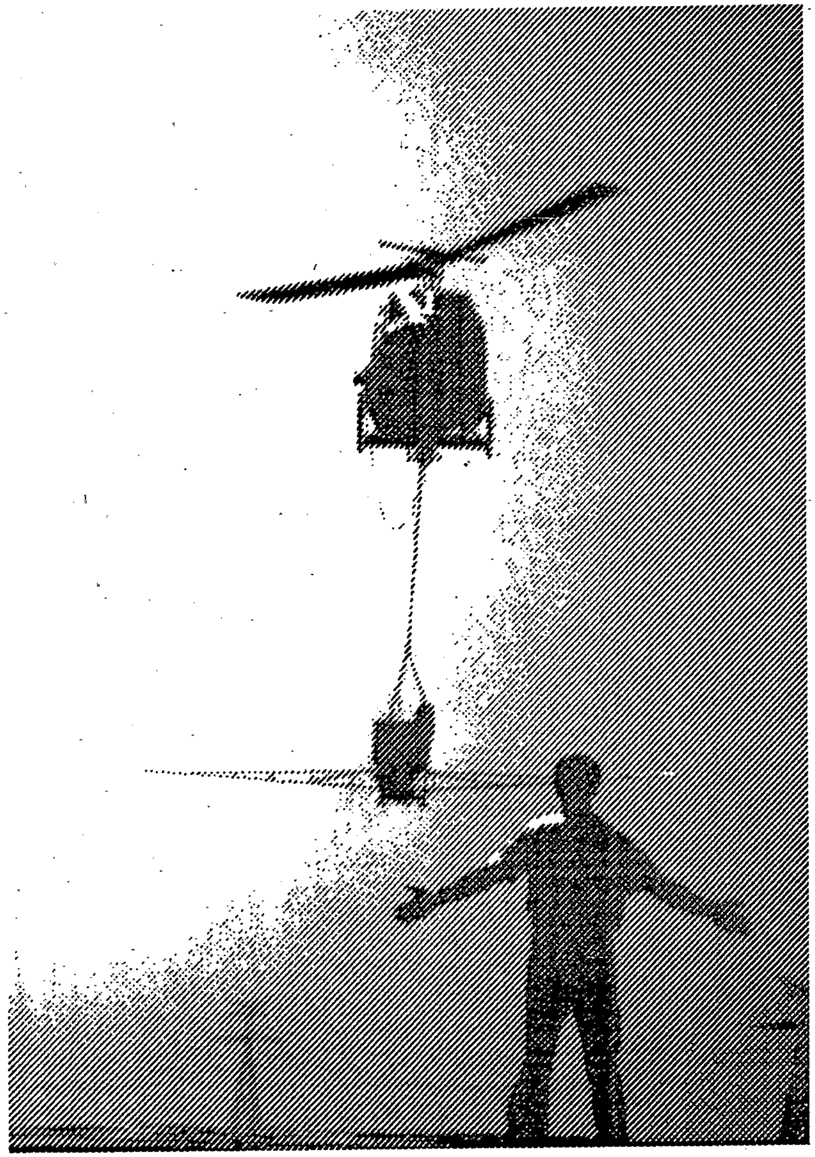

Figure 6-4. Photograph of a Bell 212 helicopter with Simplex Bucket.

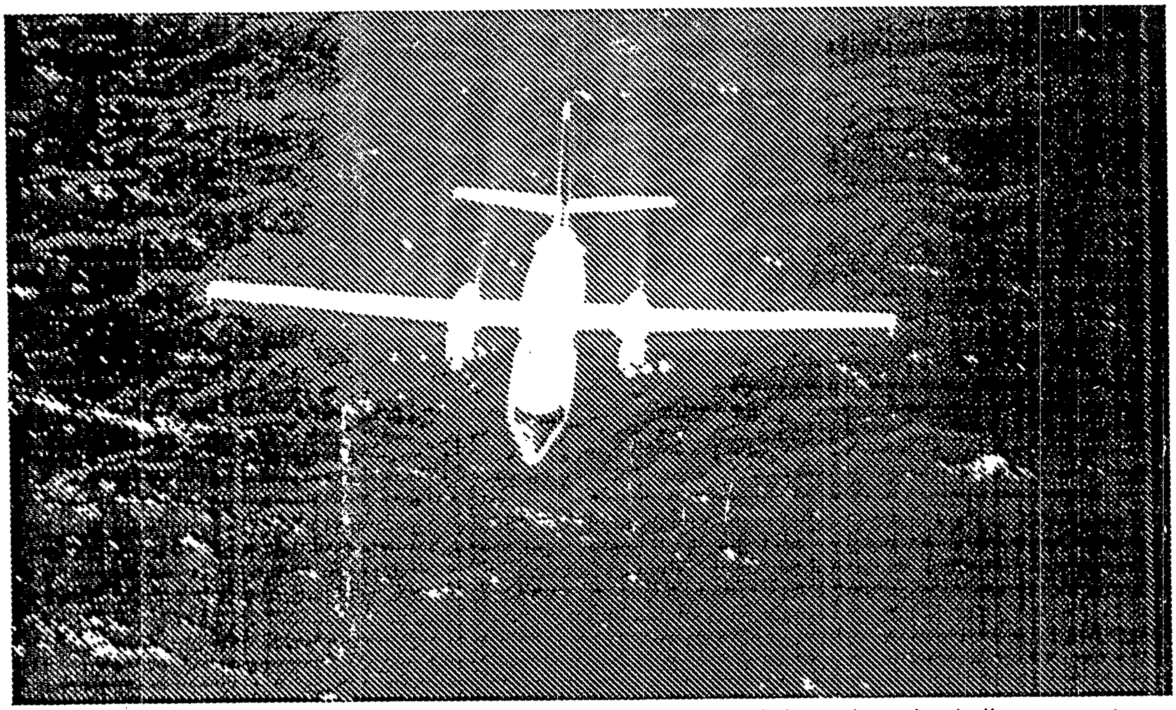

Figure 6-5. Photograph of a fixed-wing F-27 applying chemical dispersant.

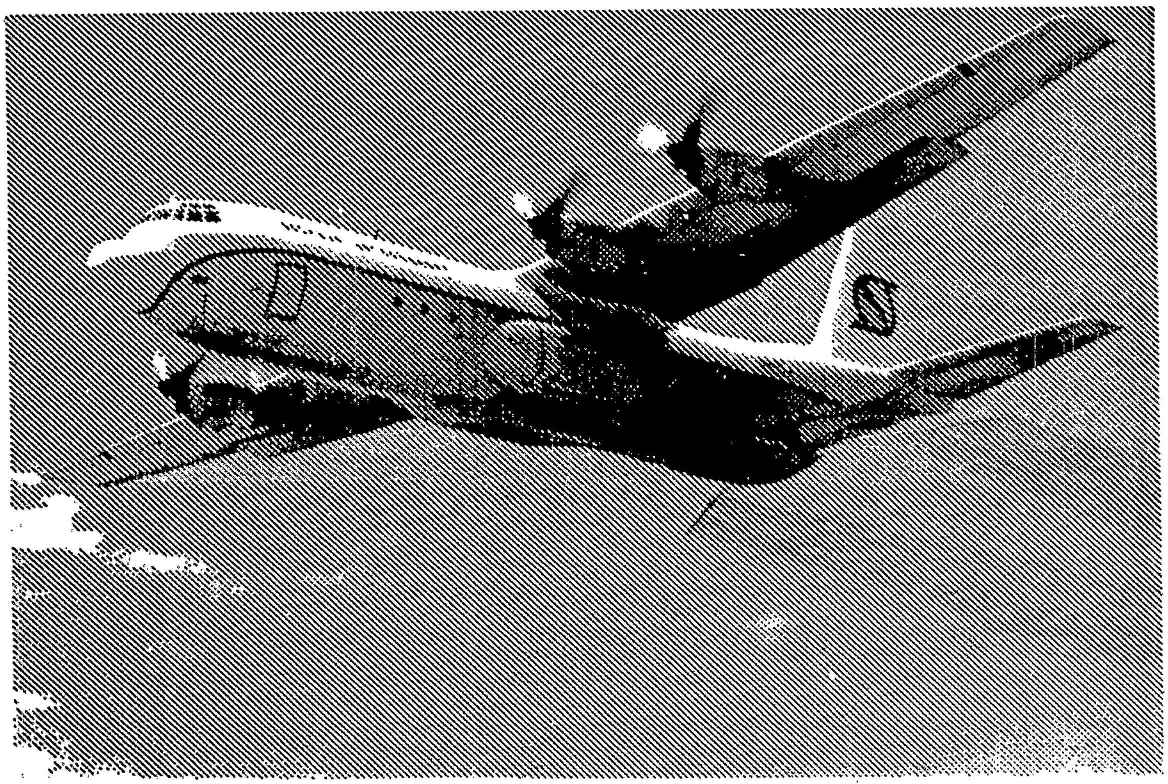

Figure 6-6. Photograph of a C-130 with ADDS pack.

equipment generally requires a special crew and maintenance personnel. A high degree of pilot skill is required to ensure that dispersant spray makes contact with the floating oil.

Shoreside logistics involving an aerial spraying operation are more complex and require a significant amount of preplanning. An efficient operation requires that facilities be located as close to the spill as practical. Aviation facilities typically are not set up to handle the special requirements described in the logistics section for a spray operation (e.g., easy access by delivery crews, and utilities and water at loading site). Further, it is difficult to target application to a nonuniform spill.

6.3.3 Equipment

Aerial spray equipment can be divided into three broad categories based on the aircraft used: small fixed-wing, large fixed-wing, and rotary-wing (helicopters). The small fixed-wing aircraft are similar to crop dusters. Such equipment specifically designated for handling oil spill dispersants is not commonly available in the United States. Although a crop duster can be used as an oil spill dispersant aircraft, it is not recommended because the dispersant could be contaminated with residual pesticides and herbicides and result in greater environmental problems unless the tanks are properly cleaned. Even with clean tanks, a crop duster may have inappropriate nozzles and application rates for use with dispersants and lack a radio for air-to-air communication.

Helicopters equipped with sling hooks can be used with special dispersant spray buckets. Also, dispersant spray devices can be installed within the cabin of a Bell 212 helicopter. The helicopter-borne buckets are designed to carry from 200 to 3000 L (100 to 800 gal) and are self-contained. Generally smaller buckets that will hold three or four drums of dispersant are more common since they can be used on a wider variety of helicopters. The spray unit comes equipped with pumps, nozzles, and controls. These systems can be transported to the staging area by truck or air and are ready for use upon arrival.

The larger fixed-wing equipment is available in two types: a permanently mounted unit installed in the aircraft and portable equipment. Only a few dedicated

U.S. aircraft are equipped with permanently mounted units. These aircraft are on contract to spill cooperatives and are on call at all times for spill response. The aircraft in use are older piston-powered planes, such as DC6's, DC4's, or DC 3's with maximum capacities of about 13,600 L (3,600 gal), 9,800 L (2,600 gal), and 5,700 L (1,500 gal) respectively. Nozzles of specified sizes and spacing are attached to a spray unit on booms mounted along the wings of the aircraft to provide spray droplets of the right size to be effective at a specific air speed and altitude. Use of dispersants with substantially different viscosities than the design viscosity can adversely affect the characteristics of the spray, and hence the effectiveness of the dispersant.

Systems are available for C-130 (Hercules) type aircraft. The U.S. Air Force has a recently developed system known as the Modular Aerial Spray System (MASS). The Airborne Dispersant Delivery System (ADDS-Pack) is a commercially available system. Both of these systems are designed to be mounted on a Hercules aircraft. Not necessarily any Hercules aircraft of convenience can be used, but more than a few are suitable. There may be contractual difficulties in using an aircraft of opportunity and this must be considered in the spill planning phase. The booms are fixed to the spray system and extend on either side of the aircraft. The spray units contain all pumps and controls needed to make them self-contained. The MASS unit is capable of carrying 7,600 L (2,000 gal) of dispersant, and the ADDS-Pack can carry about 21,000 L (5,500 gal). Neither of these units have been used extensively on U.S. spills.

6.3.4 Logistics

An effective aerial spray operation often depends on numerous logistical local restrictions in the planning and execution phase. For example, some areas restrict the transport of helicopter-slung loads over highways and commercial areas. Similarly, use or access to commercial aviation facilities may be restricted without the normal airport security clearances that often take significant time to obtain for support personnel. Preplanning on the local level must include such special considerations in order to avoid lost time and disruptions during a response. The following discussion presents some of these considerations, but planning must be done at a local level and in detail.

The area coverage of an aerial dispersant operation depends on the aircraft turnaround time--the time it takes to travel from the staging area to the spill site, return, and take off for another run. The actual application time represents only a small fraction of the total turnaround time. The majority of the turnaround time is travel time and ground time to prepare the aircraft for the return flight. Distance between the staging area and the spill site can have a significant effect on the turnaround time, as can the ground activities. A staging area located as close as possible to the spill site is the best choice, especially for helicopter application, since loaded helicopters fly at 100 knots or less and carry much smaller loads.

The staging area equipment must be compatible with the aviation equipment and operated efficiently. Aviation equipment from aircraft fuel tanks to dispersant tanks may require special fittings. Compatible fittings must be available on the ground-support equipment in order to refill both dispersant and fuel tanks. Dispersant transfer from 55-gallon drums can appreciably slow operations. Larger transfer tanks with high-capacity pumps can reduce the ground time by an order of magnitude. Advance planning for dispersant operations should consider the transfer capacity as a potential limitation to operations and make provisions for portable tanks and suitable pumps to be brought to the staging area.

The staging area should include sufficient space for the aircraft and dispersant storage. The work area needs to be remotely located from other activities that can interfere or pose hazards. Helicopters have much more versatility in this respect because they allow areas to be selected that are removed from other activities. Fixed-wing aircraft require an airport and do not have the same flexibility; they need a large work area for turnarounds. The staging area needs to be equipped with communications that can contact both the aircraft and other outside facilities. A source of washdown water is also important to deal with the frequent spills and drips of dispersant during loading operations. Dispersant can soften asphalt and make concrete slippery.

Aircraft refueling capability is necessary to maintain a continuous operation. Older piston-driven aircraft require aviation gasoline that may not always be available in sufficient quantities at smaller airports. Helicopters use jet fuel. Provisions for obtaining fuel must take into account the type of aircraft to be used. Planning for dispersant operations using helicopters offers the potential for operations from an offshore platform close to the spill site. In this case, fuel and dispersant must be brought to the platform to minimize turnaround time.

6.3.5 Application

Application from aircraft is based on the general principles outlined previously. More skill is involved in aerial dispersant application because of the high speeds and low altitudes demanded in such applications. Pilots must be trained and drilled in application techniques. Maneuvers of fixed-wing aircraft flying at more than 150 knots at 15 m (50 ft) above the sea surface leave little room for error. A three-person crew normally is used on a fixed-wing aircraft, and a two- or three-person crew is used with helicopters. The pilot and copilot work together to maintain altitude and course. Directions for commencing and halting spraying are supplied by the spotter aircraft and/or the copilot to the crew member controlling the dispersant equipment. Because the entire crew must operate as a team, they should be thoroughly familiar with the maneuvers.

Although the Air Force MASS system may be able to operate at altitudes over 30 m (100 ft), this system is still in the trial phase for dispersant application. Other fixed-wing and rotary-wing equipment normally operate at 15 to 23 m (50 to 75 ft). Higher-altitude operation may result in a fine spray over too wide an area to provide an effective dispersant-to-oil ratio. This low-altitude operation is facilitated by the use of a spotter aircraft to aid in alignment and to provide feedback on each run. The spotter is in constant contact with the pilot or copilot to provide information on the position of the aircraft in relation to the slick. The spotter can also provide the signal to commence spraying. The spotter aircraft operates at a higher altitude and to the rear of the dispersant aircraft to enable the spotter to view the spray pattern and to direct subsequent runs to adjust for wind drift and swath width.

Aircraft application of dispersant should be tailored to the slick conditions. When treating the leading edge of a slick, the aircraft often will be flying perpendicular to the wind. The flight path and alignment must be offset sufficiently to allow for wind drift and spreading of the swath that, depending on the equipment and altitude, may be in excess of 30 m (100 ft). The swath width must be considered when aircraft are used to treat windrows. Because a windrow may only have a width of 10 m (30 ft), a large aircraft would waste considerable dispersant during spraying. In such a case, blanking of some outer nozzles on the spray boom and/or smaller aircraft or marine vessels should be considered if available.

SECTION 7

DECISION PROCESS FOR DISPERSANT USE

Numerous oil spill response decision processes have been described in the literature (Fraser, 1989). The processes are usually illustrated in the form of a decision tree. Appendix C provides example decision trees from the literature. Decision tree differences are due to their origin and purpose. Some decision trees are generated from dispersant use agreements and are a formal part of the agreement, whereas others detail the steps involved in selecting a spill response mechanism. The published decision-making steps differ in the level of detail and the extent of focus, e.g., coverage of oil recovery, dispersant use, beach cleaning, and ecologic specifics.

A decision tree can become quite complex in an attempt to identify each aspect of the decision process, including such details as spill size, sea state, weather conditions, and environmental sensitivity. Such a decision tree is often quite informative, but somewhat cumbersome to use, and it tends to submerge the basic considerations in a sea of detail. A complex decision tree is desirable from a regulatory perspective when it functions as a "pre-approval" for dispersant use. A detailed plan prepared prior to an event with input from potentially concerned parties can specifically identify the steps that must be taken prior to dispersant use. This agreement on the decision process prior to a spill can relieve the OSC or the responsible party of the associated problems in addressing competing concerns and trade-offs while trying to organize the response. The EPA computerized decision process, which is presented in Appendix C, represents one of the more detailed processes (Flaherty and Riley, 1987). A complex decision process has two major problems: 1) The more detailed and rigid a decision process is, the more likely a situation will arise that does not correspond to the detailed decision steps, and 2) Such a process is more difficult to prepare and maintain. Because the EPA computerized decision process has experienced both of these problems, the system is being reviewed (Cunningham et al., 1989).

7.1 Simplified Decision Tree

Figure 7-1 provides a simplified version of a response decision procedure similar to the International Maritime Organization/United Nations Environmental Program (IMO/UNEP) guidelines (IMO, 1982). Its purpose is to illustrate the flow of response decision making at the fundamental level. It is not meant to be a substitute for a detailed decision process. The simplicity of the decision tree shown in Figure 7-1 has both advantages and disadvantages. The decision steps shown are reduced to the basic issues and provide an easy and flexible set of response actions. The process description conforms to a general approach that is common to any marine spill event, but it does not identify the specific inputs that are required to make the decision and proceed to the next decision point. The reduction of the decision process to the fundamental elements removes from the diagram some of the ancillary steps that go into the decision. The process is focused on the basic question of which response or combination of responses will provide the optimal environmental or economic protection. The absence of detail requires the user to understand the significant number of considerations that are involved with each step of the process. Some of these considerations are highlighted in the Notes to The Decision Tree, but this is not a comprehensive list of items that covers all contingencies. Development of detailed notes requires site-specific knowledge and compliance with regulatory considerations that are applicable in the particular region.

The decision process shown in Figure 7-1 places more of the responsibility on the OSC. The OSC, however, may have regulatory restraints that require the concurrence of other parties in the various steps in the decision process. The regulatory regime that controls dispersant use varies from region to region and can intersect the decision tree at

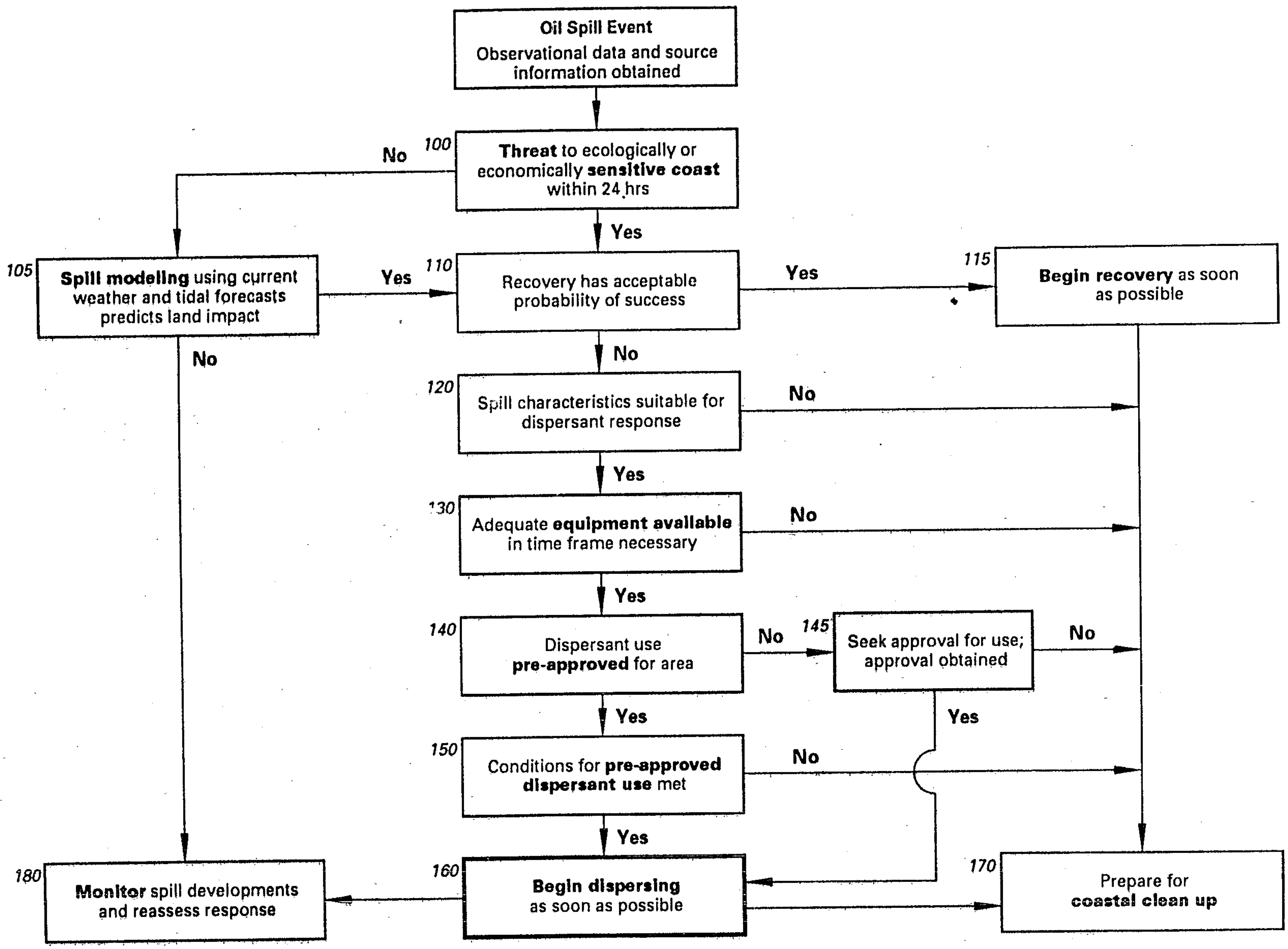

Figure 7-1. Oil spill initial response decision tree.

Notes to the Decision Tree (Figure 7-1)

The use of this decision tree presupposes the availability of observational reports or other factual data on which to make decisions. Observation and data gathering are considered fact finding and information input and therefore are not considered as a decision step, but an ongoing aspect of the spill event. No decision tree provides a substitute for experience and judgment. The formal diagram is merely an aid to identify the key elements in the decision process. The notes presented below supplement the decision tree diagram by identifying some of the inputs and judgments necessary for a decision step.

100 In order to evaluate the threat, the following basic points need to be considered:

- Spill size/location - The spill must be large enough to have a coastal impact if it moves toward shore, or be a threat to shallow-water offshore resources (e.g., corals).
- Ecological sensitivity of coastal area - Wetlands, marshes, estuaries, and bird breeding areas are extremely sensitive to oil and generally difficult to clean by mechanical means without significant adverse impact. Review of contingency planning maps will provide this information.
- Economic concerns - Developed shorelines with a large tourist use can have severe economic impacts on employment in the area if the beaches are contaminated by oil fouling. Review of contingency planning maps will provide this information.
- Oil movement - The potential path of the oil in the short term has to be assessed immediately because the different responses may not all be available in the short term. Preapproval plans for dispersant use often discuss the coastal impact for a spill in a given area. As a quick estimate of oil movement, forecasted wind conditions for a 24-hour period along with current direction can be used to estimate the slick position using the vector sum of 3 percent of the wind velocity plust 100 percent of the surface current velocity to determine the location of the leading edge of a slick over the course of the period.

105 In circumstances in which the threat is not immediate or the ecological and economic impacts of landfall are small, an additional opportunity is available to marshal response resources and produce more than one alternative. Spill modeling can provide an estimation of the long-term movement of the spill to give the OSC further information. Models available through NOAA or Regional Response Teams can supply the probable path. The following possibilities can be assessed:

- Spill will not impact coastal areas before natural breakup.
- Spill will impact coastal region and will still be in a physical state or quantity to cause significant adverse impact.
- Spill will impact coastal region but is unlikely to cause significant adverse impact.
- Long-term weather conditions will affect operations.

(continued)

Figure 7-1. Notes to the Decision Tree (continued)

110 The feasibility of mounting a successful recovery operation will require a review of the following factors at a minimum:

- Spill location in relation to recovery equipment and time to mobilize to the site
- Size of spill in relation to the amount of recovery equipment available
- Storage barges or vessels available
- Weather conditions over an extended time span
- Sea state and currents
- Trained personnel

115 Upon determination that recovery is a feasible response and has a significant probability of successfully reducing environmental and ecological impacts, the OSC must immediately mobilize recovery operations to maximize the potential for success. In addition, the OSC should consider the supplementary use of dispersant.

120 The oil slick and physical conditions must be appropriate for dispersant use. Determination of whether this is the case requires the following information to be gathered and assessed:

- Oil type
- Age of oil
- Size of spill
- Thickness of spill
- Sea state and winds
- Spill location in relation to dispersant staging area
- Type of dispersant available

The first two items need to be known to allow comparison with data on the dispersibility of specific types of oil. The size of the spill permits judgment on potential harm and potential for successful recovery. A small spill may not need action, whereas a large spill near shore with a shore trajectory may not be treatable prior to large-scale shoreline impacts. Sea state, weather conditions, and location of the spill can all influence the feasibility of mounting a dispersant application effort.

130 Equipment must be available in a time frame that allows a response to have a significant impact on the spill. The following information is useful in the assessment:

- Time to mobilize equipment to spill location
- Type of equipment available, i.e., boats or aircraft
- Adequate dispersant stockpiles available to support operation
- Staging area logistics support available
- Equipment application rate sufficient to affect a spill prior to shoreline impact
- Contracts and administrative details completed on equipment in time span available
- Trained personnel available

(continued)

Figure 7-1. Notes to the Decision Tree (continued)

140 Under the current U.S. regulatory regime, dispersant use must either be preapproved or approval must be obtained prior to its application on a spill. It is unlikely that approval from the various parties involved can be obtained within a 24-hour period and a significant application effort be mounted within a 24-hour period; therefore, unless preapproval is in place, shoreline cleanup should be planned. In the event the spill is unlikely to hit the coast for more than 24 hours, the OSC must evaluate the factors from Block 120 and determine if the oil will still be amenable to chemical dispersal in the time it may take to obtain approval.

145 If dispersant use is not preapproved and it is more than 24 hours until the predicted landfall, approval must be sought for dispersant use.

150 Preapproval plans will generally have quite specific requirements for dispersant use. In some areas, additional approvals are needed from state authorities. The OSC must ensure that the conditions for dispersant use have all been met prior to authorizing the application of dispersants.

160 Dispersant application guidelines of the preapproval plans must be followed, and other requirements set forth in the preapproval document must be implemented. The specific requirements will vary between regions and with different locations within a region.

170 Preparation for coastal cleanup for any spill that has a significant probability of coastal impact is necessary under any response. Experience has shown that neither chemical nor recovery methods have been highly successful in preventing shoreline impacts; therefore, the OSC should make preparations for the coastal cleanup activities during an off-shore response.

180 Spill monitoring to assess the response is necessary whether the response is chemical, mechanical recovery, or no response. Upon finding a response is no longer effective or conditions have changed, the OSC needs to determine if a new course of action is prudent.

different points. Thus, the apparent simplicity of the decision process presented in Figure 7-1 belies the complexity of the actual steps involved in decision making. An OSC does not have the authority to proceed through the decision tree and implement dispersant use unilaterally except where human health and safety issues are directly involved.

The decision tree presented in Figure 7-1 focuses the process on the three basic questions that need to be asked:

- Could dispersant use reduce adverse impacts?
- Is there a suitable alternative to dispersant use?
- Could a dispersant operation be implemented?

All other decisions are subordinate to these three and are based on increasingly subjective foundations. The actual use of dispersants will be controlled by site-specific environmental considerations, regulatory controls, and the individuals involved in the process.

7.2 Monitoring Dispersant Effectiveness

As discussed previously, the OSC must make a continual assessment of the effectiveness of the response in a given spill situation after the decision has been made to apply dispersants. This decision process can be based on visual observation or electronic sensing methods. Visual observation has a major subjective component that can cause significant variations in effectiveness claims between two observers (NRC, 1989). Figure 7-2 relates a general consensus oil appearance to thickness of the oil.

Electronic means such as the Side Looking Airborne Radar (SLAR), Ultraviolet/Infrared Sensing or microwave sensing are the most common electronic sensing means for monitoring an oil spill (Tennyson, 1992). Each of the electronic methods has its own advantages and drawbacks and there is no consistent way to quantitatively determine effectiveness (Descheves and Pullen, 1993; Choquet, et. al., 1993). Table 7-1 shows some key features of various remote monitoring methods, including electronic sensing techniques for monitoring oil slicks under various conditions. As noted in Section 3, fluorometry may be used in conjunction with marine craft to sample the water under the slick. However, actual analysis of the water does not offer the same versatility of movement nor supply the same information as the remote sensing methods shown in Table 7-1.

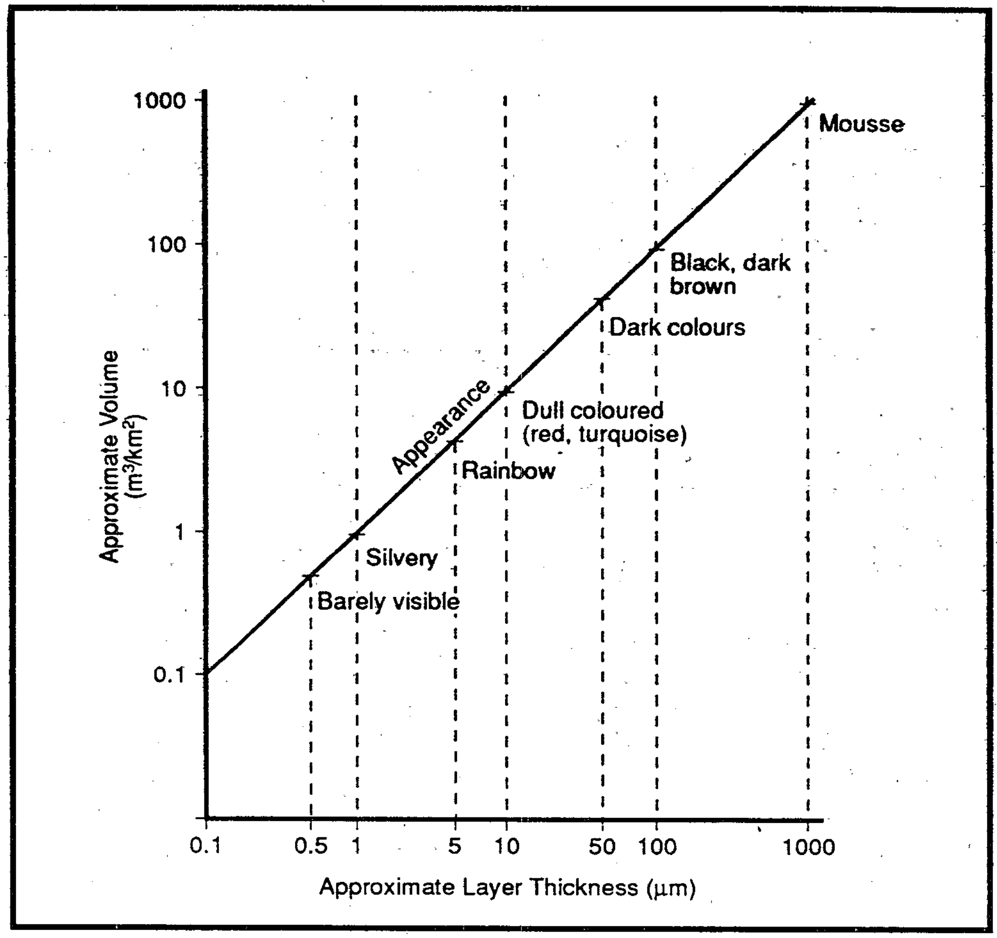

Figure 7-2. Oil appearance as a function of thickness (adapted from CONCAWE, 1988).

TABLE 7-1. REMOTE MONITORING OF OIL SLICKS[a]

	Monitoring methods						
Monitoring Capabilities	Visual Observation	Photography	Thermal Infrared Scanner	SLAR[b]	Radiometer	Fluoro-sensor Laser	Integrated Sensor Package[c]
Estimate slick thickness	•	•	•		•		•
Estimate slick surface area	•	•		•	•		•
Real-time monitoring	•		•	•	•	•	•
Day operation	•	•	•	•	•	•	•
Night operation			•	•	•	•	•
All-weather use	•	•		•[d]			•
Variable altitudes/speeds	•	•		•			•
Identify types of hydro-carbons						•	•

[a] Adapted from CONCAWE, 1988

[b] Side looking airborne radar.

[c] SLAR, radiometer, and laser.

[d] All-weather use with exception of gales.

The following spill observation guidelines should be used to determine the maximum effectiveness and application of dispersant use:

- Observations should be made from aircraft.
- Trained observers should be used to report on spill thickness and dispersant effectiveness.
- The same observer should be used as much as practical.
- Video recording and photography should be employed to document visual reports.
- Electronic data should be used to supplement visual observations whenever possible (see Table 7-1).
- More than one type of electronic sensing should be used because of individual method limitations.

The observer should vary his position and altitude in order to achieve the optimal vantage points for observing the effects of dispersant use on a slick. Light, clouds, sea state, and angle of sun all affect the observation of oil on the sea. The observer should look at differences in slick behavior between areas on which dispersant has been applied and those that do not have dispersant application. Frequently, dispersion can be quickly seen as a milky cloudiness in the water column where the dispersant has been applied. The cloudiness varies with conditions and is generally yellow. The color can vary from whitish to brownish. A brownish color generally indicates a more effective dispersion. If this cloudiness does not appear, effectiveness was low. In clear water, a whitish cloud could indicate just a mixture of dispersant and water.

The slick itself may change colors from black to brown within minutes of dispersant application, indicating partial effectiveness (McAuliffe, 1980; McAuliffe, 1981). In addition, a slick may break into smaller patches within 30 minutes to an hour after dispersant application. The observer should also keep in mind that dispersion is not instantaneous. In the absence of wind or current changes, such patches are indicative of a dispersant that is moving oil droplets into the water column. Electronic sensing can be used to support visual observations. The SLAR unit can indicate qualitatively whether the slick has disappeared appreciably, but it cannot yield any quantitative information on the thickness of the remaining slick. Microwave sensing under specific conditions can determine both the disappearance of floating oil and a relative reduction in thickness.

A spill should be continually observed because even areas that initially show no apparent effect from treatment may soon show dramatic changes in only a few hours in comparison with untreated oil areas. Thus, decision making on the efficacy of a dispersant response should not be made immediately, but rather after a period of hours.

SECTION 8

PRACTICAL CONSIDERATIONS FOR DISPERSANT USE

During an oil spill, a confluence of competing interests must be balanced. The news media likely will be on the scene requesting statements on any action that is being taken to respond to a spill event. Various interested parties such as representatives of the vessel owner, the cargo owner, local fishing interests, businesses dependent on tourism, local/state/federal government agencies, environmental organizations, equipment vendors, and cleanup companies will appear on the scene and advocate their position to both the OSC and the press. Often the various groups approach spill response from a different base with different objectives. Decision making, management, and organization of a spill response are made more difficult by maintaining open communication with the various interest groups; but eventually the effort to maintain the interaction and develop it organizationally can result in a much more effective response. Management and organization of oil spill responses have been studied (Cohn et al., 1991; Noble, 1991), but there are no tested paradigms that account for the rapid action and public input required in a crisis situation.

Under the Federal government's spill response policy and regulatory environment, the OSC has limited authority to take action. Although the OSC has authority to act unilaterally in cases directly involving human health and safety issues, the various federal agencies and the affected states must reach agreement (or at least lack of opposition) for a response involving oil spill dispersants. The burden of achieving the consensus has not been found to be unduly cumbersome or time consuming in two of the cases reported in the literature (Cunningham et al., 1991); this is a small sample, however, and the actual ability to obtain a consensus in a short period of time remains uncertain. Thus, it is important that the ground work be done prior to the need to use dispersants. This can be achieved either through a preapproval process or through a more informal means during a spill (Walker and Henne, 1991).

Misconceptions concerning the use of dispersants must be addressed. These range from the idea that all dispersants are effective in any spill situation if used soon enough, to the concern that the ecologic adverse impact of dispersant use is far worse than the adverse impact caused by the spilled oil.

Unless the decision process is communicated and explained to the news media and the various interest groups, significant pressure can arise to change the decision. For example, the press and the public may consider dispersion of a spill by wind and waves as acceptable or even desirable. In the event the decision is made to use dispersants, the similarity of dispersant action to natural action should be emphasized.

Another misconception that may be faced during a spill response is the concept that all dispersants included on the NCP Product Schedule are equally effective. Data on the relative effectiveness of dispersants are available, but these are based on laboratory analyses with a single crude oil and the results are not directly transferable to the field. Further, many dispersants show an extremely low effectiveness (less than 10 percent), even under ideal laboratory conditions. Dispersant performance is summarized in Table B-9 of Appendix B. Based on information from the RCP, the OSC must evaluate the dispersant(s) available and determine whether the dispersant is likely to produce the desired results with the equipment available and the type of oil on the water.

Potential liability questions should be given consideration in addition to the questions related to dispersant effectiveness, environmental trade-offs, and the logistics of responding to an oil spill. In the aftermath of an oil spill, there are generally a number of legal actions. There may be civil penalties for adverse impacts, fines for regulatory infractions, and civil suits between affected parties and the responsible party. The use or nonuse of dispersants can complicate the picture, with the responsible party claiming that a nonuse decision by the OSC greatly contributed to the resulting adverse impacts caused by the spilled oil. Similarly, persons dependent on fisheries may claim harm as a result of the effects of the dispersed oil on the breeding of fish stocks. Either situation is difficult to prove or disprove but can result in a more burdensome legal aftermath. The spill response will be questioned no matter what actions are implemented; therefore, it is prudent to ensure that as much agreement as practical is reached prior to implementation of a response. Unanimity among the potentially affected parties is ideal, but is unlikely to be achieved. A balance between agreement and an effectual response is usually the best that can be achieved in dispersant use decisions.

With the multitude of problems that can arise in the U.S. legal environment and the strong antipathy toward the use of dispersants that has developed among some interested parties, the OSC should reflect carefully on dispersant use and be ready for criticism. Two considerations guide the decision-making process affecting an actual dispersant use situation:

- There is a reasonable probability of measurable success (e.g., preventing oil from reaching a beach or breeding area).

- Consensus agreement has been reached between potentially affected parties that dispersant application is worthy of being evaluated as a response.

Measurable success, even if it is not complete, will vindicate the decision to use a dispersant. Although it may not be required, a consensus agreement will help to defuse critics who challenge a response that does not achieve success. Numerous other considerations will come into play in a response involving the prospect or the actual use of dispersants. It is beyond the scope of this document to attempt to identify all of the possibilities. The final decision will be based on the experience, understanding, and knowledge of the decision makers and their risk tolerance.

APPENDIX A

DESCRIPTION OF VESSEL AND AIRCRAFT APPLICATION EQUIPMENT

Vessel Application Equipment

Marine vessel application equipment is described on Pages A-2 through A-4. Table A-1 presents spraying capabilities of marine vessels ranging in size from small fishing boats to much larger offshore supply vessels. Figure A-1 illustrates spraying equipment. Manufacturer specifications are included in Table A-2.

Aircraft Application Equipment

Aircraft spraying capability is presented in Table A-3. Figure A-2 illustrates an airborne dispersant delivery system. Manufacturer specifications for a dispersant delivery system for aircraft are included on pages A-7 through A-9.

TABLE A-1
MARINE VESSEL SPRAYING CAPABILITY
(ADAPTED FROM CONCAWE, 1988)

Vessel Type	Load		Swath, m (ft)	Range, km (mi)	Speed (knots)		Transit + Spraying Time, hours[a]	Trips in 10-h Work Day	Area Covered,[b] km^2/10 h (mi^2/10 h)
	Liters	Gallons			Transit	Spray			
Runabout[c]	1,100	290	7 (23)	20 (12)	12	7	6+4	3	0.36 (0.14)
Small (coastal fishing)[d]	5,000	1,320	12 (39)	50 (31)	7	7	8 + 3.5	1	0.5 (0.2)
Medium (fishing or work boat)[e]	20,000	5,280	21 (69)	50 (31)	10	8	8 + 6.5 4 + 10	1 a	2.0 (0.77) 3.1 (1.2)
Offshore work boat	50,000	13,200	28 (92)	75 (47)	12	10	8 + 10	a	5.0 (1.9)

a Transit time includes the time to supply vessel and to arrive at the spill site. Larger vessels work a 14- to 16-hour day and can transit at night. Offshore vessels are assumed to need only one transit, then be resupplied while on station. Spray time is assumed to be limited by 10 hours of daylight.

b Application rate of 100 liters per hectare (10.7 gal/acre) used for calculation.

c Harbor type craft that can carry a few drums on deck and no sleeping accommodations.

d Vessel can handle up to 24 drums or small portable tanks on deck and no sleeping accommodations.

e Work boat either fitted with permanent tanks or capable of plumbing skid-mounted tanks into dispersant delivery system and sleeping accommodations.

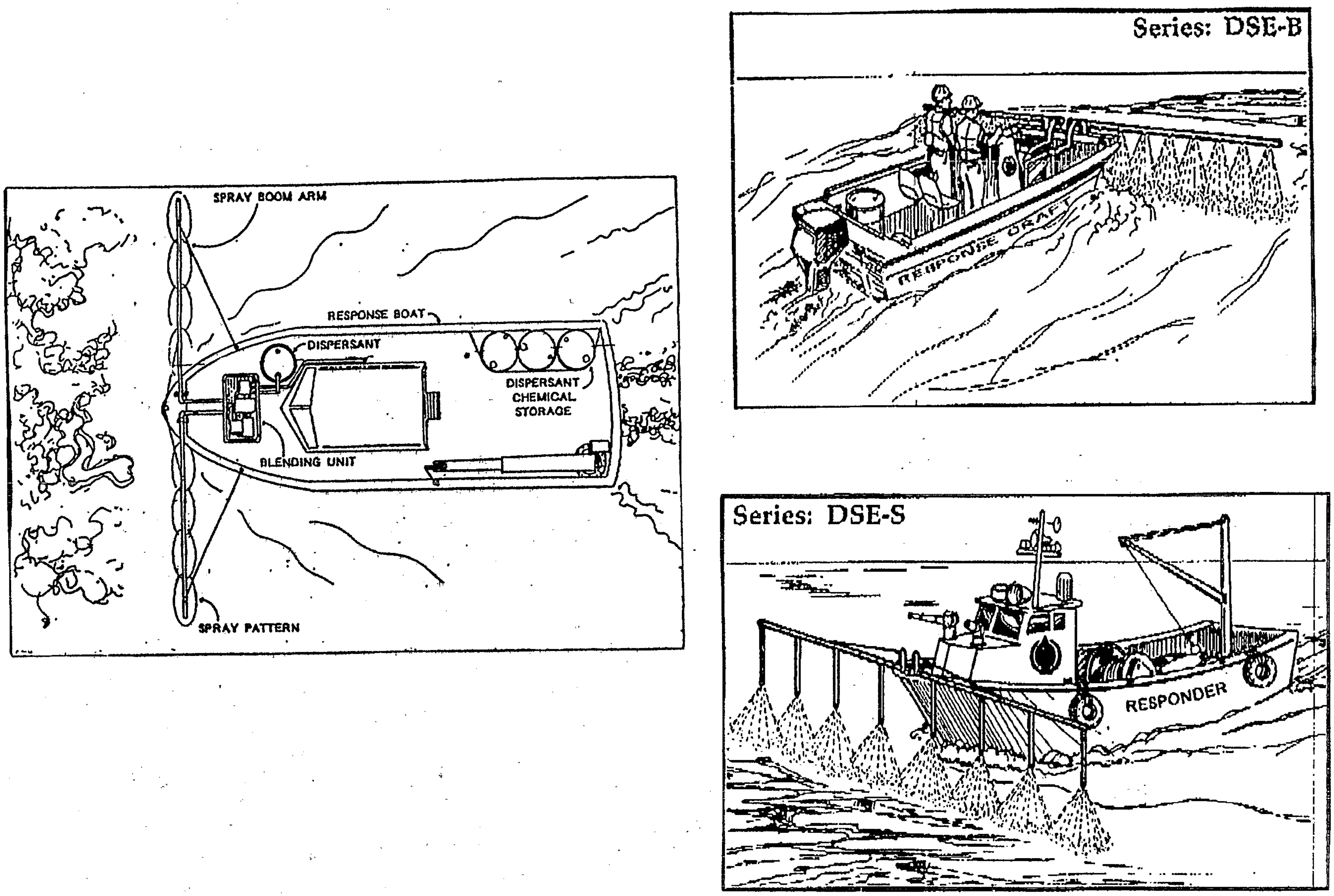

Figure A-1. Marine dispersant spraying equipment
(PETRO Boom, 1993)

TABLE A-2. DISPERSANT SPRAYING EQUIPMENT

Spray Equipment	Type	Swath, ft	Weight, lb
DSE-B	Bay	30	1100
DSE-M	Manual	10	30
DSE-S	Seagoing	80	2000

Source: PETRO Boom, 1993.

Spray equipment packages include blending skid, spraying arms, suction and discharge hoses with quick-connect fittings, support columns, and other related components necessary to operate the spraying unit.

TABLE A-3
AIRCRAFT SPRAYING CAPABILITY
(ADAPTED FROM CONCAWE, 1988)

Aircraft Type	Load		Swath, m (ft)	Range, km (mi)	Speed (knots)		Trips in 10-h Work Day	Area Covered,[a] km^2/10 h (mi^2/10 h)
	Liters	Gallons			Transit	Spray		
Bell 212[b]	680	180	13 (43)	50 (31)	90	70	9	0.6 (0.2)
Piper Pawnee[c]	570	150	15 (49)	100 (62)	90	90	7	0.4 (0.15)
Islander	1,000	264	15 (49)	200 (87)	140	110	6	0.5 (0.19)
DC3[d]	3,500	925	20 (60)	200 (122)	150	150	5	1.7 (0.6)
DC4[d]	11,000	2,900	25 (82)	300 (186)	190	150	5	5.5 (2.1)
DC6[d]	11,000	2,900	25 (82)	300 (186)	210	150	5	5.5 (2.1)
C130 (ADDS pack)	20,800	5,500	25 (82)	400 (250)	295	160	5	10.5 (4.5)

[a] Application rate of 100 liters per hectare (10.7 gal/acre) used for calculation. Area covered per 10-h period is based on different travel distances between base and spill location; thus, the aerial coverage in this column is not directly comparable between aircraft.

[b] Helicopter with a slung bucket; other helicopter units may have more capacity and higher transit speed.

[c] Crop duster type of an aircraft.

[d] Aircraft commonly maintained for use by spill cooperatives.

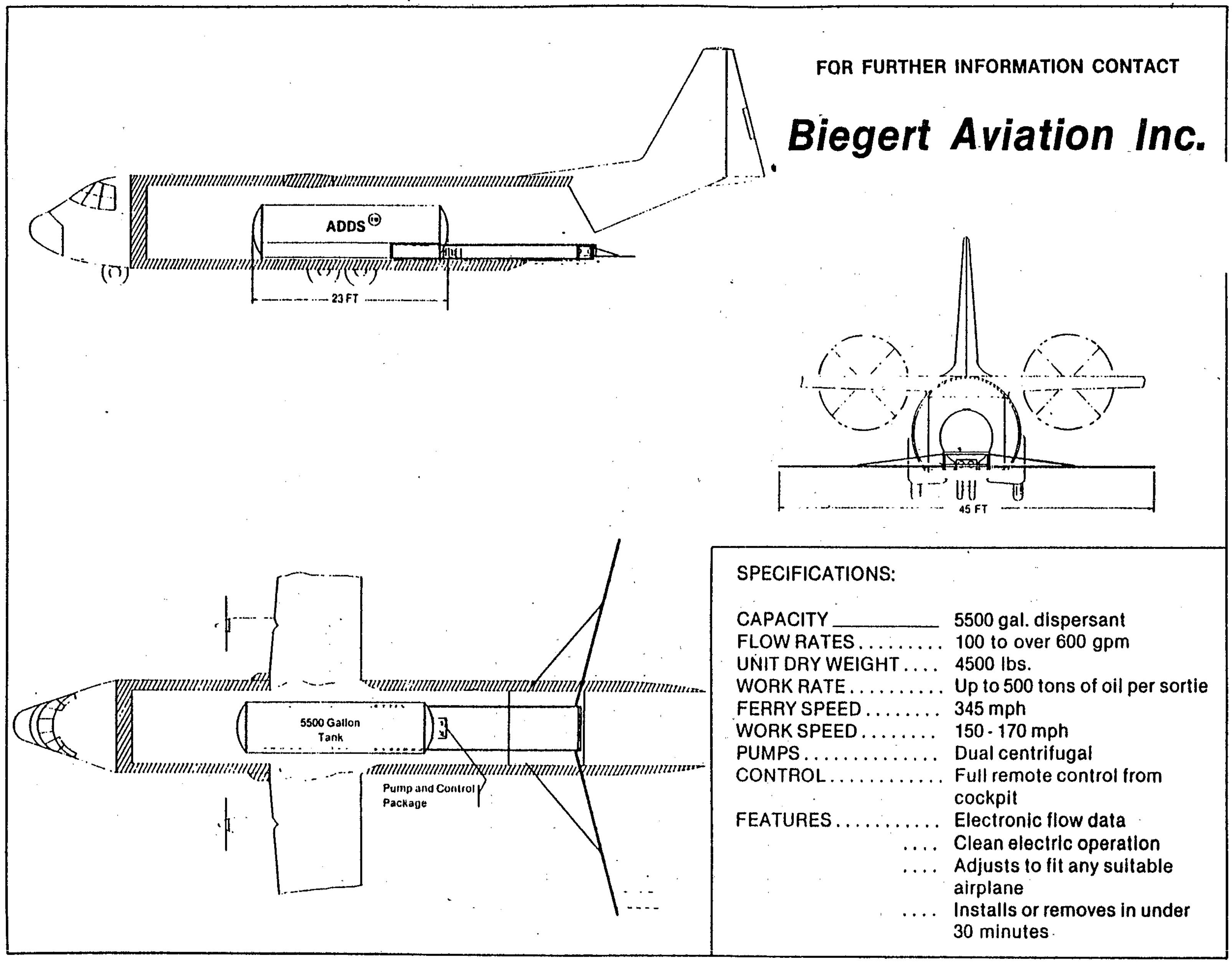

Figure A-2. Aircraft dispersant spray system

Source: Biegert Aviation, 1993

SPECIFICATIONS OF USAF MODULAR AERIAL SPRAY SYSTEM (MASS)

Aircraft Compatibility: C-130 E/H modified by T.O. 1C-130-123

Configuration: Three modules - four 500-gal tanks, one 250-gal flush tank
(Two tanks are stainless steel, and two are aluminum).
Two Modules - Two 500-gal tanks, one 250-gal flush tank.

Power Source: Electric, 28-Volt d.c. from aircraft

Dry Weight: Three modules - 8981 lb; Two modules - 6412 lb

Applications: High volume (HV) - 100 to 1600 gallons per minute
Low volume (LV) - 60 to 600 gallons per minute
Ultra low volume (ULV) - 0 to 60 gallons per minute

Liquid Payload: 2200 gallons

Nozzle Sites: ULV - 50 sites
LV - 42 sites
HV - 92 sites on two fuselage booms

Aircraft Attachment: Floor of aircraft with dual rail system

Attachment Time: 30 minutes

The MASS was developed as a roll-on roll-off spray *system for the* C-130. The spray system consists of four 500-gallon tanks for chemical applications at varying rates of 0 to 1600 gallons per minute. The MASS consists of three modular platforms with interconnecting plumbing and electric circuits.

The MASS may be arranged in two or three module configurations depending on the type of mission requirements (ULV, LV, and HV). In a three-module configuration, the MASS consists of four 500-gallon chemical tanks, one 220-gallon flushing tank, and the operator's console. This is the primary configuration for LV/HV missions.

In a two-module configuration, the MASS consists of two 500-gallon stainless steel tanks, one 220-gallon flushing tank, and the operator's console. This configuration is used primarily for ULV missions.

The MASS venting system is totally enclosed and connected to the aircraft venting system in order to vent all fumes outside the aircraft.

The operator's console is located on Module 1. All loading, mixing, spray control, tank-flushing, and boom purging procedures are accomplished from this control panel. Fluid is transferred between tanks for mixing, recirculation, and spray operations by use of electropneumatic actuators that control the opening and closing of butterfly valves; diverter valves are controlled by the operator at the panel. Three centrifugal pumps provide output pressure for mixing, transferring, recirculation, and spraying for LV/HV missions. Each of the pumps can be controlled individually by the operator, depending upon the flow rate desired. Two gear-driven pumps are used to provide pressure for flushing and the ULV systems. A 220-gallon aluminum tank is also located on Module 1. This tank stores the flushing agent used to clean the chemical tanks and associated systems (main sump, ULV sump, wing and fuselage filtering systems, and their respective wing lines and booms). All systems used with chemicals are flushed upon completion of each sortie. The flushing system has its own pump and filtering system, and all controls are operated from the console. After the flushing is completed, this material is sprayed over the target area. Then the booms are purged by the wing and fuselage air purge systems.

Each MASS platform is built from modified cargo pallets to enhance the loading and off-loading of the spray system. These pallets lock into the C-130's dual rail system to secure the system after loading. The operator's console, pumps, cradles for flushing, and chemical tanks are all secured to these modified pallets. The pallets are modified further to incorporate a 1-½-in. lip around the entire pallet in order to catch any spillage of chemical or flushing

APPENDIX B

CONVERSION FACTORS AND CALCULATION TABLES

The following tables and figures present useful conversions and equivalents, oil slick thickness and slick volume relationships, dispersant doses per volume of oil, marine vessel dispersant spray data, area coverage by marine vessels at various speeds, aerial dispersant spray data, the Beaufort wind scale, the NCP Product Schedule effectiveness ranking, and API-recommended cleanup methods. Most of these tables were obtained from the Oil Spill Chemicals Applications Guide (Exxon Chemicals, 1985).

TABLE B-1. CONVERSIONS AND EQUIVALENTS

Gallons (U.S.) x 0.8327	= Gallons (imperial)
Gallons (imperial) x 1.20	= Gallons (U.S.)
Gallons (U.S.) x 3.785	= Liters
1 Barrel of petroleum	= 42 Gallons (U.S.)
Liters x 0.264	= Gallons (U.S.)
Cubic Meters x 264.2	= Gallons (U.S.)
Feet x 0.3048	= Meters
1 mile (statute)	= 5,280 feet (1,609.3 meters)
1 nautical mile	= 6,076 feet (1,852 meters)
Feet/minute x 0.0183	= Kilometers/hour
Feet/minute x 0.0114	= Miles/hour
Feet/second x 0.682	= Miles/hour
Kilometers/hour x 0.5396	= Knots
Kilometers/hour x 0.6214	= Miles/hour
Knots x 1.852	= Kilometers/hour
Knots x 1.150	= Miles/hour
Knots x 0.5144	= Meters/second
Miles/hour x 1.609	= Kilometers/hour
Miles/hour x 0.8690	= Knots
Gallons (U.S.)/acre x 9.353	= Liters/hectare
Bbl/acre x 39.27	= Cubic meters/square kilometer
Cubic meters/square kilometer x 16.29	= Bbl/square mile
Liters/hectare x 0.1	= Cubic meters/square kilometer
1 acre	= 43,560 square feet
1 square mile (640 acres)	= 2.59 square kilometers
1 hectare	= 10,000 square meters (0.01 km^2)
Hectares x 2.471	= Acres
Metric ton crude	= 7.3 barrels (approximately)
Square Kilometers x 247.1	= Acres

Source: Exxon Chemicals, 1985 and CRC, 1988.

TABLE B-2. CORRELATION OF OIL VOLUME PER UNIT AREA WITH SLICK THICKNESS

gal (U.S.)/ acre	gal (U.S.)/ hectare	bbl/mi^2	m^3/km^2	bbl/acre	mL/ft^2	mL/m^2	$ft^3/acre$	Liter/ hectare	Thickness stabilized film (mm)
1	2.471	15	0.9	0.02	0.09	0.94	0.13	9.4	9.35×10^{-4}
4.2	10.37	64	4	0.10	0.36	3.87	0.56	38.7	3.94×10^{-3}
5	12.35	76	5	0.12	0.43	4.63	0.67	46.3	4.69×10^{-3}
8.4	20.76	128	8	0.20	0.73	7.85	1.12	78.5	7.88×10^{-3}
10	24.71	152	9	0.24	0.87	9.36	1.33	93.6	9.30×10^{-3}
12.6	31.13	192	12	0.30	1.09	11.73	1.68	117.3	1.18×10^{-2}
21	51.89	320	19	0.50	1.82	19.58	2.80	195.8	1.97×10^{-2}
42	103.78	640	39	1.00	3.65	39.27	5.60	392.7	3.94×10^{-2}
50	123.55	762	47	1.19	4.33	46.58	6.67	465.8	4.66×10^{-2}
53.6	132.44	817	50	1.28	4.65	50.03	7.16	500.3	5×10^{-2}
84	207.56	1280	78	2.00	7.30	78.54	11.20	785.4	7.88×10^{-2}
100	247.10	1524	93	2.38	8.67	93.27	13.33	932.7	9.33×10^{-2}
150	370.65	2286	140	3.57	13.01	139.97	20.00	1399.7	0.14
168	415.13	2560	157	4.00	14.60	157.07	22.40	1570.7	0.16
214.6	530.28	3270	201	5.11	18.58	199.89	28.61	1998.9	0.20
250	617.75	3810	234	5.95	21.65	232.92	33.33	2329.2	0.23
268	662.23	4088	251	6.38	23.23	249.92	35.76	2499.2	0.25
420	1037.82	6400	393	10.00	36.50	392.68	56.00	3926.8	0.39
525	1297.27	8000	491	12.50	45.62	490.80	70.00	4908.0	0.49
535.8	1323.96	8165	501	12.76	46.45	499.73	71.44	4997.3	0.50
839	2073.17	12800	785	20.00	72.91	784.39	111.87	7843.9	0.79
1071.6	2647.92	16329	1002	25.51	93.12	1001.82	142.88	10018.2	1.00
1607	3971.88	24484	1503	38.26	139.68	1502.73	214.32	15027.3	1.50

Source: Courtesy of Exxon Chemical Company (Exxon Chemicals, 1985)

TABLE B-3. VOLUME OF OIL IN BARRELS PER ACRE THAT CAN BE TREATED AT VARIOUS DOSES OF DISPERSANT

Dispersant-to-oil ratio	Dispersant (gal (U.S.)/acre)				
	5	7	10	20	50
1:1	0.12	0.17	0.24	0.48	1.20
1:2	0.24	0.33	0.47	0.94	2.35
1:4	0.47	0.65	0.94	1.80	4.70
1:10	1.20	1.70	2.40	4.70	12.00
1:20	2.40	3.30	4.70	9.40	23.50
1:30	3.50	5.00	7.20	14.30	36.00
1:50	5.90	8.40	11.90	23.80	59.50
1:100	11.90	16.60	23.80	47.70	119.00

Source: Courtesy of Exxon Chemical Company (Exxon Chemicals, 1985)

TABLE B-4. WORKBOAT SPRAY DATA[a]

Knots	mph	km/h	Time (min) to cover one acre for various swath widths (ft)[b]			Acres/hour for various swath widths (ft)		
			20	30	40	20	30	40
1	1.15	1.85	21.48	14.32	10.74	2.79	4.19	5.59
2	2.30	3.71	10.77	7.18	5.39	5.57	8.36	11.13
3	3.45	5.56	7.17	4.78	3.59	8.37	12.55	16.71
4	4.60	8.52	5.38	3.59	2.69	11.15	16.71	22.30
5	5.75	9.26	4.31	2.87	2.16	13.92	20.90	27.78
6	6.90	11.12	3.59	2.39	1.80	16.71	25.10	33.33
7	8.05	12.97	3.07	2.05	1.54	19.54	29.27	38.96
8	9.20	14.82	2.69	1.79	1.35	22.30	33.52	44.44
9	10.35	16.68	2.39	1.59	1.20	25.10	37.74	50.00
10	11.50	18.53	2.15	1.43	1.08	17.91	41.96	55.55

[a] Basis: 6076 feet per nautical mile.

[b] Minutes to cover one acre = travel distance per acre in feet ÷ speed in feet per second x 60 (see Table B-6 for travel distance time per acre for various swath widths).

Source: Courtesy of Exxon Chemical Company (Exxon Chemicals, 1985)

TABLE B-5. MAXIMUM AREA COVERED IN 16 HOURS AT VARIOUS BOAT SPEEDS FOR SWATH WIDTHS OF 30 AND 50 FEET[a]

	30-ft Swath width			50-ft Swath width		
Knots	Acres	mi^2	km^2	Acres	mi^2	km^2
1	67	0.10	0.27	112	0.17	0.45
2	134	0.21	0.54	223	0.35	0.90
3	201	0.31	0.81	335	0.52	1.35
4	267	0.42	1.08	445	0.69	1.80
5	334	0.52	1.35	557	0.87	2.25
6	402	0.63	1.63	670	1.05	2.71
7	468	0.73	1.89	780	1.22	3.16
8	536	0.84	2.17	893	1.39	3.61
9	604	0.94	2.44	1007	1.57	4.07
10	671	1.05	2.71	1118	1.75	4.52

[a] Gallons per acre x acres = gallons per 16 hours (Boat size may restrict load, thereby requiring reloading at chemical stock point with attendant loss of transit time).

Source: Courtesy of Exxon Chemical Company (Exxon Chemicals, 1985)

TABLE B-6. TRAVEL DISTANCE REQUIRED FOR SPRAY BOAT OR AIRCRAFT TO APPLY DISPERSANT TO ONE ACRE OR ONE HECTARE

Total swath width		Travel distance	
feet	meters	ft/acre[a]	m/hectare[b]
20	6.10	2178	1639
25	7.62	1742	1312
30	9.14	1452	1094
40	12.19	1089	820
50	15.24	871	656
60	18.29	726	547
70	21.34	622	469
80	24.38	545	410
100	30.48	436	328
120	36.58	363	273
150	45.72	290	219
200	60.96	218	164
225	68.58	194	146
250	76.20	174	131
300	91.44	145	109

[a] Distance in ft/acre = 43,560 ÷ swath width in feet.

[b] Distance m/hectare = 10,000 ÷ swath width in meters.

Source: Courtesy of Exxon Chemical Company (Exxon Chemicals, 1985)

TABLE B-7. AERIAL SPRAY DATA

Speed				Time (sec) to cover one acre for various swath widths (ft)				Acres per minute of spraying time for various swath widths (ft)[a]			
knots	mph	ft/sec	km/h	100	120	150	200	100	120	150	200
50	57	84	93	5.17	4.30	3.44	2.58	11.6	13.9	17.4	23.3
60	69	101	111	4.31	3.59	2.86	2.15	13.9	16.7	20.9	27.9
75	86	126	139	3.45	2.87	2.29	1.72	17.4	20.9	26.2	34.9
100	115	169	185	2.58	2.15	1.72	1.29	23.2	27.9	34.9	46.5
150	172	253	278	1.72	1.43	1.15	0.86	34.9	41.9	52.2	69.8
200	230	337	370	1.29	1.08	0.86	0.65	46.5	55.5	69.8	92.3

[a] Acres ÷ 640 = square mile.

Source: Courtesy of Exxon Chemical Company (Exxon Chemicals, 1985)

TABLE B-8. BEAUFORT WIND SCALE

Beaufort No.	Description	Specifications L: on land S: at sea far from land	Speed equivalent at height of 10 m m s^{-1}	Knots
0	Calm	L: Calm; smoke rises vertically. S: Sea like a mirror.	0-0.2	1
1	Light air	L: Wind direction shown by smoke-drift but not by wind vanes. S: Ripples resembling scales are formed, but without foam crests.	0.3-1.5	1-3
2	Light breeze	L: Wind felt on face; leaves rustle; ordinary vanes moved by wind. S: Small wavelets, still short but more pronounced; crests have glassy appearance.	1.6-3.3	4-6
3	Gentle breeze	L: Leaves and small twigs in constant motion; wind extends small flag. S: Large wavelets; crests begin to break; foam of glass appearance; scattered whitecaps.	3.4-5.4	7-10
4	Moderate breeze	L: Raises dust and loose paper; small branches are moved. S: Small waves, becoming longer; fairly frequent whitecaps.	5.5-7.9	11-16
5	Fresh breeze	L: Small trees in leaf begin to sway; crested wavelets form on inland waters. S: Moderate waves, taking a more pronounced long form; many whitecaps.	8-10.7	17-21
6	Strong breeze	L: Large branches in motion; whistling heard in utility wires; umbrellas used with difficulty. S: Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray).	10.8-13.8	22-27
7	Near gale	L: Whole trees in motion; inconvenience felt when walking against the wind. S: Sea heaps up and white foam from breaking waves begins to be blown in streaks along direction of the wind.	13.9-17.1	28-33
8	Gale	L: Breaks twigs off trees; generally impedes progress. S: Moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in well-marked streaks along wind.	17.2-20.7	34-40

(continued)

TABLE B-8 (continued)

Beaufort No.	Description	Specifications L: on land S: at sea far from land	Speed equivalent at height of 10 m m s⁻¹	Knots
9	Strong gale	L: Slight structural damage occurs. S: High waves; dense streaks of foam along wind; crests of waves begin to roll over; spray may affect visibility.	20.8-24.4	41-47
10	Storm	L: Seldom experienced inland; trees uprooted; considerable structural damage. S: Very high waves with long overhanging crests; foam, in great patches, is blown in dense white streaks along wind; sea takes on a white appearance; tumbling of sea becomes heavy and shocklike; visibility affected.	24.5-28.4	48-55
11	Violent strom	L: Very rarely experienced; accompanied by widespread damage. S: Exceptionally high waves (small- and medium-sized ships may sometimes be lost to view behind waves); sea is completely covered with long white patches of foam lying along the direction of the wind; all edges of wave crests are blown into froth; visibility affected.	28.5-32.6	56-63
12	Hurricane	L: Very rarely experienced; accompanied by widespread damage. S: The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected.	≥32.7	≥64

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TABLE B-9. NCP PRODUCT SCHEDULE RANKING OF DISPERSANT EFFECTIVENESS (APRIL 1993)

	Product name	Effectiveness, % (25 mL, 2 h)
1	Corexit 9550	109.00
2	Slickgone NS	75.00
3	SX-100	74.60
4	Corexit 9527	60.00
5	Anteco Oil Spill Dispersant	59.00
6	Inipol IP 90	53.00
7	Corexit 9554	42.70
8	Mare Clean 505	41.60
9	Gold Crew Dispersant	39.00
10	Witco EXP 5250-109	37.70
11	Stik-A-Way	32.00
12	Witcomul 4016	23.30
13	Neos AB3000	18.60
14	NK-3	18.00
15	M.C. #1 Dispersant	18.00
16	Witcomul 4078	17.90
17	OSD/LT	16.90
18	Toxigon-2000	16.00
19	Energy III	16.00
20	BioSolve	14.70
21	Wellaid 3316	11.70
22	Ec.o Atlan'tol AT-7	11.00
23	Ecology Plus	8.70
24	YCC BlueClean	7.90
25	Micro-Blaze Out	6.70
26	Cold Clean 500	5.00
27	Finasol OSR-7	3.90
28	Petro Tite M.M.E.	3.50
29	Improve Colloidal	3.10
30	Enersperse 1100	3.00
31	Naxchem Dispersant K	1.70
32	Grancontrol-O	1.00
33	Simple Green	0.70
34	Nurture Oil Dispersant	0.65
35	Witco EXP 5150-97	0.30
36	Jansolv-60	0.26
37	Petrotech FEII	0.23

The effectiveness data given above is that reported to EPA by the product manufacturers. The percent effectiveness is determined using the Revised Standard Dispersant Effectiveness Test, as required by Subpart J of the NCP regulations. The data reported in the product schedule is strictly that reported to EPA by the manufacturer; EPA does not change the reported value in any way.

TABLE B-10. CLEANUP METHODS RECOMMENDED BY THE AMERICAN PETROLEUM INSTITUTE FOR VARIOUS HABITATS (DUNFORD, 1991; API, 1985)

Methods	Open Waters - Offshore/Nearshore	Open Waters - Enclosed Bays & Harbors	Soil Bottom Subtidal	Seagrass Beds (Intertidal)	Seagrass Beds (Wade Zone Subtidal)	Rocky Subtidal - Open Hard Bottom & Rocky Reefs	Kelp Beds	Exposed Rocky Intertidal	Sheltered Rocky Intertidal	Sandy Beaches (Exposed)	Sandy Beaches (Sheltered)	Sheltered Tidal Flats	Gravel/Cobble Beach (Exposed)	Sheltered Gravel Beaches	Sheltered Cobble Beaches	Coral Reefs (Lagoons)	Coral Reefs (Deep Fore, Flats, Crests)	Mangrove Forests	Salt Marshes
Beach Cleaning Machines										P	P								
Booms/Skimmers	P	P					V	V	P			P				P		P	P
Burial				A						A	A	A	A	A					
Burning	NA	NA					A	NA	NA	A	A			A		A	A	A	A
Dispersants	P	V		NA	NA		NA	V	NA	V	A	NA	P	A	V	NA	V	P	V
Earth Barriers																			
Herding	V	V																V	V
High Pressure Flushing				A		NA	NA	NA	NA	A	A	A	NA	A	NA			NA	A
Low Pressure Flushing				V	V		V	V	V		V	P	P	V	P		V	P	P
Management (Drainage)																		P	P
Manual Removal			V	NA	NA	NA		V	V	P	P	V	NA	P	NA	V		V	A
Natural Cleansing	P	P	P	P	P	PV	P	P	NA	P	V	P	P	NA	P	P	P	V	P
Sand Blasting								A					NA		A				
Sinking Agents	A	A					A												
Sorbent	V	V		NA	V	V	V	V	V	V	V	P	NA	V	V	V	NA	V	V
Steam Cleaning								A	A				A		A				A
Substrate Displacement				A						P	A	A	A		A				
Substrate Removal			NA	A				A	A	P	NA	A	A	NA	A			A	A
Vacuum Pumping	V	V	NA	A	A	V	NA	V	V	P	P	V		P		P	V	V	V
Vegetation Cropping				A	NA		V	NA	NA										NA

P = Preferred V = Viable NA = Not advisable A = Avoid

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APPENDIX C

EXAMPLE DECISION TREES

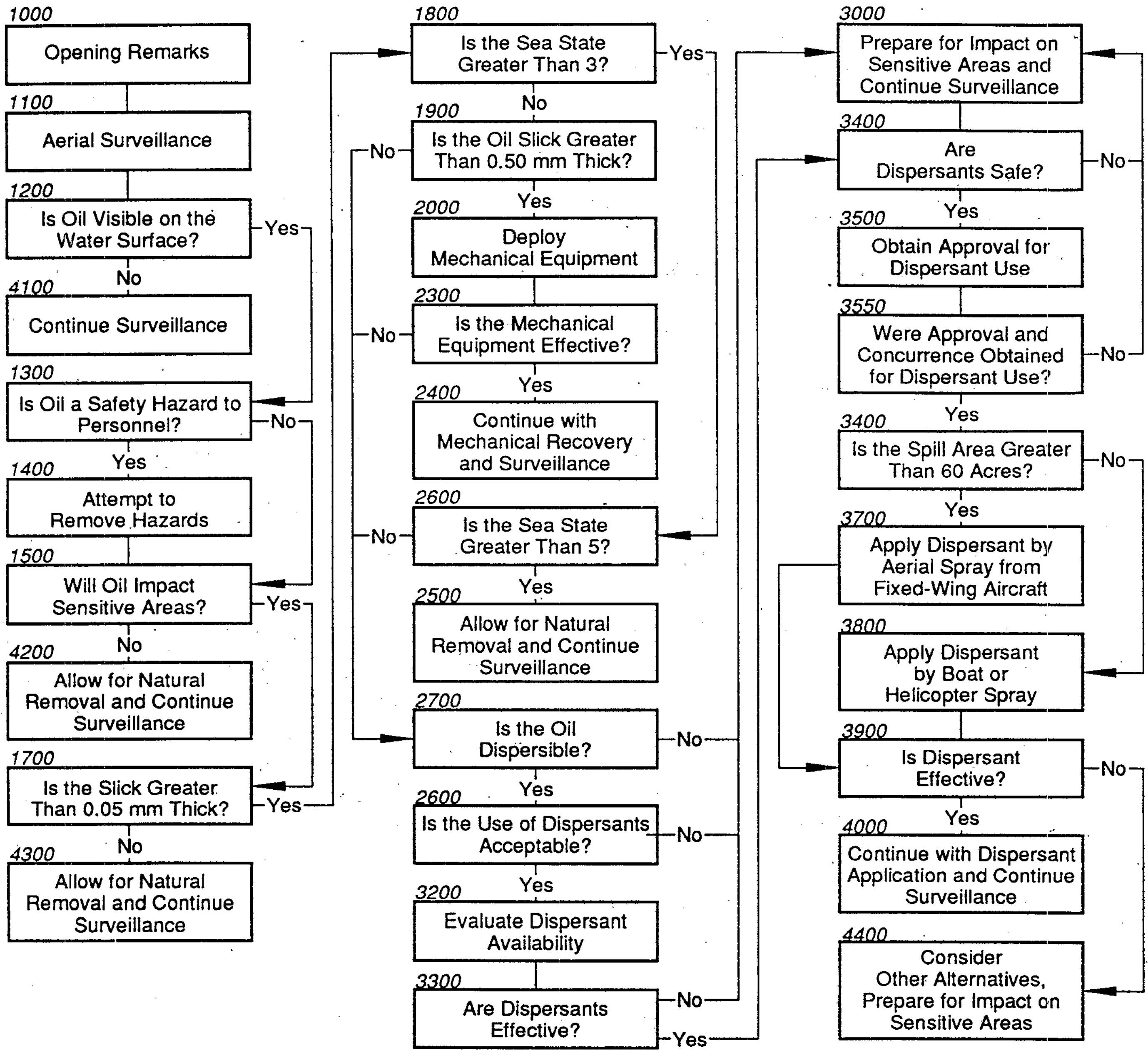
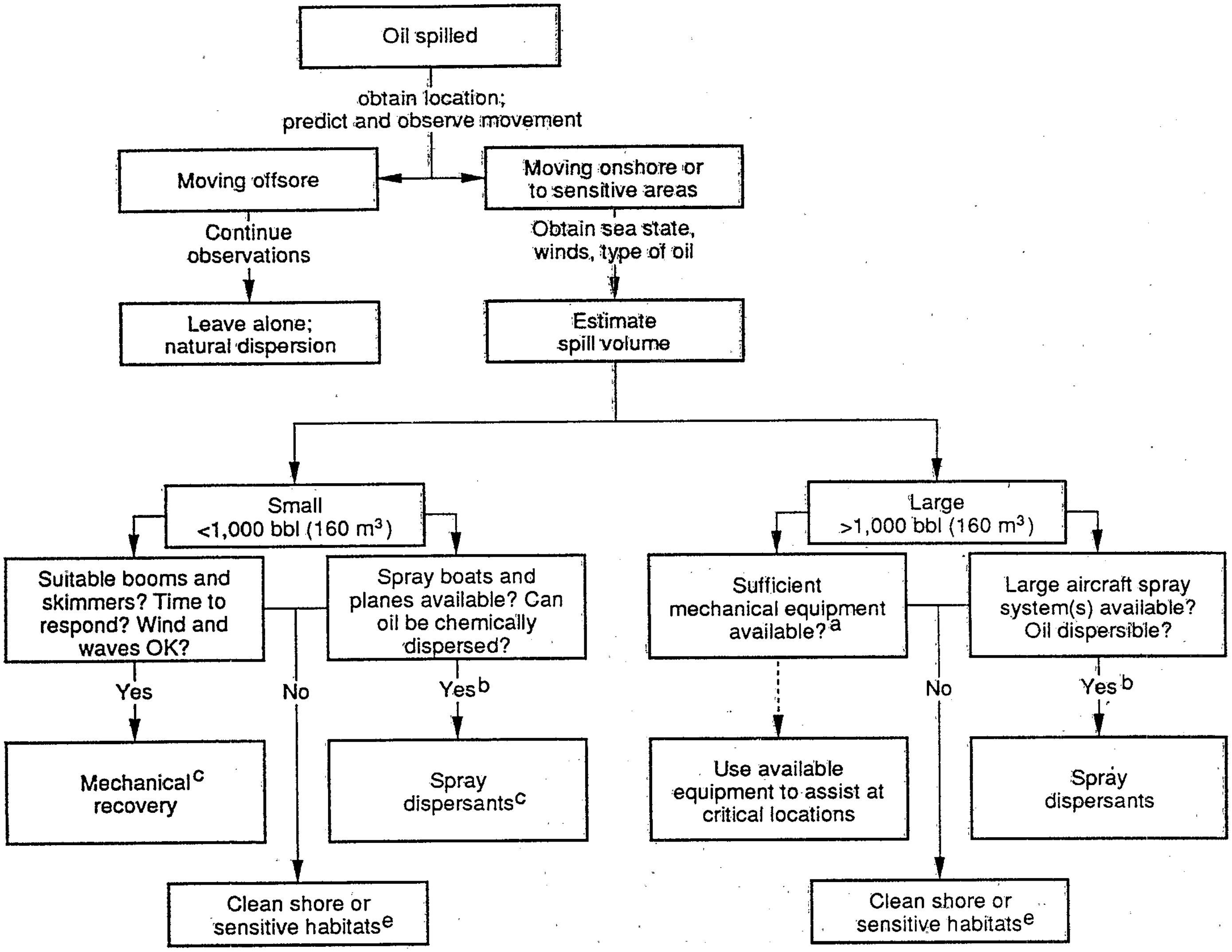


Figure C-1. U.S. Environmental Protection Agency oil spill response decision tree. (Flaherty and Riley, 1987; NRC, 1989)



[a] It is unlikely that sufficient mechanical equipment will be available to clean up a large spill.

[b] With the approval of the federal on-scene coordinator and the concurrence of the EPA and the state(s).

[c] Small spills normally should be completely controlled, particularly if both mechanical and chemical methods are used. Under some conditions, however, some oil may need to be removed from the shore.

[d] Large spills, particularly 10,000 to 30,000 bbl per day, will be difficult to control. Only large aircraft spray systems are suitable and some oil may still strand. however, oil that is kept off the shore will lessen the adverse effects.

[e] Appropriate methods should be used to clean shorelines and sensitive habitat. See, for example, API (1985).

Figure C-2. API dispersant use decision diagram.
(API, 1986; NRC, 1989)

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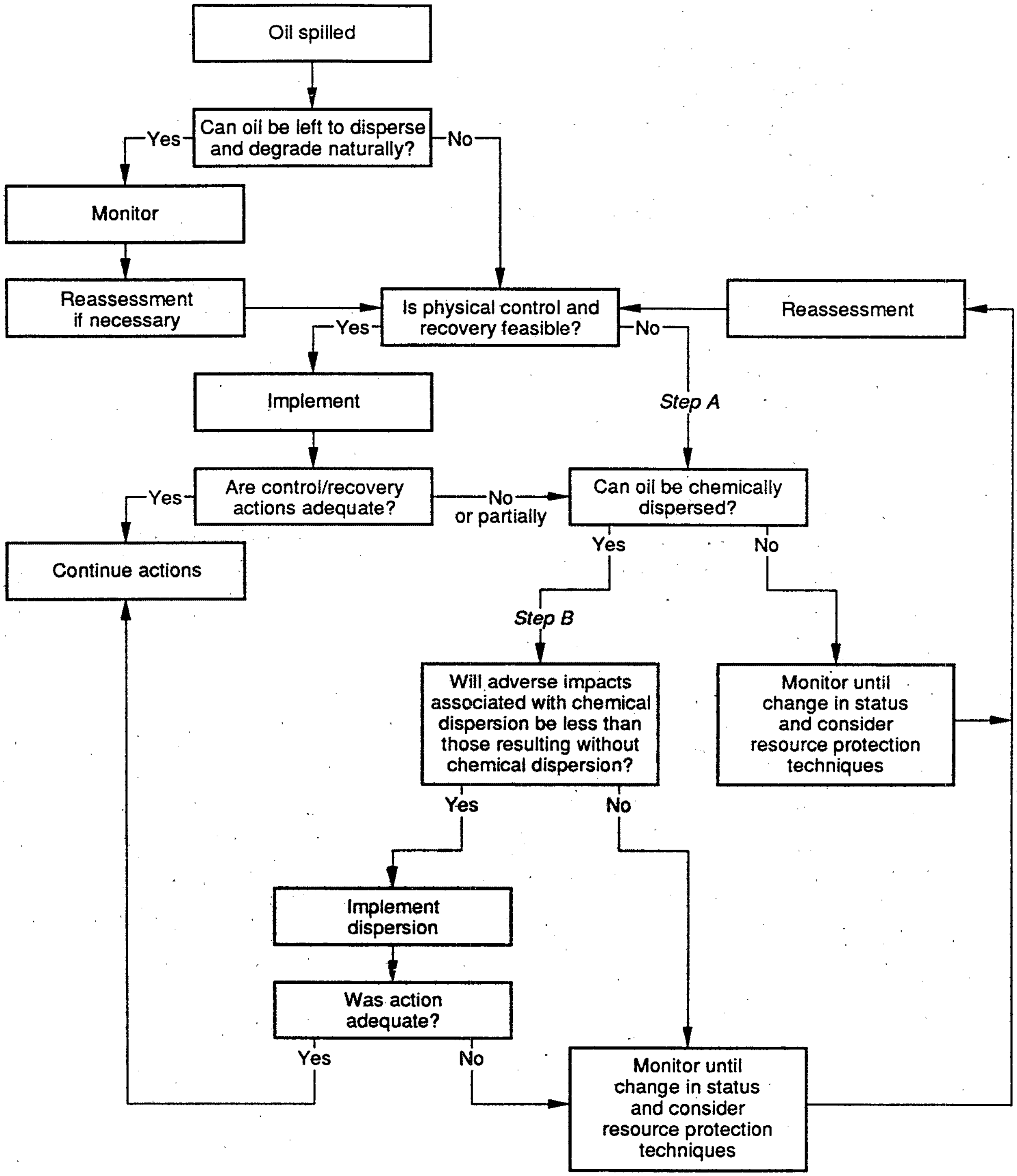

Figure C-3. Environment Canada dispersant use decision tree. (Environmental Protection Service, 1984; Fraser, 1989)

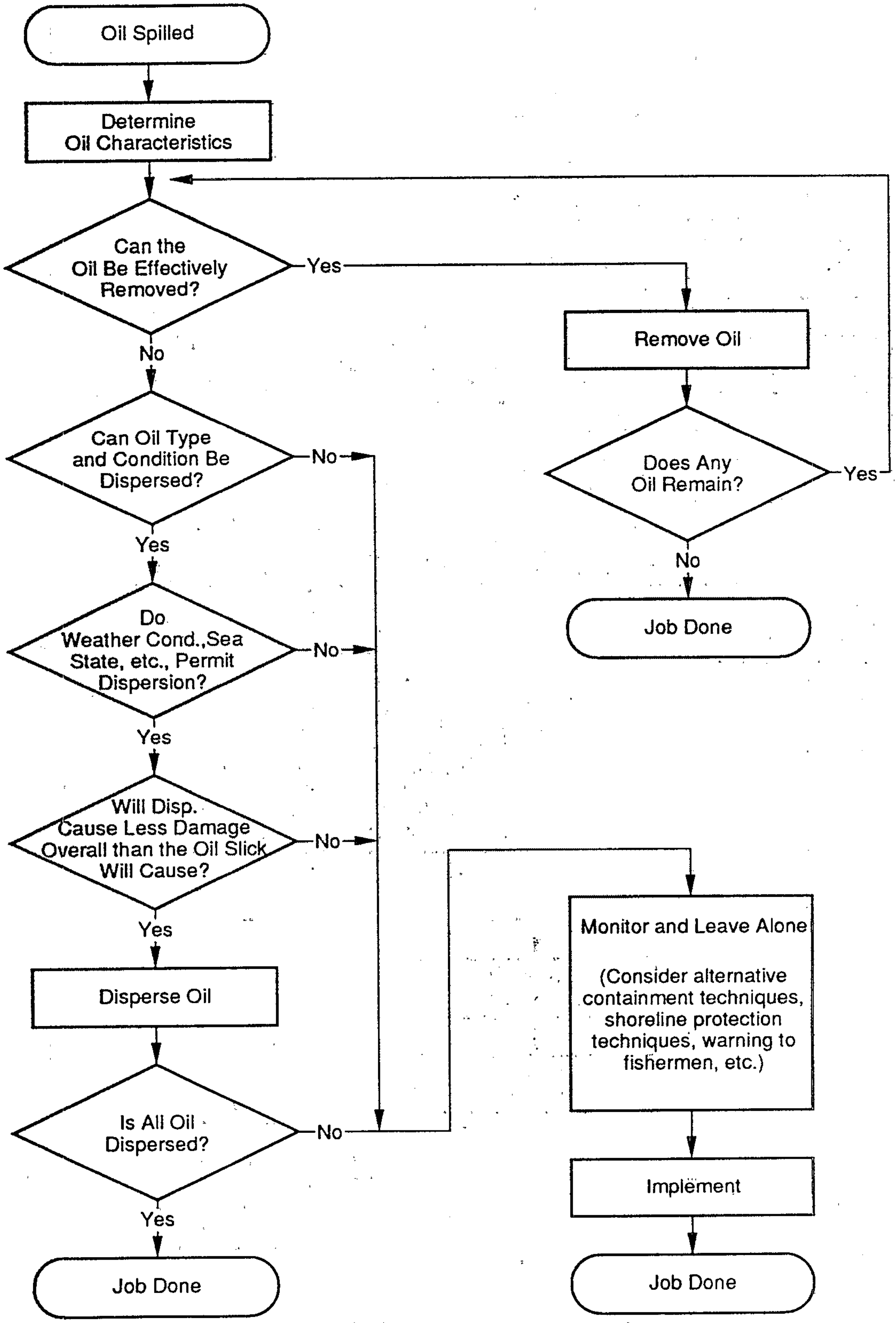

Figure C-4. IMO/UNEP – Example of a typical oil spill response decision procedure. (IMO, 1982; Fraser, 1989)

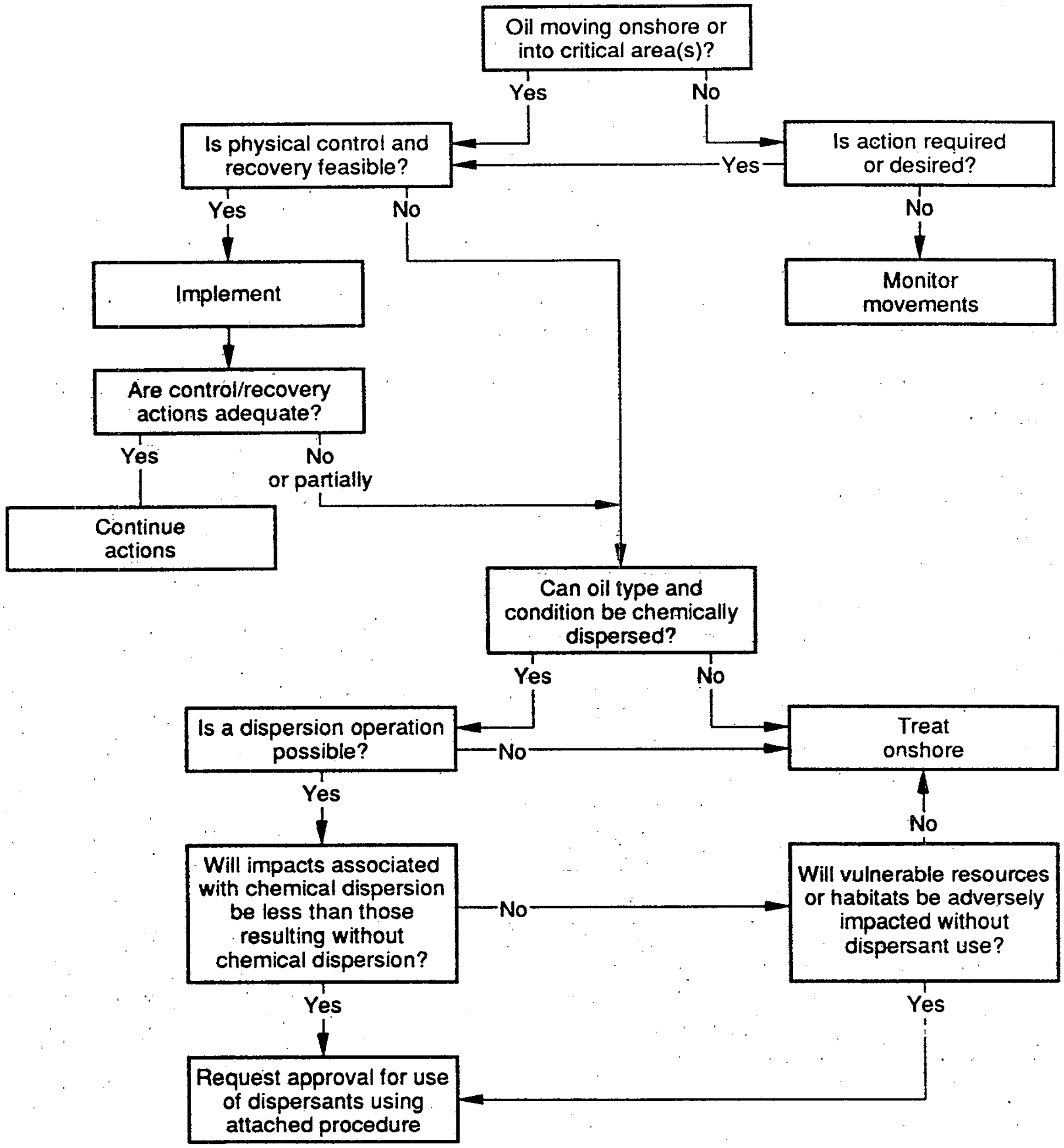

Figure C-5. State of Alaska dispersant use decision matrix. (RRT Working Group, 1986; Fraser, 1989)

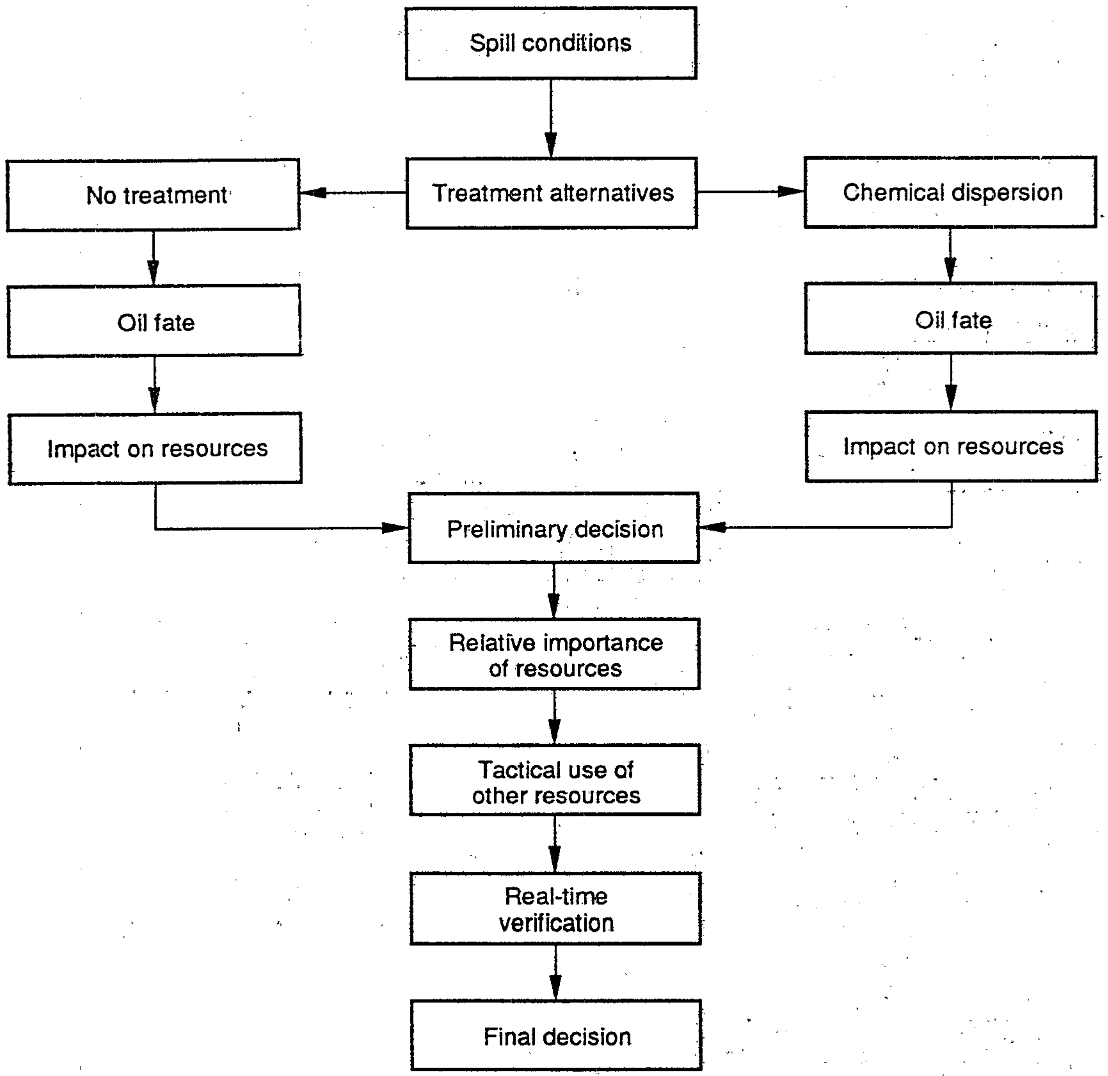

Figure C-6. SLR dispersant use decision-making method. (Trudel and Ross, 1987; Fraser, 1989)

APPENDIX D

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