Summary

The end objective of dispersant research has been and should be that of answering the following questions:

1. When should a dispersant be used?—The section of this volume titled **Contingency Planning and Guidelines** does not give definitive answers, but does provide some information on the current methods used and insight into the thinking of the experts. The answer to the question will always be subjective because it will always involve trade-offs. However, further refinement and development of such guidelines as those now being developed by ASTM Subcommittee F20.13 on Chemical Treatment of Oil Spills, a subcommittee of ASTM Committee F-20 on Hazardous Substances and Oil Spill Response, will provide the decision-maker with a more informed basis on which to make his decision.
2. What will be the results of the dispersant application?—The answer to this question is partially addressed in the sections on **Laboratory Toxicity and Effectiveness Testing** and **Field Effectiveness.** The age-old problem, that of correlating laboratory test work with field results, is still present. Meaningful laboratory tests should provide some predictive data on the potential success of field usage. However, accurate scaling or simulation of the field in the laboratory is obviously not possible. Some individual investigators have selected methods that strive to simulate field conditions and others have selected methods for researching individual phenomena associated with dispersants. Both approaches have yielded results that have contributed to technology.
3. What will be the short-term and long-term costs to the environment?—Oftentimes decisions related to dispersant usage must weigh short-term costs against long-term costs. The section on **Fate and Effects** discusses costs to the environment and should help the decision-maker with the short-term and long-term trade-offs.

The sections and papers are presented in the following order:

Laboratory Toxicity and Effectiveness Testing

The first paper, by *Getter and Baca,* describes the effects of oil and dispersants on mangroves. These authors found that the source of the stock, whether the oil was dispersed or not dispersed, and the part of the plant that received the toxicant each had a significant effect on the results. The leaves of the red mangrove were the most sensitive part of the plant tested, but root dosing with dispersed light Arabian crude had the greatest effect.

Anderson et al discuss testing with fixed and diminishing concentrations of dispersed oils. They have developed a toxicity index which takes into account the concentration of the exposure and the duration of exposure. This test method also allows observation of the different effects from the same toxicant during varying environmental conditions. The cold months can produce toxicity indexes that are approximately three times higher than the summer and spring values when testing with shrimp (*Pandalus danae*). The toxicity index values in ppm·days typically varied from 2.3 to 12.

The paper by *Wells et al* discusses the adoption of uniform methods of preparing test solutions and chemical analysis procedures for toxicity experiments with chemically dispersed oils.

Mackay et al discuss three items: (1) recent developments in effectiveness testing, particularly with the Mackay-Nadeau-Steelman laboratory test, (2) a newly developed flume test which simulates boat application at sea, and (3) a mathematical model for correlating effectiveness and linking laboratory tests to application conditions at sea. These authors present some interesting thoughts related to the problems associated with effectiveness testing, which may not be supported by test data but are of value to those considering test work in this area.

Martinelli presents some valuable information on the revolving flask test developed by Petrofina Ltd. Initial tests of the device showed that the results were dependent on laboratory technique and equipment. A later program to improve the testing technique was successful. The revolving flask test does represent one of the simplest methods of testing the effectiveness of a dispersant. A comparison of revolving flask test results and spraying at sea was conducted with positive results.

Byford and Green compare the Mackay and Labofina tests. This study shows that, when the Mackay test indicated wave dampening characteristics with some dispersants, no sensitivity was observed in the Labofina test. Other than this anomaly with the Mackay test, both methods seemed to produce fairly good results, which correlated. These authors suggest that the Labofina test will probably be utilized principally in Europe, and the Mackay test will evolve as the standard in North America. They further discuss the possible synergism of various surfactant combinations for possible enhancement of dispersant efficiency.

Canevari reviews the relationship between the characteristics of the spilled oil and the dispersant's effectiveness. His paper warns that laboratory effectiveness tests cannot always be replicated in the field. He describes and documents the finding that the slick thickness can have a significant effect on the overall mechanism and effectiveness of the dispersant. In addition, viscous oils can cause such problems as dispersant roll-off and water-in-oil emulsions. Also, the individual chemistry of crude oils varies considerably, so that naturally occurring surfactant barriers can be present to prevent effectiveness of the applied dispersant.

Rewick et al describe an improved interfacial tension method of measuring dispersant effectiveness. This method is the drop weight test. It is different from other effectiveness tests in that it measures individual properties of the dispersant rather than trying to simulate overall field conditions, as is done in the Mackay tests. It allows investigation of some of the interfacial properties that make a dispersant work, such as the critical micelle concentration, the packing efficiency of surfactant molecules at the oil/water interface, and the reduction of interfacial tension. Effects of temperature and salinity on dispersant performance can also be studied. Seventeen different water-based dispersants were evaluated with this method and the results were compared with those from the standard EPA effectiveness test.

Lehtinen and Vesala have been concerned about the effectiveness of dispersants in the Baltic Sea, which has low salinity and low temperature. They found that the effectiveness of all dispersants tested showed a strong dependency on temperature, and significant differences were observed with variations in salinity. Their conclusion was that the "choice of the right dispersant under such circumstances is extremely important and should be made with the utmost care."

Field Effectiveness

The second section contains four papers. The first, by *Bocard et al,* actually reports on several different subjects:

1. The results of dispersant tests at sea when the dispersant was applied by aircraft are reported. In the sea test it was found that, with low-energy surface turbulence, the complete emulsification of a moderately thick slick is a slow process and may take several hours.
2. A second part of this paper relates to flow-through bioassay tests in the laboratory. The procedure was able to distinguish between good and bad dispersants, as well as to determine the difference between the lethal effects of two relatively good dispersants.
3. Finally, these authors conclude that any single "laboratory test" will be unlikely to give a decisive indication of product performance and will have to be reconfirmed in practice by a field trial.

Goodman and MacNeill present test work on the use of aircraft in remote sensing to determine a dispersant's effectiveness. Infrared scanning, ultraviolet scanning sensors, and visual sensors were used to compare the difference in dynamics between the surface and subsurface movements of the slick, which is, therefore, an indication of the nature of the dispersant process.

Failure of water column sampling equipment prevented obtaining a water chemistry analysis to provide a definitive correlation between what was happening in the water and what the remote sensors were indicating. Remote sensing still has the potential to provide quantitative data on the characteristics of a dispersed oil slick and, therefore, on the effectiveness of a dispersant.

Gill reports on efforts to achieve optimum control over the spray flume from aerial application of dispersants. It had been thought that an aircraft flying closer to the ground, at a slower speed, and with a delivery system that produces a higher exit velocity out of its nozzles would generate a narrower swath width and have larger mean droplet sizes. Previous test work done in 1979 involved applying Corexit® 9527 with a DC-6B aircraft. Results showed that only 65% of the dispersant released from the aircraft could be accounted for over a 61-m (200-ft) flight path. In 1980, the theory was tested, and it was found that uniform dispersant application centered about the flight line could be achieved, provided the aircraft flew directly into the wind. Under these conditions more than 80% of the released dispersant could be accounted for in the 61-m (200-ft) swath width. Low-viscosity dispersants produced a smaller mean droplet size and were more susceptible to blowing. The best results were achieved with a system of 70 Delevan raindrop nozzles. The extent of solvent evaporation during the descent of the dispersant toward the target was found to be insignificant for Corexit® 9527.

Kaufmann reports on the successful use of dispersants on land to minimize the fire hazard of a gasoline spill near Boston. The 1978 spill contained 7 750 000 L (2 000 000 gal) of gasoline leaked from a tank. The leakage presented a significant fire hazard for both tenement houses and a racetrack stable. The regional response team made a decision to authorize the use of dispersants to neutralize the fire hazard caused by the gasoline. The spill was safely controlled, and no fire resulted.

Fate and Effects

Wells, in the first of nine papers in this section, presents a detailed review of past toxicity testing. He summarizes the known lethal and sublethal thresholds for various available dispersants, particularly Corexit® 9527, BP1100X, and Corexit® 7664. The specific physiological toxic effects that predominate are respiratory and nervous system reactions. Wells found that it was not appropriate to generalize about the toxicological effects of dispersants on organisms. The effect of a particular dispersant on various organisms is different, and obviously, the use of different dispersants on individual organisms will produce varied results. He suggests that, when the toxicological effects of a dispersant are studied, the components within the dispersant should be studied individually rather than the entire compound.

McDonald et al investigated the incorporation of volatile liquid hydrocarbons (VLH) into the water column as a function of the type of dispersant, original oil composition, time of dispersant application, wind speed, and temperature. The first three factors seem to be the most significant. Temperature and wind speed exert only minor influences on VLH incorporation. The conclusion of these authors is that, to minimize VLH incorporation, it may be desirable to allow a surface slick to weather 12 to 24 h before using the dispersant.

Anderson et al investigated the incorporation of oil and dispersed oil into sediments. They found that 83% of the oil remained in the top 3 cm of the sediment. Dispersed oil was shown to penetrate more deeply than oil alone and, therefore, persists at higher concentrations. Field samples taken six months after exposure show that only small amounts of hydrocarbons were still associated with the sediment, and these would probably not be sufficient to affect organisms. Harmful effects on organisms in the sediments are most likely to occur within the first two months, when high levels of hydrocarbons are present. The recovery rate of live animals after six months in the field was high for both dispersed oils and oil alone. However, high concentrations of dispersed oil in the sediment did produce higher mortality and significantly reduced growth in organisms.

Baker et al discuss the effects of dispersed oil and dispersant alone on field plots of rocky shores, salt marshes, intertidal sea-grass beds, and sand and mud flats. In the rocky shore and salt marsh habitats, oil followed by dispersant had a greater effect than dispersant alone. All the treatments reduced the sea-grass bed covers. Both treated and untreated sand and mud flats showed little long-term oil retention. However, freely draining intertidal flats may retain greater concentrations of dispersed oil than of untreated oil.

Page et al report on two nearshore test spills near Searsport, Maine. The effects of hydrocarbons on benthos were determined by chemically and biologically analyzing sediments and tissues of clams and mussels from the test plots. The test plots were exposed to crude oil alone and also to crude oil mixed with dispersant. This represented the worst-case scenario for oil exposure to benthos from a nearshore spill. Results showed that oil reaching the bottom had lost most of its volatile hydrocarbons. Sediments and bivalves, one week after the spill, contained less hydrocarbon from the dispersed oil than they did from the undispersed.

Baca and Getter investigated the toxicity of chemically dispersed oil to sea grass, *Thalassia testudinum.* It is known that chemically dispersed oil can increase the concentration of hydrocarbons in the water over 50 times. The toxicity of dispersed oil to sea grass was evaluated in both static and flow-through test systems. It was concluded that both test methods provide information that would be useful for real-world applications. Prudhoe Bay crude water-soluble fractions were more toxic than dispersed oil or dispersant alone. For a single dose, the flow-through test lethal concentrations were sublethal when the plants were flushed with a fresh medium within 12 h of exposure. The studies also showed that the percentage of green (chlorophyllous) leaves was useful in visualizing toxicity effects.

The objective of *Owens et al* was to determine the practicality and effectiveness of dispersant usage in the arctic beach environment. In a control plot where oil alone was applied, natural cleaning was relatively effective during the sample period. Where the Exxon dispersant was used, surface contamination was reduced by 90% and subsurface contamination by 50%, in comparison with the control plot. With the BP dispersant, the surface measurements were very low 8 days after the dispersant application, and subsurface measurements remained relatively constant. After 40 days, only traces remained. These authors state:

> Dispersants can and do remove oil from the shore zone. On most arctic beaches where natural cleaning is effective within a single open water, it is unlikely that cleanup measures would be required or implemented.

Boehm reports on the analytical methods used in another Baffin Island experiment in the arctic nearshore. Untreated oil was discharged on the surface and chemically dispersed oil was discharged below the surface. Transfer of the surface-discharged oil into the sediments took days to weeks. However, after two weeks, the sediment concentrations were low (approximately 10 ppm). Direct penetration of chemically dispersed oil into the top 3 cm of sediment was observed to be 5 to 10 ppm in concentration. Analyses of filter feeders and deposit feeders show that these are good sentinel organisms for water column contamination and for longer term sediment contamination.

Contingency Planning and Guidelines

Lindstedt-Siva et al, in this final section of the book, discuss the work of an ASTM-sponsored task force developing ecologically based guidelines for dispersant use in marine and estuarine environments. The guidelines, organized by habitat type, deal with dispersant use to protect the habitats from impact, to mitigate impacts, and to clean habitats after a spill impact. Each guideline contains a habitat description, a background section on relevant literature, and a recommendation section. With the goal of minimizing the ecological impact of oil spills, the use of dispersants is considered a primary response tool, along with other methods, and not a last resort. The "no cleanup" alternative is also considered.

Pavia and Smith discuss regional response team (RRT) guidelines for dispersant usage. The guidelines are used to speed up the RRT's decisions regarding approval of dispersant use during a spill. These guidelines balance the economic, social, and natural resource damage costs associated with oil spills. They have also set up criteria for documentation of dispersant application. These criteria are (1) the dispersant type and application rates, (2) visual observation of its effectiveness, (3) restrictions imposed on the quantity used, and (4) the application methods.

Trudel reports on a mathematical model for predicting the ecological impact of treated and untreated oil spills. In this study the model was specific to the Grand Bank cod population and the Funk Island common murre. Impact was defined in terms of the projected proportion of the population killed and the length of time required for the population to recover after the spill. The model predicts the movement of the spill, looks at the sensitivity of the organism, and ultimately projects the oil exposure conditions that would be lethal. The model showed that the size of the surface slick decreased dramatically with increasing wind speeds. The effect of chemically treated oil on fish would be strongly determined by the distribution of the target population. The author indicates that "further study of the interaction of sea birds and oil slicks . . . is clearly required."

Chapman discusses the possibility of South Africa having an alternative to the use of dispersants. In the majority of cases, he suggests that doing nothing would be appropriate since natural dispersion occurs readily, although it takes somewhat longer. Sensitive areas, such as tourist beaches, may require the use of dispersants. However, he still feels that there are many cases in which dispersants are now used unnecessarily.

Crain describes Aramco's diversified dispersant application capabilities. This company has an array of vessels from 7 m (23 ft) up to 74 m (243 ft) with a dispersant capability built in. In addition, the company has helicopters and fixed-wing aircraft which are not dedicated but which can be quickly diverted and adapted for dispersant spraying. Some of these aircraft have been modified with mounting brackets so that their conversion to dispersant spraying can be expedited. The large fleet of nondedicated vessels and aircraft allows effective response times at an affordable price.

Although we have read about the developments of many researchers addressing specific problems, we must remember that all of the subjects discussed in this volume are interrelated, and one should not be considered or researched without contemplating the consequences or its relationships with the others. ASTM Committee F-20 and Subcommittee F20.13 have played a significant role in addressing questions on dispersants in the past, and we hope that these committees will continue to contribute in a useful way.

Tom E. Allen
Group leader, MRD, Halliburton Services, Duncan, OK; chairman, ASTM Subcommittee F20.13; editor.