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International Council for the Exploration of the Sea

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Marine Environmental Quality Committee

OVERALL REPORT OF THE AD HOC GROUP ON OIL POLLUTION INCIDENTS

Brest, France, 2-9 June 1978
Charlottenlund, 13-15 March 1979

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R E C O M M E N D A T I O N S

ESTABLISHMENT OF PLANS:

Those nations which have not already done so are encouraged to:

a. Establish scientific contingency plans dealing with oil spills;

b. This plan should be closely integrated with the technical contingency plan dealing with the contaminant clean-up and should have at least one scientist, preferably an ecologist, on the contingency team;

c. Nations should consider the usefulness of separate scientific response for inshore and offshore zones, although if such arrangements are made, the principal coordinator and his alternate should be common to both plans;

d. National lists of experts and proposed projects should be developed and made available.

FUNDING:

It is proposed that the Council take up for discussion the fact that appropriate funding cannot wait for an emergency to happen. Much scientific research should take place in anticipation of oil spill events, and scientific response must be available immediately when an event occurs. Certain scientific studies stimulated by the event may continue long after the "emergency" is over, therefore, some form of secure, long-term funding is essential, in addition to guaranteed funding/or specific response during emergencies. Individual nations may chose to finance such scientific work from different sources. There is no single, recommended source, but the need for adequate funding must be stressed.

INTERNATIONAL COOPERATION:

a. It is recognized that individual nations have differing levels of expertise and interest in scientific studies of oil spills. Individual nations should be able to request scientific assistance in responding to spills and, where appropriate, should be encouraged to permit interested scientific groups from other nations to conduct scientific research. Development and maintenance of national lists of experts should assist this exchange.

b. When scientific assistance is requested or offered, contact should be made between national scientific coordinators or their alternates. When appropriate, joint national response programs should be harmonized in advance. Outside territorial waters, it is essential that an agreed international plan exists.

I N T R O D U C T I O N

In the past several years, marine scientists have aided their nations in responding to large oil spill incidents such as the Argo Merchant, Ekofisk-Bravo and the Amoco Cadiz. The marine scientific community has been asked to give suggestions on the development of oil spill clean-up strategies, assess biologic damage and to predict the recovery of damaged biotic resources. Because scientific reaction to these incidents was often the result of ad hoc reactions rather than a previously thought out programme, ICES formed an ad hoc Group on Oil Spill Incidents whose goal was to stimulate planning of meaningful programmes of scientific studies to investigate the effects of a significant oil spill or blow out, including identification of important observations, resources and expertise needed. The following report is the result of the proceedings of this ad hoc Group. The findings presented herein are the result of consulting experts from various ICES member countries, synthesis of national and regional oil spill response plans and information gleaned from the growing literature on oil spill incidents.

The basic framework of this report is contained in our lengthy table (1) which outlines tasks and research items that were deemed important in the scientific investigation of spilled oil in the marine environment. The authors recognize that all oil spills are not the same and many of the tasks outlined in this table may be unnecessary or unwarranted because of prevailing conditions at the spill. However, we felt compelled to provide the reader with a complete outline of the optimal tasks and research items that may be needed under various circumstances. Our table or matrix is vertically segmented into three sections:

1. pre-event tasks and research
2. operational tasks and research
3. basic or applied research items available to the research during or following a spill.

Analysis of scientific involvement in previous oil spill incidents has shown that the scientific input into the clean-up strategy and their analysis of impact on biologic resources would be greatly aided by some "pre-event" preparations and analysis. One of the most valuable sets of information the scientist would like to have at the time of a spill is maps that provide information on the temporal and spatial variations of biotic resources at the spill site. Maps that show distribution of larvae and eggs, distribution of fisheries and effort, and benthic communities, allow the scientist to give better advice on protection of sensitive areas during clean up. Such information is also invaluable in providing baseline information which allows more precise assessment of change or damage. Maps of prevailing currents, tides and winds will also aid the scientist in predictions of oil movement with time. Other "pre-event" tasks such as pre-arranged analytical methods, intercalibration protocols, and sampling methods will aid in the scientific validity of the information obtained during a spill study. We urge governments to provide contingency funds in advance of incidents, so that required research during a spill proceed, rather than "wait" until funds are allocated for the incident at hand. Much needed information might be lost and valuable advice not given, while scientists wait for funding authorization.

During an oil spill incident, the marine science community has an important role to play in the operation aspects of the spill response. Aerial photography, analysis of wind and current patterns and computer modelling can aid in the predictions of oil movement in the sea. Knowledge of local biotic resources and their sensitivity to oil can aid in decisions to usage of detergents and booming of specific sensitive coastal areas. Scientific information is required to determine damage to biologic communities and potential closure or impact on commercial fisheries. The general public and government officials will ask and expect answers as to questions involving biologic damage and rates of recovery of damaged resources.

An oil spill itself offers many opportunities to study and learn how to handle the next incident better. Information can be gleaned on recovery rates of biologic communities, impact of oil on specific species and the residual times of oil in various environments. The scientific community must be urged to learn as much as possible from the experience at hand as to react better in the future if such events should occur.

The following report briefly discusses the various research disciplines appropriate in the scientific investigations of an oil spill in the sea. It is <u>not</u>

intended as a manual on how to carry out the tasks suggested, but it should provide the reader with the rationale for the suggestions made. References are given to provide the reader with methodologies, techniques and results of previous oil spill investigations.

SEABED AND RESOURCES CHARTING

Pre-Event Tasks: Several recent papers have been concerned with the protocols to be followed in responding to spills of oil and other hazardous substances. Hershner *et al* (1978) have outlined the procedures for study of accidental discharges of petroleum in estuarine, coastal and oceanic ecosystems. Their general approach to biological damage assessment entails analyzing the distribution and abundance of organisms in an area affected by oil. The authors note that "one of the major difficulties with most post-spill studies is a lack of any data documenting pre-spill conditions in impacted areas" (Hershner *et al*, 1978).

Other Working Groups and authors concerned with responding to spills of petroleum have emphasized the frequent lack of baseline data against which to compare the effects of sudden releases of oil (Sherman and Pearce, 1979; Pearce, 1978). Investigators (Lewis, 1978) have also suggested that there is a need for widespread baseline/surveillance schemes, particularly in regard to establishing benthic baselines.

Recently, the International Council for the Exploration of the Seas (ICES) passed a resolution (C.Res. 1977/4:12) that charts should be prepared which indicate the distribution and abundance of living resources in relation to areas likely to be the sites for extraction (mining) of marine aggregates (sands and gravels). The General Secretary of ICES (1978) provided the formats and guidelines for the preparation of such charts. The ICES Working Group on Oil Pollution Incidents (WGOPI) at its first meeting in Brest, France (June 1978) recommended that similar charts should be prepared for coastal areas of each nation indicating the local resources which could be seriously damaged by oil spills.

The proposed charts would show the distribution and abundance of principal commercially important finfish and shellfish. Also, charts would be prepared which indicate these variables for certain important planktonic (phyto- and zooplankton) and benthic species which are parts of foodchains or recognized indicator organisms of pollution effects.

Other charts should illustrate the temporal abundance and distribution of fish eggs and larvae and the boundaries of principal nursery grounds. Charts for benthic organisms should indicate diversity of benthic communities and information such as biomass, community structure and distribution. The distribution and temporal variation in fishing effort, where well documented, could also be shown.

Levels of productivity, including primary production, have already been mapped for limited areas in Europe and North America. Seasonal distribution of nutrients, which might be affected by petroleum and other pollutants, should also be shown on charts.

Physical data, including information on major and local current systems, are available as charts for much of the east coast of North America and some European waters. Data on the distribution of sediment types and the association of petroleum-derived hydrocarbons with sediments, are available for limited areas and have been mapped in a few instances. The same is true for hydrocarbons in the water column but since there is considerable variability in these, little effort has been made to chart such data. Programs such as MUSSEL WATCH and Ocean Pulse offer the possibility of mapping the distributions of petroleum hydrocarbons in tissues of selected indicator species. Since it is known that certain organisms, including the filter feeding bivalve molluscs, are capable of rapid uptake of hydrocarbons (Lee, et al, 1978), such maps will provide substantial baselines in the event of oil spill incidents.

All charts must be periodically reviewed and updated. In many instances, ongoing fiery assessments required for management purposes will provide the needed data for the adult populations as well as information on the distribution and abundance of key benthic species in heavily polluted areas such as the New York Bight, as well as on principal fishing grounds such as the Dogger and Georges Banks. In the case of the New York and Middle Atlantic Bights, annual surveys allow regular upgrading and revision of charts on benthic distributions. As stressed by the ICES General Secretary (1978), to be most useful, charts should be developed to standard scales.

OPERATIONAL TASKS:

When a spill of oil or other hazardous material occurs, it will be the responsibility of an on-scene coordinator (OSC) to request immediately all charts and maps indicating the distribution of living resources likely to be affected, as well as charts showing current direction velocity and other physical/chemical facts to be evaluated in the context of damage assessment and mitigation. The charts and maps can then be used immediately to locate resource species and habitats: (1) which should receive special protection by "booming", barriers and similar techniques, and (2) to which dispersants, detergents and similar oil control chemicals should not be applied. The charts can also be used to locate areas to which collected petroleum can safely be removed to, as well as areas which function as beaches, marinas and harbor areas.

The maps of resource species and physical data such as currents can also be used by the OSC to predict possible impacts on important fisheries, marine ecosystems and coastal amenities, such as swimming beaches. Such predictions can then be used to allocate equipment, personnel and supplies to reduce impacts, protect resources and mitigate damage. The charts and maps will permit an early assessment of the long-term implications of a particular spill.

Charts which show the distribution and abundance of petroleum hydrocarbons and other contaminants will serve as baselines against which increases in petroleum in the physical environment (sediments) can be compared and the persistence of a specific oil spill can be evaluated.

REQUIRED RESEARCH TASKS - MAPPING

At the present time, data exist for many resource specimens in Europe and North America to permit charts to be prepared which could serve as baselines for their distribution and abundance. For many important species and geographic areas, however, there is insufficient information for mapping purposes. Such areas and species should be identified on a national basis and efforts made to collect data which would permit the development of charts.

Following spills, affected areas should be mapped or re-mapped; control or reference sites should be identified. Effects on fishing efforts and recovery of contaminated fishing grounds or habitats should be considered and depicted on maps.

In mapping living resources, great importance should be given to using standard methods of collection, analyses and data presentation for biological physical and chemical studies. Stefan and Grant (1978) outline the standard methods to be used in sampling phytoplankton and O'Reilley and Thomas (1979) provide a manual for measurement of primary production using the ^{14}C technique. Jacobs and Grant (1978) provide guidelines for zooplankton sampling in baseline and monitoring programs. Mearns and Allen (1978) and Swartz (1978) have developed standard methods for coastal fishery assessments using small trawls and sampling and for analyzing the benthos, respectively. Gonor and Kemp (1978) have set forth procedures for quantitative ecological assessments in intertidal environments; their standard techniques may be used in making measurements which would be used in mapping intertidal and sub-littoral environments.

Hershner et al (1978) have provided procedures to be used in responding scientifically to accidental oil spills; these, again, might provide standard methods or guidelines for developing data to be used in mapping. Finally, Maienthal and Becker (1976) have reviewed the literature on sampling, sample handling and long-term storage for environmental materials. Again, proper sampling and handling of samples is extremely important in research designed to provide monitoring and baseline data for mapping and other purposes.

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PHYSICS-MODELLING OF PHYSICAL PARAMETERS

Pre-event Tasks

A number of numerical models exist for prediction of the movement and mixing of oil under varying wind, sea state and current regimes (see Stolzenbach et al., 1977; Grose and Mattson, 1977; Ahlstrom and Wise, 1976). Most models solve the mass balance or distribution of variables equation (Sverdrup, et al., 1942) using marked particles and a basically Lagrangian approach, representing diffusive effects stochastically or with Mone-Carlo techniques. A second characteristic of existing models is that they typically do not include more than a few of the most obvious processes. There is usually an estimate of the residual ocean current which advects oil particles. Wave/oil/wind processes are simulated by a displacement that is proportional to the wind, usually 1 to 3 percent of the wind velocity, and this is vectorially added to the ocean current displacement. Models intended for smaller scale spills may include explicit spreading algorithms and an attempt to represent weathering (Stolzenbach et al., 1977). In at least one case, a simple parameterization is introduced to simulate beaching processes (Ahlstrom and Wise, 1976). Current conceptual approaches are largely empirical, and observational data from actual spills, particularly in the early stages, are generally lacking. In summary, present-day modelling efforts, particularly for large-scale spills, are conceptually simplistic. Most have concentrated on adequately representing the background oceanographic environment of currents and winds. Results have been a qualified success in that even with modest amounts of current data and regional wind statistics, the dominant direction of the trajectory can be determined and initial estimates of scatter are available.

Several research groups are currently working to improve our understanding of the processes controlling oil distribution and develop more realistic modelling algorithms. Most current research is directed toward the processes of oil spreading, wave/oil momentum transfer, and weathering.

Oil Spreading

The extent and form of oil spreading is a complex function of the fluid properties of both the oil and water. A number of studies have been carried out to describe the process (see Stolzenbach, et al., 1977). Models of the process are highly idealized and typically require constraints derived from observational data. Considerable variation is noted from data set to data set, not surprising considering the limited physics included in the parameterization and the general difficulty in obtaining quantitative spill data. It is reasonable to say that all spreading models adequately represent the initial increase in slick surface area, however, in all cases the quality of the representation breaks down as the processes involved become more complex -- thick and thin regions, pancakes, stringers, or wind rows. Considerable further research will be required before suitable descriptions of oil spreading are possible.

Wave/Oil Momentum Transfer

Despite a long observational history, the dynamics of the wave/oil slick interaction are poorly understood, yet the details of these processes are of particular significance to oil transport and environmental impact problems. It is observed that short gravity waves and capillary waves are quickly dampened when entering an oil slick. Wave momentum is transferred to the oil slick or a boundary layer just beneath it, or possibly to both the slick and boundary layer. The consequences of this process are at least twofold. First, the momentum exchange acts to propel the oil slick through the water, thus making it move faster than the surface drift in the direction of the dominant waves (downwind). In addition, since the shorter gravity waves and capillary waves have some components coming from all directions there will be an additional momentum transfer acting as a compressional force on the oil slick. This effect acts to counter the natural spreading of the slick and tends to reinforce surface tension effects. It can be seen that two major components needed in trajectory predictions appear to be closely tied to this wave/oil momentum transfer process: 1) differential oil/water movement and 2) final expected spreading, pancake formation, etc. Experimental data appear to give ambiguous parameterizations of these processes (Stolzenbach, et al., 1977). It is likely then that the relevant physical or chemical characteristics of the oil have yet to be identified. Recent work by Steward (1976), indicates that surface active molecules are playing a major role in these processes. To the extent that these interface characteristics introduce new, or distinctly different, dynamic effects from those attributed to either the bulk form of oil or water, it will be necessary to develop alternate parameterization schemes. We are faced with the possibility that the actual controlling dynamics will depend on some small molecular fraction of the oil. In addition, weathering effects will preferentially modify this surface active fraction so that the required algorithms will depend on oil type, environmental conditions and complex time histories.

Regardless of what algorithms are ultimately chosen to represent oil/wave momentum transfer and the associated drift, compressional forces, and secondary circulations, it is clear that an appropriate dynamic theory has yet to be developed. In the pursuit of an acceptable theory, more carefully collected data are needed in conjunction with expanded conceptualizations of actual processes.

Weathering

Hydrocarbons once released in the marine environment cannot be treated as conservative quantities. As time goes on they are both modified in form and removed from the surface by a number of processes including evaporation, emulsification, sediment interactions, and biological degradation. Some hydrocarbons will evaporate from a surface slick, resulting in significant losses of mass to the atmosphere. This process is not at all uniform and depends on a number of characteristics of the oil. Obviously the lighter molecular fractions of the oil tend to evaporate more rapidly than the heavier ones. This process modifies the bulk properties of the slick in such a way that certain feedback mechanisms become important. The heavy residuals left at the surface of the slick can form a crust or skin that inhibits further evaporation until mechanical processes, such as wave action, break or perturb the surface. Another important secondary effect associated with evaporation is the fractionation of the oil, which leaves the heavier component behind. In some cases the heavier fractions may be dense enough to sink. There have been examples where patches have sunk in relatively large chunks, and recent studies (Mattson, 1978) suggest that small flakes (which were presumably originally in suspension in the lighter oil fraction - USNS Potomac spill) can sink as a residual after evaporation. Observational data show very large variations in the loss of mass of oil due to evaporation from spill to spill. Although the accuracy of the observations can certainly be questioned, the range of losses appeared to be from practically nil in the Argo Merchant spill (#6 oil) to over 50% in the Ecofisk spill (light crude oil).

A second weathering process is associated with emulsification. It occurs in two ways, leading to quite different results. Oil-in-water emulsifications can form where small oil droplets go into suspension in water. In such a case the oil no longer behaves as a surface slick, but moves with the water, mixing throughout the upper layer somewhat like plankton. Sustained weathering effects in this form are not known, but oil-in-water emulsions appear to remove the oil from the surface so emulsification agents are often considered part of a cleanup strategy. A second type of emulsification (water in oil) is one in which the mixture contains up to 80% water. Such a water-in-oil emulsification, often called mousse, appears to resist certain types of continued weathering and takes on physical properties quite different from those of surface oil. The development of algorithms to predict mousse formation is of major importance for predicting overall oil impacts.

A third type of weathering process affecting oil slicks is related to oil interacting with suspended sediments in the water column. In at least some cases, oil droplets appear to adhere to sediment particles. This is not a universal effect, and probably depends on complex geochemical interactions as well as oil characteristics. For example, in the Santa Barbara blowout, sediment from the Ventura River sent large quantities of oil whereas large amounts of oil from the Argo Merchant spill did not appear to end up in the sediments. In other cases (Arrow, West Falmouth spill and Metula) it appears that mechanical mixing was actually responsible for oil being driven into the sediment where the weathering processes and residence times were entirely different from those of oil in the water column.

A fourth weathering process is related to biological utilization of the hydrocarbons as an energy source. This tends to be a slower process than the ones mentioned above and consequently is of secondary importance, at least during the initial stages of a spill. For the long term fate of spilled hydrocarbons, biological breakdown is still likely to be significant, but this is typically beyond the period when trajectory tracking techniques can contribute to a meaningful estimate of the hydrocarbon mass balance.

Summary

Improvement in the state-of-the-art in spill modelling will depend on advancements along both theoretical and observational fronts. In the near term, most progress may be expected from the detailed study of spill incidents as they occur. Unfortunately, the mechanism does not currently exist for the prompt exchange of findings among workers in several countries. A useful role may thus be served by ICES in the consolidation and exchange of data obtained during spill incidents and controlled experiments.

Operational Tasks

During the spill incident, mechanisms must exist to rapidly obtain information on the initial distribution and composition of the oil, as well as data on current and predicted meteorological and oceanic conditions. Estimations of various model coefficients are also required. Much of this information will result from initial mapping activities discussed in earlier sections. Time is of the essence in this activity and rapid means of data communication to and from the spill site is essential.

Experience indicates that frequent updating of the actual distribution of the spill is necessary to "re-initialize" the model as well as detect possible errors in dispersion and other coefficients used in model calculations. Continued mapping activity, measurement of surface currents and winds, calculation of oil/water differential motion, and measurement of subsurface oil concentrations is necessary throughout the spill incident in order to refine subsequent trajectory predictions.

Following the Event

Given that sufficient mapping data are available, it is especially useful, after the event, to "hindcast" physical spill parameters using actual winds, currents, and other relevant data obtained during the incident. This process very clearly reveals errors in model assumptions and provides further insights regarding underlying physical processes not otherwise obtainable. The exchange of such "hindcast" results from a number of incidents (involving several oil types and environmental settings) will substantially aid the development of improved physical models.

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C H E M I S T R Y

Pre-Event Research

Purpose of Chemical Analysis of Oil:

There are many reasons for wishing to analyze oil, but in almost all cases the requirement is as a service to other interests. Examples of the requirements for oil analysis at the time of a spill or afterwards.

- the need to be able to estimate the quantity of oil released;
- the need to be able to establish the dispersion of the oil laterally across the surface, vertically in the water column, and its incorporation in sediments and in the biota;
- the need to be able to advise fish sales and public health authorities on the presence of components of oil which might cause taint, or pose health risks, e.g. PAH compounds;
- the need to be able to follow the weathering of the oil--which compounds are lost and at what rate;
- the need to be able to relate effects observed by biologists to concentrations of oil present;
- the need to be able to assess the effectiveness of oil-combating measures.

What Must Be Done In Advance:

In all cases where analysis is required, the answers will be needed at the time of the incident. For this reason, there will not be time or opportunity to test or develop methods once the accident has occurred. For this reason, most of the development work in relation to the methods of both sampling and analysis must be well established in advance. Except at a very simple level, it will not be possible to develop the necessary techniques once the incident has taken place.

It will, therefore, be necessary for the national authorities to establish in advance of an incident what facilities for chemical sampling and analysis are available, can they be deployed in the event of an incident, what methods are used by the chemists for sampling and analysis, how comparable are the results they obtain, and whether or not these are suitable methods of preservation. If the necessary facilities are not available or if the methods, etc. have not been satisfactorily tested, then time will have to be devoted to this task.

Methods of Analysis:

Several methods of analysis are available which are applicable to oil. They vary considerably in the degree of sophistication and a major difficulty is the comparison of results obtained by different methods. A list of the majority of techniques which have been applied to the analysis of oil is given below in approximately increasing order of complexity, cost in terms of apparatus and time and specificity of results obtained.

Gravimetry
Colorimetry
UV Spectrophotometry (fixed wavelength)
" (scanning)
IR spectrometry
Fluorimetry (fixed wavelength)
Gas chromatography
Fluorimetry (scanning)
Fluorimetry (synchronous scanning)
Gas chromatography-mass spectrometry

These methods are arranged in a hierarchy. It can probably be assumed that all laboratories will be equipped for gravimetric and colorimetric analysis, fewer for fluorescence or gas chromatography, and very few for gas chromatography-mass spectrometry. Fluorescence and gas chromatography represent an additional problem: they are complimentary, in that they give different information about the same sample. Results obtained by one cannot be compared with results obtained by the others, and few laboratories use both routinely. In most spill situations, several laboratories of differing capabilities will be involved, and at some point, results of each will be compared with others. Intercomparison is only possible using a common technique, i.e. the highest-level technique in the hierarchy that is common to all laboratories.

In order to achieve comparability, it has been suggested (Whittle et al) that a tiered approach should be used, and a brief outline of such a system is presented in Annex 1.

With such a system, samples would be subjected to analysis by methods lowest in the hierarchy and each laboratory would move steadily up the scale of methods until they have reached the highest level of which they are capable.

In practice, in the event of a spill the analyst is likely to be called upon to analyze very many samples and it will probably not be practicable to fully utiize a fully tiered system of anaysis. For this reason, one of the two following alternatives may be the only practical solution.

1. The laboratory should use that method or methods in which it has the most experience and for which it is best equipped. A proportion of the samples would, however, be passed through the tiered system.

2. The laboratory should use only that method or methods in which it has the most experience and for which it is best equipped. As far as practicable, sub-samples of each extracted sample should be stored for possible future analysis by some other laboratory which may be better equipped or can do the work at some future date.

It should be recognized, however, that the goal of total intercomparability may not be achievable for two reasons: (a) Oils involved in different incidents are themselves likely to be different in composition. In consequence, the effect in terms of concentrations of total oil may be very different. (b) Effects of weathering and sample matrix will alter irretrievably the ability to intercalibrate certain techniques; for example, gas chromatography and fluorescence.

The problems of intercalibration are being addressed by the Marine Chemistry Working Group of ICES, and for this reason they are not discussed further here.

Even allowing for the fact that the equipment available to different analysts will probably not be identical due to recognized idiosynchrisies in individual methods and the unlikelihood of obtaining a concensus among laboratories, difference in results are almost inevitable, even if all analysts could use a single method. For this reason, specific analytical procedures are not stipulated here. Rather, each laboratory should calibrate its method against a standard oil (e.g., an API Standard Oil) or a sample of the specific oil involved in a spill incident.

Sampling Methods

The procedures used for collecting samples which are to be analyzed for petroleum hydrocarbons are almost as numerous as the laboratories involved in analysis. Examples of methods which have been found suitable for particular purposes are given below. These examples are certainly not exclusive of other methods and the main point which must be remembered is that unlike most other trace analyses, contamination of the sample can arise not only from the sampling platforms and sampling equipment, but also from oil floating on or dispersed in the water column as a result of the spill being investigated.

Surface film can be sampled using a 200 mesh stainless steel screen (Mackie *et al*, 1977) or a Teflon disc (Miget *et al*, 1974) but this can be done only when sea conditions are relatively calm.

Water column samples are taken at 1 m below the surface and at additional selected intervals between surface and bottom depending on the depth. Depending on water depth, 10 m intervals are used. Samples of 2 1/2 or 5 litres are collected using either manual bottle filling (IGOSS 1976;

Mackie et al, 1977) or remote bottle filling (Keizer et al, 1977). These are only applicable down to depths of 10-20 m; deeper samples are obtained using a modified Menzel-Dazzler bottle (Mackie et al, 1978) or the Teflon-coated General Oceanus type 1080 sampling bottle. Sub-slick samples should always be collected last. When sampling under continuous slicks it is difficult to prevent contamination of samples by entrainment from the surface layer, but sampling devices may be put under the surface outside the slick area and towed subm rged to the sampling site. Alternately, a sampler developed by General Oceanics ("sterile bag samples"), which can sample through slicks, should be investigated. Whenever possible, samples will be extracted on board ship and in the ideal situation, where a spectrofluorimeter is not available, will be quanitified for total hydrocarbons. Further analyses would then be conducted in the onshore home laboratory.

Tarballs would be sampled by neuston net (Derenback & Ehrhardt 1975) and a tow of 1 nautical mile would normally be used as standard.

Sedimenting particles would be sampled using suspended sediment traps (Payne & Davies 1977). This approach has been found more useful for collecting particulate material than 5 l water samplers, and can give information on the movement of oil towards the seabed and on the resuspension of settled material.

Bottom sediments. In water depth of less than about 20 m core samples can be collected by divers and this is the most satisfactory method. In deeper water or when no divers are available, corers, box-corers or grabs would be used on a (rope) warp, if necessary attached to a metal cable, but the shockwave travelling ahead of the instrument will disturb the surface and some light flocculent material will be lost. The grab must be kept as free as possible of oil-based lubricants; samples of any lubricant used should be taken for subsequent analysis in cases where contamination is suspected.

The use of filtering organisms. Because organisms such as mussels concentrate particulate contaminants, they can be used to facilitate the analysis of particulate oil in a semi-quantitative fashion. Where such an approach is adopted the animals used should be collected from an oil-free, clean area and be suspended in cages at appropriate water depths, or placed on the bottom, and subsequently analyses and compared with species from the clean, oil-free area.

Plankton sampling. A variety of plankton nets is available and oblique, horizontal or vertical tows would be used as required. A 250μ mesh with a bucket-type codend may be used when live organisms are required. In the presence of a visible slick, plankton collections would, if possible, be done by diver operating from a small boat in order to avoid contamination. Under way collecting using a plankton pump is possible and this may be useful in reducing contamination.

Benthos. Again, this is best sampled by a diver where possible, but otherwise a dredge or grab will be used, with all the precautions already referred to.

Fish. Pelagic and bottom trawls are required. The danger of contamination during hauling and on deck after catching must be recognized, especially if the fish are washed with water; this applies also to sieving of benthic samples.

Rapid Field Methods. Methods have been developed for the rapid detection of oil in the field. These methods are distinct from the quantitative, laboratory-based methods outlined above. One method (Brown et al, 1978) involves extraction, paper chromatography and UV detection, and can be executed in a few minutes; it yields a qualitative indication of the presence of oil in water and sediment.

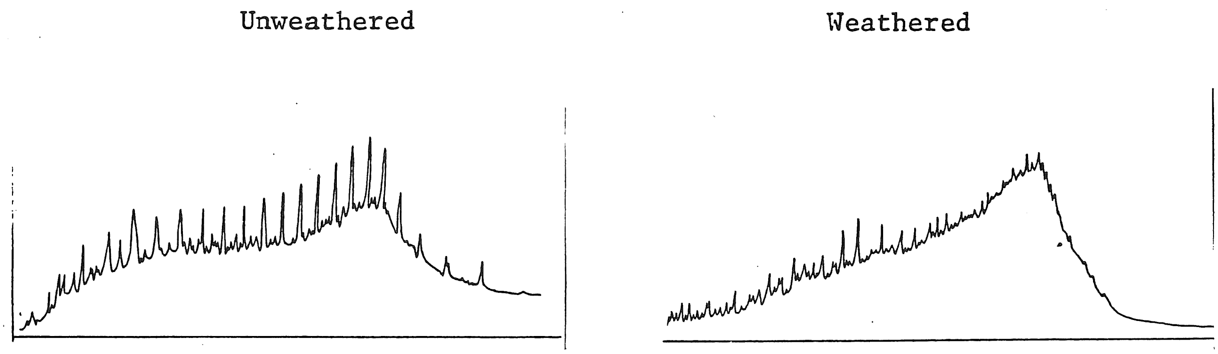
Sample Matrices. Samples will consist of whole oils, or oils in water, sediments or tissues. Whole oils or solutions or suspensions in water can be prepared for analysis by extraction into a suitable solvent:

(a) methylene chloride for fluorescent, GC, or gravimetric analysis

(b) CCl_4 for IR analysis

Sediments can be extracted by shaking with water and a suitable solvent. The solvent should be less dense than water and as polar as possible if measurements based on PAH are contemplated, so that PAH are desorbed from sediment particles.

Weathering. The effect of weathering on the relative sensitivity of various analytical methods must be investigated. Similarly, the mechanisms of weathering must also be investigated: (a) evaporation only, (b) evaporation plus solution, (c) evaporation plus solution plus photooxidation, etc. Changes in the raios of alkanes (GC) to PAH (fluorescence) are often used as in index of weathering. Alternately, the "unresolved complex mixture" envelope observed in GC analysis tends to change from a single to a double envelope.



Tainting. The (classes of) compounds involved in tainting must be identified and specific methods for their analysis in all matrices (especially tissues) developed. The quantities involved probably limit these investigations to laboratories equipped with GC/MS or at least FID-EC/GC; in addition, access to properly trained taste panel will be necessary.

Carcinogenic Hydrocarbons. Recent observations strongly suggest that although carcinogenic hydrocarbons can be detected in most oils, mutagenic activity in the Ames test cannot be detected. This may be due to (a) low concentration comparable to those observable in non-oil-polluted matrices or (b) competition of non-mutagenic compounds for the activation sites in exposed organisms. The fact that tumors have been detected in fish near spill sites strongly suggest that this question urgently requires further research.

Analysis of Oil Spill Dispersants. Although there has been some progress towards analysis of dispersants, the analysis of dispersants in a spill situation may be impractical for the following reasons:

(A) It is unlikely that only one dispersant will be used and even individual dispersants vary in composition according to batch of manufacture.

(B) The amount of dispersant deployed in a large spill will be only a small proportion of the total oil released.

(C) Dispersant biodegradability and hydrolythic instability in water requires special sample preservation procedures.

(D) A growing body of evidence indicates that dispersants do not potentiate the toxicity of oil, but merely make it more available to organisms. Toxicities are related to the measured concentrations of oil in the water, and not to the presence or absence of dispersant.

OPERATIONAL CHEMICAL RESEARCH APPLICABLE TO CLEANUP

Samples

At the time of an incident the chemists' role will primarily be to provide a service using the facilities and expertise developed in advance. The areas listed below are those which will be of particular interest during the incident.

It is recognized that it is of the utmost importance to all phases of the study to obtain a sample of the original, unweathered, uncontaminated oil. As large a sample as possible should be obtained, and stored in sealed glass bottles in the cold and dark.

Immediately the following data should be obtained for the purpose of the cleanup effort:

Flash point	(ASTM D 93)
Flash point and flame point	(ASTM D 92)
Pour point	(ASTM D 97)
Viscosity	(ASTM D 445)
Surface & interface tension	(Ring method of Dunoüy)

Samples should be distributed to all involved laboratories for intercalibration purposes, along with all pertinent data.

Weathering

A sample of the original oil should be subjected to weathering conditions similar to those occurring in the field (temperature, wind velocity, etc.) in order to provide information on the potential dispersibility of the oil and to provide standard samples for calibration of analytical procedures.

Composition with respect to PAH can be determined by UV, synchronous-scan fluorescence, or GC/MS to predict the toxicity of the oil and the changes in toxicity due to weathering.

Rapid methods

Facilities for rapid oil detection should be provided for the use of biologists and cleanup technologists (to aid in the selection of samples and sampling sites).

It is understood that this is simply a utility and that the data are to be considered with appropriate suspicion.

BASIC RESEARCH DURING & FOLLOWING THE EVENT

Since the results of chemical analysis will be required primarily in connection with other disciplines, most of the chemists' activity will be in service of their needs for information on the concentrations and composition of oil in the various compartments in the marine environment. The purpose of virtually all purely chemical post-spill research is the refining of analytical and sampling techniques developed in the pre-event research phase.

Examples of projects which in the course of post-spill investigations conducted by other disciplines will require chemical input area: identification of toxic (acute and chronic) carcinogenic/teratogenic/mutagenic/pheromore substances detected by biological studies and the identification of the fate and changes in composition of the spilled oil.

ANNEX I

Tiered Protocol[a]

Method	References / Cost[b]
Gas Chromatography-Mass Spectrometry	(references F) Cost [b]$500+
Packed and Capillary Column Gas Chromatography	(references E) $300
UV Spectrophotofluorimetry UV Absorbance	(references D) $50-100/sample
IR Analyses	(references C) $50-100/sample
Survey Methods Rapid methods Gravimetric and colorimetric methods	(references B) $10-50/sample

[a] All extracts from the methods in the tiered protocol may not be suitable for analysis by instruments from the other levels of the protocol i.e. raw extracts used in some analyses (UV spectrophotofluorimetry etc.) are not suitable for analysis by GC without isolation of the hydrocarbon from the lipids. Similarly samples extracted with hydrocarbon solvents are not compatible with analysis by IR.

[b] The cost of the analyses vary depending upon the type of extraction chromatographic clean up, and analytical instrumentation.

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B I O L O G Y

In the study of oil spills, a variety of biological approaches are available. Many of these are referred to in the National Plans submitted by a number of countries and the attached table summarizes which procedures are appropriate to particular components of the ecosystem. Additional discussion is provided in the following notes, but it is perhaps with commenting that observations and experiments done in the field during and following an oil incident will rely heavily on data and experience arising from work done throughout the course of longer-term background research.

MICROORGANISMS:

Biodegradation by microorganisms is the main process by which oil is destroyed. Together with evaporation and dilution of dispersed oil, it is responsible for waters and beaches becoming "clean". Oil degrading microorganisms are the only organisms for which oil serves as a nutrient.

The actual degradation rates are not dependent on the size of the microbial population present at the beginning of an oil spill, as long as oil degraders are present at all, which is normally the case in coastal areas and the shelf region.

The actual degradation rates are all dependent on:

1. the kind of oil (chemistry, solubility, surface to volume ratio)
2. the environmental conditions as e.g. available inorganic nitrogen and phosphorus salts, temperature, oxygen, interfering substances. Likewise, organisms which feed on microorganisms can limit their growth and activities.

From this follows that microbiological investigations have to be made in close co-work with investigations of the chemistry of the oil and its changes, the environmental conditions and planktonic or benthic organisms which would interfere.

Sampling should be done in the same depth as for plankton and chemistry research.

Special attention should be paid to the surface layers. The surface film should be sampled by Teflon discs (Miget et al, 1974) and 200 mesh stainless steel screen (Mackie et al, 1977) or Millipure filters applied to the water surface. The uppermost centimeters should be sampled by application of a suction funnel (Oppenheim et al, 1977).

The time consuming work required to process samples for microbiological analyses is likely to limit the number of samples which can be handled. At least one additional water sample, e.g. from 10 m depth should be taken. The upermost layer of the sediment should be investigated. In any case, floating oil should be included in the investigations. Dilution series of the oil can be made after emulsifying the oil in sterile seawater after adding a relatively non-toxic, non-degradable emulsifier and a deforming agent and application of a high speed mixer (Gunkel et al, 1965).

Standard microbial techniques for counting saprophytes and hydrocarbon degrading bacteria on suitable media should be used (e.g. Gunkel, 1973). In addition, a count of total numbers using epifluorescence techniques should be used (Zimmermann et al, 1974). The data should reveal changes in the ratio of hydrocarbon degraders to total saprophytes and total numbers and serve as an indicator but say little about the true activity of microorganisms.

This requires use of complimentary techniques, for example:

1. Direct measurements, using ^{14}C labelled substrates of the mineralization of selected important hydrocarbons, which will indicate the rates at which particular groups of compounds would be mineralized (Massie, 1978).
2. Determination of oxygen consumption of sample water and after addition of stripped crude, sampled oil and individual hydrocarbons after different times of incubation.

Neither method is wholly satisfactory, but in combination they give some indication of the microbial response to hydrocarbons.

Stress should be laid on changing available methods, that they also could be used in determining the activity of oil degrading microorganisms (Rheinheimer, 1978) and their effects especially upon the first steps of oxidation, that is the formation of aldehydes, ketones and organic acids.

PHYTOPLANKTON:

Oil has been shown to change the size structure of phytoplankton populations from large to small species and this, together with measurements of primary production, might be utilized. In addition, the ciliary measurements of certain uncellular algae are affected in a quantifiable way by oil and this could be used as a bioassay.

ZOOPLANKTON:

A wide range of holoplanktonic animals have been studied, but copepods are perhaps most popular because of abundance and availability and because they are amenable to experimental work. Survival and growth, as well as the general well being of copepods (the latter usefully measured by the rate of fecal pellet production) may be measured at sea in water taken from below a slick, and attempts may be made to assess direct effects on zooplankton populations from examination of net hauls.

BENTHOS:

In spills at sea in deep water, benthos is not likely to be affected unless or until oil sinks to the seabed. Benthic animals such as filter-feeding bivalve molluscs can be used in cages to assess the extent and effects of contamination. On shore or in shallow water, benthos will clearly be directly affected, and immediate lethal impact can be determined from counts of dead organisms, while longer term effects can be detected by a study of community structure and recruitment.

EGGS AND LARVAE:

Planktonic stages, i.e. egg and larvae of fish and shellfish, particularly of commercially important species, can be examined from a number of viewpoints. Experiments to determine their survival and development in sub-slick water can provide guidance on the toxicity of the contamination. Tow net collections from the area of the spill may indicate developmental abnormalities which may be due to genetic damage or to direct morphological effects. Finally, effects on year class strength may be considered by comparing hauls in clean and oiled areas, and as well as the points noted above, observers should consider effects on larval behavior (feeding, predator avoidance, vertical migration) and growth rates.

FISH AND SHELLFISH:

Areas worthy of study are as follows:

(1) the behavior of different species in response to oil ± disperants, especially avoidance of contaminated water by fin fish and the ability of shellfish to survive various exposures to contaminated water,
(2) the uptake of substances derived from oil ± dispersants by different species from food and water and the organs affected,
(3) the rates of self-cleansing of contaminants and taints and loss by excretion and biodegradation,
(4) the threat to human health from contaminated species (especially carcinogenic effects),
(5) long-term effects on fish and shellfish such as the incidence of tumors, fin rot and mutagenic effects,
(6) short-term effects, such as unnatural mortality, fertility and growth rates,
(7) effects of sunken oil on burrowing species such as Nephrops.

Finally, indirect effects of oil ± dispersants on larvae, juveniles and adults of fish and shellfish could occur through changes in the abundance and composition of phytoplankton and zooplankton on which they feed. One specific aspect would be the influence on the timing and intensity of seasonal phytoplankton blooms.

For fish and shellfish, the question of tainting is of great significance. Tainting can take place either directly from oil in the water or on the bottom, or the catch can be affected by contaminated fishing gear. Whenever possible, trained taste panels should be employed to assess the quality of the product. In addition, long-term basic research is needed to determine the threashold for tainting and to identify the oil fractions responsible.

BIRDS:

Ornithologists are highly conscious of the threat of oil to sea birds and a great deal of work is underway. It is perhaps sufficient to note here that in mounting a fishery-oriented program, the activities of those concerned should be recognized so that coordination can be arranged.

MARINE MAMMALS:

Where possible, information should be obtained on the behavior of mammals in and near oil slicks, on the incidence of oil in the stomachs of animals found dead, and on external wounds which might be related to oil.

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TYPE OF OBSERVATION \ ENV. COMPONENT	MICRO-ORGANISMS	PLYTOPLANKTON	ZOOPLANKTON	BENTHOS	EGGS AND LARVAE	FISH	SHELLFISH	BIRDS AND MAMMALS
LC_{50} tests		Productivity measurement	Copepod survival	Survival	Survival and development			
Physiology	Degradation rates		Fecal pellet production by copepods	Scope for growth and other indices in molluscs Enzyme induction	← Growth rate →		Accumulation and depuration of PNAH	
Pathobiology					Abnormal development	Fin rot tumors skeletal anomalies		
Behavior		Ciliary action	Vertical migration feeding rate	Reduced burrowing by bivalves changes in antennal activity in crabs		Changes in stocking & distribution (migration habits)	Feeding rates	+
Genetics					Abnormal embryo development chromosomal abnormalities			
Populations				Changes in rock flora & fauna changes in burrowing animals	Field observations in mortality			Mortality
Recruitment				Following population recovery		Check on entry of impacted year groups to commercial stocks		
Communities	Changes in ratios of different physiological groups	Changes in size structure production	Changes in copepod dominance	Changes in species structure production				
Smothering				Of intertidal organisms	Coating of eggs			
Tainting						Taste panel assessment Long-term studies of fraction and thresholds		

GENERAL TASKS

In addition to the tasks mentioned in the previous sections, there are several other more general areas where it is important or useful that work be carried out. The tasks in this section have been divided according to whether they pertain to scientific or administrative matters.

Due to their more general nature, most of the tasks discussed here are part of the pre-event preparations for an eventual oil incident.

Pre-event Preparations on Scientific Issues

Sampling methods and analytical techniques for the determination of oil in sediments, water and biota. While recognizing that some work has already been done on this subject, it is considered necessary that further inter-comparison exercises or, where necessary, standardization of sampling and analytical techniques be done on a broad basis to promote comparability of results obtained by different laboratories.

Sample storage. Storage at -90°C is considered appropriate because deep-freezing at normal temperatures is inadequate.

Tissue or specimen banks. It was considered useful to establish specimen banks for retention of tissue and sediment samples (see Annex I).

Controlled oil spills. It was considered practical to utilize controlled oil spill situations to test the full or most appropriate scientific research programme in an actual oil spill situation.

Pre-event Administrative Preparations

Lists of coordinators and experts. It is proposed that each country be encouraged to prepare lists of project coordinators and experts in each relevant scientific field for internal use within the country. For international assistance, it is proposed that one responsible authority be designated in each country who could identify appropriate experts who would be able to assist in the area(s) where expertise has been requested. The authorities in each country should be encouraged to consider how international assistance and coordination can best be carried out.

Inventories of projects and studies. It is proposed that each country prepare an inventory of planned and on-going studies related to oil pollution and its effects on the marine environment. This inventory could be prepared every (5) years and be collated and published by ICES.

Dissemination of information. It is considered that scientists and authorities concerned have a general responsibility to disseminate within their country information relevant to oil pollution response research, for example to inform the general public so they can understand the broad scope of scientific resources needed in response to an oil spill situation.

Funding. It is considered that adequate funding for scientific research in response to an oil pollution incident is an important but internal responsibility of each country. It is recognized that different mechanisms exist for such funding in different countries.

Practice oil spill situations. It is considered useful to test the actual capability of the scientific research team to respond to an oil pollution incident, including testing the adequacy of the organization of the activity and the possibility of assembling the appropriate experts, technicians and equipment.

Tasks In A Basic Research Context

Under this heading, it was considered that activities should be the same as those for pre-event preparations in the following areas: Sampling methods and analytical techniques, sample storage, lists of experts, and dissemination of information.

As a follow-up activity to research conducted in response to an oil pollution incident, it can be useful to conduct a post-event examination among the participating scientists of the coordination and success of the scientific operations.

Annex I

Specimen Banks

The matter of collecting, handling and storage of samples to be used in pollution studies was the subject of a recent meeting held in Berlin, October 1978. This meeting was concerned principally with long-term storage of samples from the terrestrial and fresh water and marine environments. A formal report from the Berlin workshops to the environmental protection agencies of the Federal Republic of Germany and the United States will include precise techniques for:-

1) collection and analyses of biota, water, sediments and of air for more important toxic substances and contaminants as well as for
2) the storage of samples for eventual analyses of these materials as well as for as yet unrecognized pollutants.

The United States National Bureau of Standards also has recently produced a document entitled "A Survey of Current Literature on Sampling, Sample Handling, and Long-Term Storage for Environmental Materials" (Maienthal and Becker, 1976) which is the result of an extensive literature survey to establish optimum sampling, sample handling and long term storage techniques for a wide variety of environmental samples to retain sample integrity. The components of interest in these samples are trace elements, organics, pesticides, radionuclides or microbiologicals. This survey was done both manually and by use of various bibliographical retrieval services. Also the advice and opinions of workers in various aspects of the fields was obtained.

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	Task Area	Pre-event Tasks
Mapping	Mapping renewable and non-renewable resources	Map resources:-
	Distribution fish and fishing effort	Map fish and fishing distribution and seasonal variations
	Distribution fish eggs and larvae	Seasonal distribution - fish eggs and larvae
	Distribution benthos	Distribution of benthos
	Distribution plankton	Distribution of plankton - seasonal variations
	Distribution spawning areas	Known spawning areas
	Distribution zones of productivity	Zones of primary and secondary productivity
	Distribution hydrocarbons including biogenics	Baseline distribution of hydrocarbons
	Distribution sediment types	General distribution of sediment types
	Summary of risk indices	General summary of risk areas
	Summary of hydrographic features/nutrient distribution	General summary of currents, water masses
	Selection of reference sites	Selection of baseline study areas
Physics	Meteorology	Maps of general climatic conditions and seasonal changes
	Hydrography	General studies of ocean processes
	Predictive modelling, effects of winds on currents	Predictive modelling - effect of winds on currents
	Physical properties of oil	Physical properties of oils - general studies
	Oil reservoirs	
	Dispersion routes and rates	General studies on dispersion -includes mousse formation
	Downward mixing	
	Sedimentation	
	Slick thickness, surface tension viscosity	
	Oil budgets	
	Oil/ice interactions ± dispersants	
Chemistry & Biochemistry	Chemical properties of oil	General studies - oil/ice interactions ± dispersants
	Sampling of source	Reference manual of chemical properties of oils
	Weathering properties of oils.	Weathering properties of oils ± dispersants
	Identification of analytical techniques	Development of analytical techniques
	Intercalibration	Intercalibration - between participating laboratories - national & international
	Rapid field analysis techniques	Development of rapid analytical methods for field use
	Screening tests for dispersants	Tests of dispersants against representative organisms
	Hydrocarbon concentrations, water and sediments	Baseline studies of hydrocarbon concentrations - water and sediments
	Hydrocarbon concentrations, biota - carcinogens	Baseline studies of hydrocarbon concentrations in biota - includes carcinogens
	Tainting, incorporation of PAH, depuration	Studies of tainting and depuration - incorporation of PAH
	Nutrients, nitrates, phosphates, etc.	Seasonal distribution of nutrients - relevant to microbial biodegradation
Geomorphology	Distribution of sediment types	Baseline studies on sediment distribution
	Energy levels of coastline	Studies of degree of exposure relevant to self-cleaning of beaches
	Fate of oil on beaches	
Biology	Community structures - recovery of ecosystems	Baseline studies on ecosystems
	Primary and secondary productivity effects of oil ± dispersants	Distributon of areas of productivity
	Productivity indices	Baseline productivity indices
	Natural mortality rates	Baseline studies on mortality in natural populations
	Fish eggs and larvae - toxicology and physical effects	Variations in fish egg and larval abundance
	Fish eggs and larvae - relationships to year-class strength	Annual variations in egg and larval mortality
	Effects on benthos of oil ± dispersants	Laboratory studies on benthos
	Effects on standard organisms	Laboratory studies on selected pelagic species
	Effects on behaviour	Laboratory studies on behaviour - especially fish
	Effects on different trophic levels, ecological niches	
	Effects on reproductive processes	Laboratory studies on reproductive processes
	Genetic changes and mutations, teratogenic effects	Laboratory studies on genetic effects
	Histopathology of marine organisms	
	Microbiology - biodegradation	
	Planktonic biodegradation systems	
	Marine mammals - distribution and vulnerability	Distribution and vulnerability of marine mammals
	Marine birds - distribution and vulnerability	Distribution and vulnerability of marine birds
Technical	Sampling technique development	Development of techniques for sampling water, sediments, organisms
	Sample storage	Development of storage techniques and availability
	Tissue banks for hydrocarbons	Creation of tissue banks for future reference
	Effects of oil on boats and fishing gear	
General	Lists of experts and projects	Preparation of national action plan and lists of experts
	Exchange of information	Dissemination of information
	Exercises - including controlled spills	Exercises to test national plans, ± controlled spills
	Logistics - including international cooperation	Logistics - includes cooperation at international level
	Public relations	Public relations - identify responsible agencies
	Funding	Funding - identify and secure sources for baseline and emergency programs

RELATED TO NEARSHORE AND OFFSHORE OIL SPILLS

Operational Tasks		
Applicable to cleanup	Applicable to socio-economic impacts	Research Opportunities During and Following Event
Aerial reconnaissance Commercial fish distribution	Estimation of vulnerability and impact	Mapping affected areas - location of control sites Effect on fishing effort and success - recovery of spoiled grounds
Benthos distribution in path of slick Plankton distribution in path of slick Species spawning and distribution Productive zones in path of slick Hydrocarbons in water and sediments Sediment types in path of slick	Prediction of effects Prediction of effects Prediction of effects Assessment of vulnerability	See below: Effects on Biological Systems Distribution of hydrocarbons in water and sediments
Current measurements, identification of water masses Selection of reference sites	Predictions of risk in vulnerable areas	Verification of risk predictions
Meteorological observations		Atmospheric dispersion and fate of volatiles
Prediction of slick trajectories Physical properties of source samples Oil distribution and state Evaluate dispersion - longshore transport Mixing of oil in water column Sedimentation - incorporation into bottom Slick thickness, distribution, viscosity, etc. Fate of oil on beaches Ice studies as appropriate	Identification of sensitive targets Strategy for cleanup Strategy for cleanup	Use of oil "tags" for current plotting Testing slick trajectory predictions Weathering rates and routes Long-term stability of oil reservoirs Effect of small or large bulk releases on dispersion Vertical dispersion of oil in water column Sedimentation processes and fate of sedimented oil Dispersion rates and routes at water surface Weathering and dispersion of oil from beaches Interactions of oil and ice
Reference samples of source - properties Weathering rates, dispersion routes Selection of analytical techniques Intercalibration of labs Selection of field techniques Selection of suitable dispersants Measurement of contamination in water and sediments Measurement of hydrocarbons in biota Assessment of tainting	Implication for fisheries closures	Chemical aspects of weathering Field testing of dispersants, cleanup techniques Relationship between hydrocarbon concentrations in water, sediments and biota Permanence of tainting, recovery, depuration
Sediment distribution in threatened area Assessment of erosional/depositional beaches Fate of oil on beaches	Affects cleanup strategy Affects cleanup strategy	Recovery of contaminated sediments Geomorphological stability of contaminated beaches, sediments Effects of cleanup on beach structure
Effects of oil dispersants on communities Effects on productivity		Effect of oil on structure and diversity and recovery of communities Long-term effects on primary and secondary productivity
Effects on fish eggs and larvae Mortality, teratogenic effects Effects on benthos Effects on standard organisms and pre-arrival data	Short-term predictions	Additional effects of oil on natural mortality in plankton populations Effects of oil on different species of fish eggs and larvae Long-term studies on future year-class strength following oil spills Long-term studies on benthos and recovery following oil contamination Effects on standard or pre-selected species Effects on behaviour, migration, etc. Differential effects at trophic levels or ecological niches Effects on reproductive processes, physiological and behavioural Genetic effects, mutagenic effects Histopathology of affected organisms
Mircobiology		Microbiology - "switching on" microbial degradation ~~response~~ Effect on plankton on biodegradation processes
Marine mammals distribution and vulnerability Marine birds distribution and vulnerability	Affects cleanup strategy Affects cleanup strategy	Marine mammals - basic research into affects of oil Marine birds - opportunity for shared resources - ships of opportunity
Selection of techniques, methods Storage techniques Sampling of contaminated tissues Effects of oil on fishing gear, vessels	Costs of cleaning or loss of effort	Development of sampling techniques Development of storage techniques Long-term accumulation of oil - PAH in tissues Development of alternate fishing techniques or strategies
		Dissemination of information
Logistics - + international cooperation Public relationships		International cooperation, exchange, coordination Funding - long-term sources