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THE VALIDITY OF OIL SPILL COMBATING METHODS:

The Decision Making Process - A critical study

By

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2003

DECLARATION

I certify that that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the university.

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ABSTRACT

Title of dissertation: **The Validity of Oil Spill Combating Methods: The Decision Making Process- A Critical Study**

Degree: **MSc**

The dissertation is a study of the prerequisites of a "correct decision" in cases of oil spill combating. The decision-makers miss-perceptions are investigated and identified using several techniques such as case studies, questionnaire as well as personal interviews.

A comprehensive study is conducted to highlight and discuss the identified technical miss-perceptions as a foundation for introducing a scientific Decision support tool for producing a sound decision in cases of oil spills.

The active contribution of oil spill decision-makers in the stages of building up their national oil spill contingency plans is examined and evaluated. In addition a study is conducted on the capabilities and limitations of the widely used oil spill modeling techniques.

The concluding chapters introduce the Oil Spill Management Simulators as a viable training and assessment tool for oil spill decision-makers. A model structure of a spill crisis handling simulator is proposed and an investigation of the capabilities and cost effectiveness of such facilities is conducted. Finally a number of recommendations are made concerning the need for enhancing the knowledge and competence standards of oil spill decision-makers.

KEY WORDS: Oil Spill, Decision-Makers, Chemical Combating, Mechanical Combating, Spill Models, Simulation, Virtual Reality, Training, Assessment, Decision Support Tool.

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List of Abbreviations

AASTMT	Arab Academy for Science, Technology and Maritime Transport
AMOP	Arctic and Marine Oil Spill Program
DBMS	Data Base Management System
DMs	Decision Makers
DOR	Dispersant to Oil Ratio
EPA	Environmental Protection Agency
ERA	Ecological Risk Assessment
GIS	Geographic Information System
HELCOM	Helsinki Commission
IOSC	International Oil Spill Conference
IPIECA	International Petroleum Industry Conservation Association
ITOPF	International Tankers Owners Pollution Federation
NEBA	Net Environmental Benefit Analysis
NOAA	National Oceanic and Atmospheric Administration
NOSCP	National Oil Spill Contingency Plans
OSCs	On-Scene Commanders
OSMS	Oil Spill Management Simulator
PERSGA	The Regional Organization for Conservation of the environment of
RDBMS	Relational Data Base Management system
	the Red Sea and the Gulf of Aden
VR	Virtual Reality
VRTE	Virtual Reality Training Environment
WMU	World Maritime University

Chapter One

Introduction

In response to a query on maritime law, the emperor Antonius once advised his fellow Romans that "…*I am the lord of the whole…the law is the lord of the sea". A* similar philosophy can be applied to oil spill emergencies, for they neither respect national boundaries nor national laws and can impact on anyone and everywhere.

Each time a major oil spill occurs questions are asked about why, decision makers usually drift away from the right decisions and yet we remain unable to deal with spilled oil on the surface of the sea and thereby prevent it from fouling beaches and damaging wildlife and coastal resources. Most of the time the spill incidents are incorporated with lots of uncertainty. Facing this, the decision makers usually focus on increasing levels of a detail about something of which there is limited knowledge, and thereby provide very precise answers that tend to be precisely wrong.

The problem is far more difficult than many people are willing to acknowledge, as can be illustrated by recent major incidents such as the BRAER off the Shetland Isles, the SEA EMPRESS in Wales, the NAKHODKA in Japan, the EVOIKOS in the Malacca strait and the ERIKA and PRESTIGE in the Bay of Biscay. ITOPF oil spill statistics (see fig.1.1) shows that the average number of large spills (>700 tonnes) during the 1990s was less than a third of that during the 1970s. Despite such dramatic reduction and even with the evolution of new oil spill combating technologies and the billions spent on equipment stock piles by the industry and the governments as a part of their national contingency plans the decision makers still receive a black eye at most spill incidents.

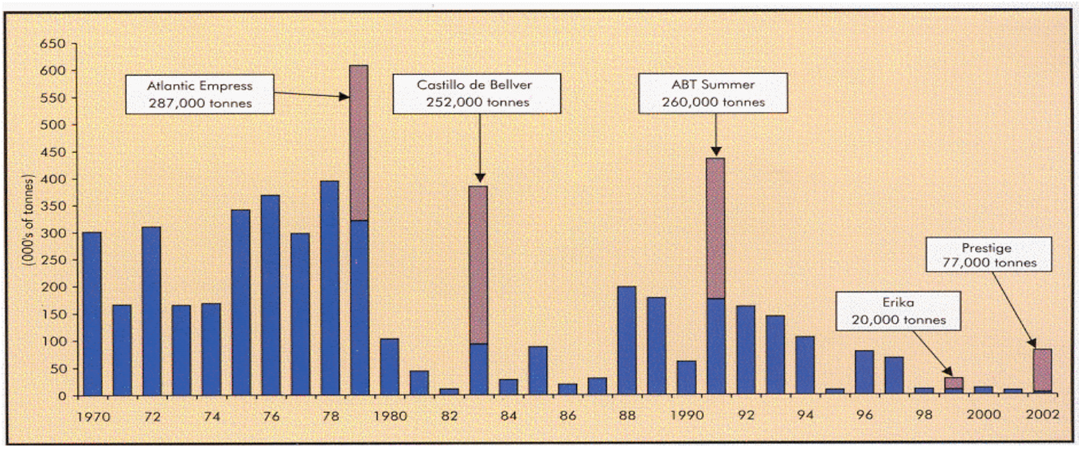

Fig1.1 Quantities of oil spilled

Source: (ITOPF year book p.9)

1.1 Research Objectives

There is no doubt that an adequate knowledge of the fate of various types of oils under chemical and natural dispersion conditions is essential. Further, the validity of oil containment and recovery means is most needed. Moreover, the knowledge about ecological impacts when each method is used is essential. This research will try to investigate the latter items for decision-makers, and further discusses the building-up of a scientific supporting tool for oil spill decision makers.

The study will start by discussing the vague areas in oil spill behavior and combating technologies that decision-makers usually have misconceptions leading to faulty decisions. Following this the study will try to introduce how the issue of enhancing the knowledge of such personnel could be approached. Finally the focus will be on the decision-makers competence and skill element, and what the oil spill management simulators can achieve in the effective training of current and potential oil spill management staff.

1.2 Research Methodology

To achieve the latter objectives the author reviewed a considerable number of spill cases in the last three decades (see appendix I). The aim was to try to discover when the decision regarding spill countermeasures went wrong? Why was it wrong? Was it too late to take the right decision? Why was there a delay? What are the adverse effects of such delays? Is a lack of knowledge behind this delay or wrong decisions? Could the lack of skill or experience be the reason for these delays and faulty decisions? Was the decision in the hands of well-trained competent personnel?

The cases studied identified some common areas of misperceptions among decision makers, which are discussed in this study. Moreover a questionnaire was generated and directed to current and potential decision makers in various countries. The questionnaire consisted of two sections (see appendix II). The first section focused on questions about areas in oil fate and spill countermeasures where decision makers were having a noticeable un-certainty. The second section was dedicated to how such decision makers view the use of oil spill management simulators as a training approach, and do their opinions regarding whether they could contribute in enhancing skill and competence levels?

As the tackled subjects are dynamic and some are still being reviewed and assessed the search and collection of data focused mainly on recent technical papers presented to the specialized seminars and conferences. These papers provide a wealth of the most updated data needed for this research. Various research institutes having relevant on-going or earlier relevant research were also contacted where they presented their own expertise and contributed by supplying some environmental modeling software, which aided in the research process by displaying their capabilities and their limitations. These models in some cases would present an acceptable tool for predicting the behavior of oil in various hydrographic and meteorological conditions. They could also be used to predict the potential bio-economic impacts providing that accurate data is fed to the model.

The field trips of WMU were utilized to the utmost by a series of discussions and interviews with all oil spill related staff in all response organizations, classification societies, equipment manufacturers and IMO Technical Co-operation Division staff visited (see appendix III).

1.3 Critical Issues Discussed in the Research

The research discussed why is it difficult to execute the planned measures during oil spills? Is it because they are extremely rare events with impacts far greater than those experienced during more routine emergencies? Or is it because the society does not deal easily with low probability high consequence events?(Harrald, 1989, p.139). Reviewing causes for major spills we find that accidents are the overwhelming cause, with groundings and collisions accounting for 63% of the total during the period 1974-2002 as shown in fig1.2.

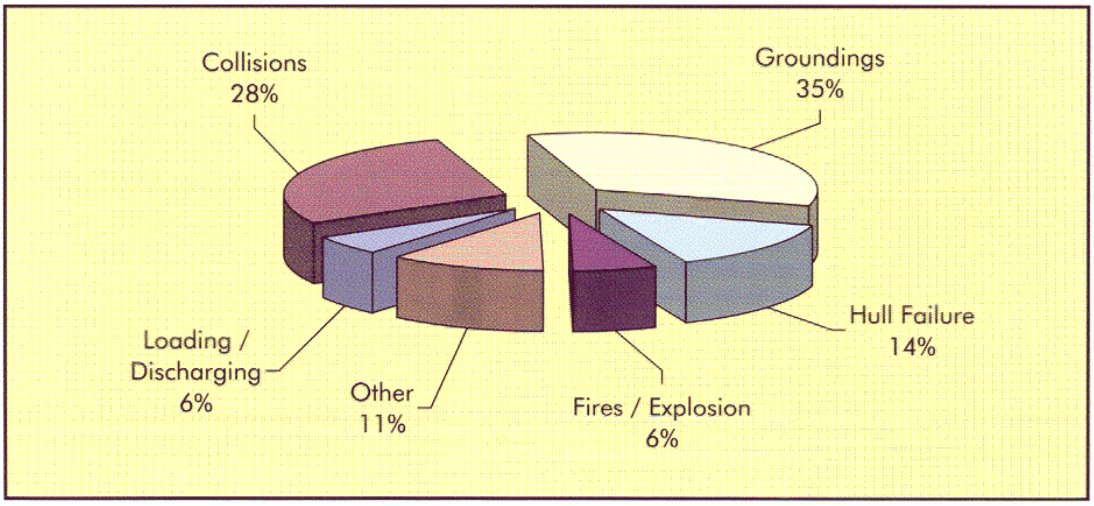

Fig.1.2 causes of pollution accidents (ITOPF, 2002)

From the above, some other vital questions arise. How can contingency planners guard against such un-predictable events? Can this be done by only preparing for worst-case scenarios? Can Ecological Risk Assessment (ERA) contribute in upgrading such plans? Can decision makers have a role in the ERA process? Why is quantifying the net environmental benefits needed before deciding which spill combating technology is to be used? What are the impacts of oil on biological resources? What is time curable and what is not? What should be given top priority? Is it public health or the good image in front of the media? What are the limitations of oil spill trajectory models? Are oil spill professionals really dedicated to their duties? Is oil spill staff trained properly for these duties? What was the basis of their choice? Can their performance in the middle of an oil spill crisis be assessed? How?

The research will try to answer some of the above-mentioned questions in an attempt to provide the proposed support tool for oil spill decision makers. The research will also evaluate the effectiveness of Oil Spill Management Simulators as a training tool. It should be noted that in the context of this research "Decision Maker" (DM) means any person who is legally authorized to make a decision in an oil spill incident ranging from the operational level first responders, on-scene commanders reaching to management staff. These decisions could be related to the choice of spill countermeasures, shore line clean-up techniques, protection of sensitive resources, mobilization and de-mobilization of resources, or even the leave-alone and monitoring option.

Chapter Two

Fate of Oil and Bio-Ecological Concerns

2.1 Introduction:

The following chapter will focus on some of the vital data that decision makers should be aware of; especially areas were there are often some misperceptions leading to eliminating viable possibilities about fate and behavior of spilled oil and adverse impacts resulting from such faulty decisions.

2.2 What Should DMs Know?

One of the main areas that decision-makers should be well aware of is the fate of oil in the marine environment whether it is naturally or chemically dispersed and how this is affecting the biological resources and the food chain. Decision makers (DMs) should also bear in mind the concept of net environmental benefits where the potential consequences of spraying dispersants is weighed against the impacts of leaving the slick untreated. The tradeoffs between impacts should be clearly defined to decision makers either on shoreline habitats and wild life on the water surface or on the water column and benthic organisms.

2.3 Behavior of Oil

When oil is accidentally spilled on the marine environment two main types of transformation processes occur. The first is weathering in which the physical and chemical characteristics change. The second is a group of processes relating to the movement of oil. (Fingas, 2001.pp.39-59). This specific behavior is vitally important to decision makers for knowing what lies ahead of them. For example, if an oil slick evaporates rapidly, cleanup is less intense but air pollution is a high probability which may require more stringent safety procedures for personnel dealing with combating equipment in such volatile atmospheres, on the other hand the main problem may be that the spill could be carried by surface currents or winds to the shore and severely affect the wild life and their habitat.

The weathering process includes spreading, evaporation, emulsification, dissolution, dispersion, photochemical oxidation, microbial degradation, adsorption onto suspended particulate materials, sinking and degradation as shown if figure 2.1, The relationships between these processes and the use of specific response technologies needs to be well understood in order to estimate and delineate windows of opportunity for specific clean-up methodologies and technologies. Maximum environmental and cost benefits are achieved when responders choose tactics and technologies to fit the windows of opportunity for each technology (National Research Council, 2002).

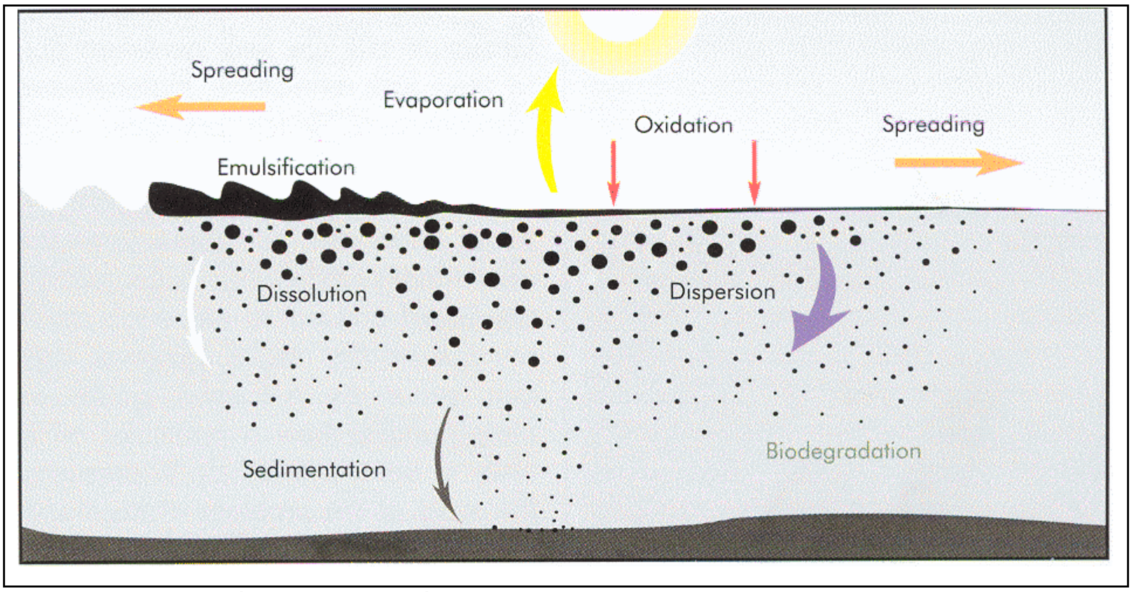

Fig 2.1.fate of oil

Source: ITOPF yearbook 2003/2004

2.3.1 Evaporation

This is considered as the most important process decision makers should monitor closely as it defines what amount of oil would be left on water or on land after a spill. Evaporation increases flash point, pour point, density and viscosity. If about 40% (by weight) evaporates, its viscosity could increase by as much as a thousand fold. Its density could rise by as much as 10% and its flash point by as much as 400% (Fingas.2001, p.42). Light fuels such as gasoline could be completely evaporated in several days while less than 5% of Bunker C is subject to evaporation. The rate of evaporation is very rapid immediately after the spill then slows down as shown in fig.2.2.

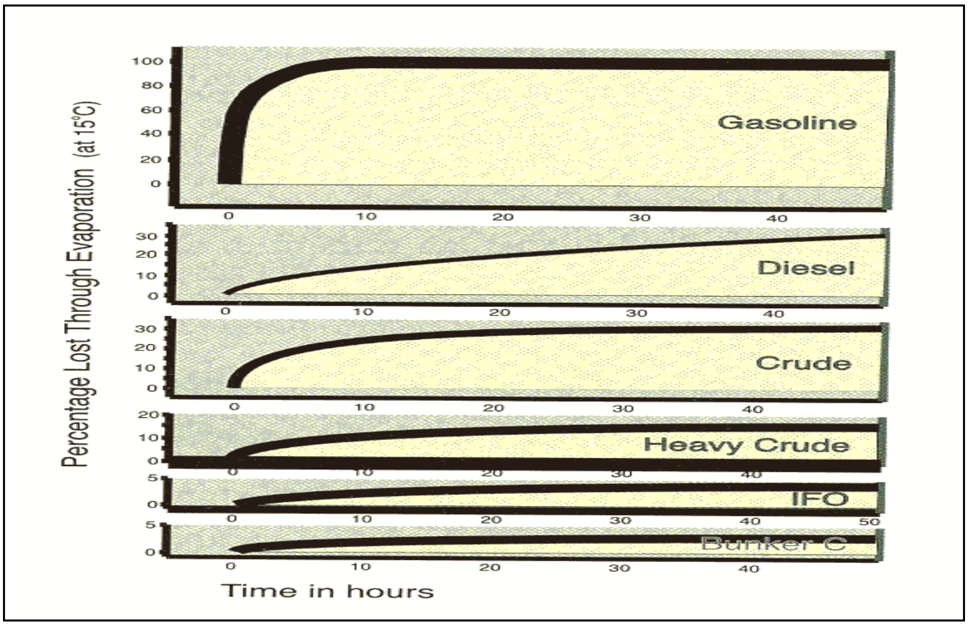

Fig.2.2 Evaporation Rates of different types of Oil at 15^0c Source:(Fingas 2001)

2.3.2 Emulsification

Emulsification is the incorporation of water into oil, forming what so called “mousse”. Figure 2.3 shows the formation process (Lee, 1999, pp.117-126). As oil emulsifies, it forms stable water in oil emulsion[1], which can include up to 80% water. This imposes limitations on clean-up technology as it considerably increases the slick volume (almost tripled). This emulsified slick will need to be recovered and is difficult to disperse and recover with skimmers. If the spilled oil contains a high asphaltine and resins content the viscosity can rise up to 800 times higher than the spilled oil and the emulsion will remain stable for weeks and even months after formation.

[1] When the droplet size in emulsified oils have reached a small enough size so that the forces of gravity do not naturally separate them, the emulsion is termed stable.

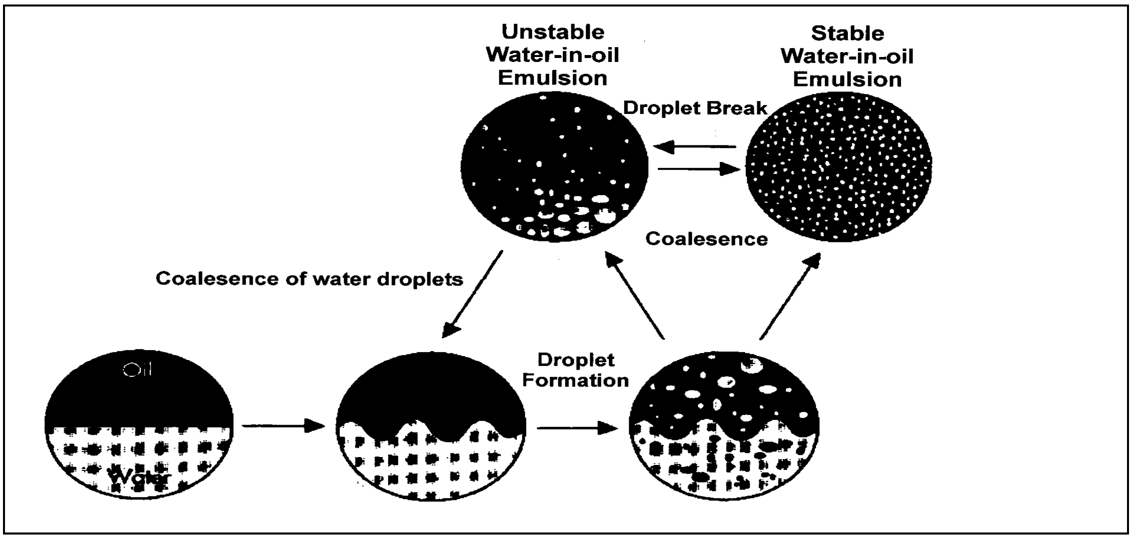

Fig.2.3 Formation of oil emulsions. source: (champ, 2002)

2.3.3 Dissolution

The lower molecular weight aromatics and some of the polar compounds are usually rapidly dissolved in the water, what enters the water column is less than a fraction of a percent of oil. Decision makers should note that soluble aromatic compounds are particularly toxic to fish and other aquatic life. The toxic effects are likely to be more prominent in protected shallow water areas with gasoline, diesel oil, and light crude oils.

2.3.4 Natural dispersion

This occurs when droplets of oil are transferred into the water column by turbulence and wave action in rough seas. The smaller droplets tend to remain in the water column for a longer time than the larger ones. This process can be significant to the extent of removing the bulk of oil as in the case of the *BRAER* in which the high seas entirely dispersed the whole slick. The dispersible nature of this particular cargo should be considered.

2.3.5 Sedimentation

When oil droplets in the water column become denser than water after interacting with mineral matter in the water it starts depositing on the sea bottom and usually get covered by other sediments which results in very slow degradation. This is very harmful to biota, which comes in contact with those sediments, and decision makers should consider this as a potential threat.

2.3.6 Biodegradation

Many species of bacteria, fungi and yeasts metabolize hydrocarbons to an oxidized compound, which may be further degraded, may be soluble or may accumulate in the remaining oil. This process is directly proportional to temperature. Petroleum products containing higher amounts of aromatics and asphaltine biodegrade slowly. The existence of oxygen and nutrients such as nitrogen or phosphorus is vital to this process, because these nutrients are mainly available at shorelines or in land it is noticed that more biodegradation occurs near coast lines (Nordvik, 1995).

2.4 Where will it go?

Following a spill, the oil tends to spread into a slick over the water surface; this process is speeded up by the effect of winds and currents. If the oil slick is in coastal waters with relatively calm winds (less than 10 km/h) the main mover will be the surface current, as it will move with a rate of 100 % of the surface current and only about 3% of the wind speed. But if the wind speed gusts to more than 20 km/h in open waters it takes precedence in determining the slick’s movement, in all cases both factors should be considered as shown in fig.2.4

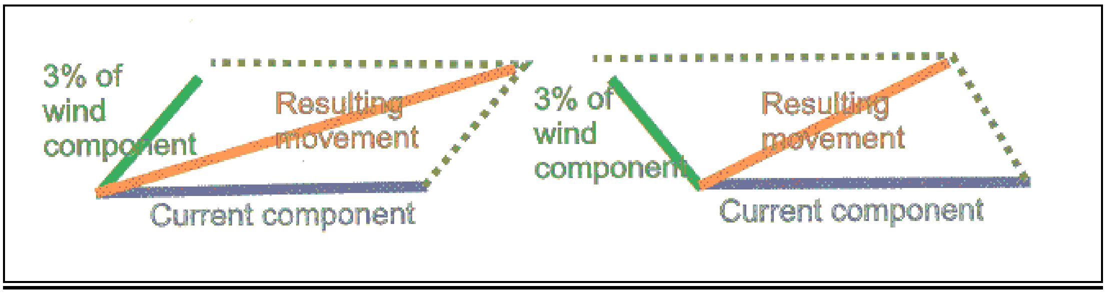

Fig.2.4 Effect of wind and currents on the movements of an oil slick (Fingas, 2001)

2.5 How to predict?

To enhance the effectiveness of clean-up operations, decision makers would need rapid and accurate tools for predicting not only the direction of the spill with usual mathematical models plotting spill trajectories but also the changes in oil properties through a dynamic data base containing data and information on the capabilities, capacities and limitations of response technologies and methodologies (Engelhardt, 1994.p.17). This would be studied in depth in a following chapter of this research.

2.6 Impacts of natural dispersion of oil spills

Regulators and decision makers often think about impacts from human health perspective neglecting the potential dangers to biological resources, which may not be a priority at the time of the spill. However long-term effects could reside in the environment for years. In this context the study focused on those impacts in the case of natural dispersion oil or when it is dispersed by means of chemical dispersants.

2.6.1 Impacts on sea Foods

Seafood contamination can result from the exposure to the dissolved fraction of oil, dispersed oil or an oil coating. The aromatic fraction of oil poses the greatest exposure risk, as they are more soluble than other components oil. (Yender et al, 2002, pp.6-8). Table2.1 summarizes the risk of contamination for the five oil groups commonly encountered by spill responders. For simplicity oils have been grouped into types with similar properties (similar API gravities[2]) to assist in recognizing the potential for seafood contamination when screening a spill incident. As the human health aspect is always one of the prime concerns to decision makers a sampling process for commercial harvest should be considered and results should be compared with reference samples to be able to make statistical inferences to the entire area. If authorities conclude that eating contaminated fish or shell fish

[2] API Gravity is used by the petroleum industry rather than density. It is determined by the following equation: API at 60°F = 141.5/oil density -131.5.

collected from or around the spill site poses an unacceptable human health risk, they may issue local fish consumption advisories or harvest closures for specific water bodies or parts of water bodies and specific species.

Table 2.1 Characteristics of oil types affecting the potential for seafood contamination (modified from NOAA and API 1994).

Gasoline Products	Diesel-like Products and Light Crude Oils	Medium-grade Crude Oils and Intermediate Products	Heavy Crude Oils and Residual Products	Non-Floating Oils
Examples – Gasoline	Examples – No. 2 fuel oil, jet fuels, kerosene, West Texas crude, Alberta crude	Examples – North Slope crude, South Louisiana crude, IFO 180, lube oils	Examples – San Joaquin Valley crude, Venezuelan crude, No. 6 fuel oil	Examples – Very heavy No. 6 fuel oil, residual oils, vacuum bottoms, heavy slurry oils
Specific gravity of <0.80; Floats on surface	Specific gravity of <0.85; API gravity of 35-45° Usually floats on surface; although can contaminate suspended sediments that are then deposited on the bottom	Specific gravity of 0.85-0.95; API gravity of 17.5-35° Usually floats on surface, although can mix with sand by stranding on beaches or in the surf zone, and be deposited in the nearshore	Specific gravity of 0.95-1.00; API gravity of 10-17.5° Usually floats on surface but can sink in fresh water or in seawater if they emulsify or mix with sand (in the surf zone or after stranding on beaches) and deposit in the nearshore	Specific gravity greater than 1.00; API gravity < 10° Will sink in fresh water; may sink in seawater if they emulsify or mix with sand (in the surf zone or after stranding on beaches) and deposit in the nearshore
High evaporation rates; narrow cut fraction with no residues	Refined products can evaporate to no residue; crude oils do leave residues	Up to one-third will evaporate in the first 24 hours; will form persistent residues	Very little product loss by evaporation; will form persistent residues	Very little evaporation when submerged; also very slow weathering overall when submerged
Low viscosity; spread rapidly to a thin sheen; readily dispersed; will not emulsify	Low to moderate viscosity; spread rapidly into thin slicks; readily dispersed by natural processes; may form unstable emulsions	Moderate to high viscosity; dispersed by natural processes only very early in the spill; readily emulsifies	Very viscous to semisolid; will not readily disperse or mix into the water column; can form stable emulsions	Very viscous to semi-solid; will not readily disperse or mix into the water column; can form stable emulsions
Low risk of seafood contamination because of rapid and complete loss via evaporation; potential contamination for spills in confined areas with high mixing, such as small rivers; no reported cases of tainting for marine spills	Moderate to high risk of seafood contamination because relatively high content of low molecular weight, water-soluble aromatic hydrocarbons, which are semi-volatile and so evaporate slowly; dispersed droplets are also bio-available	Moderate to high risk of seafood contamination because of high percentage of low-molecular weight aromatic hydrocarbons; coating of gear and intertidal species can be significant	Low risk of finfish contamination because of low water-soluble fraction and little natural mixing in the water; moderate to high risk of shellfish contamination where shoreline oiling is heavy; can coat gear and intertidal species	Low risk of finfish contamination because of high viscosity; where thick oil accumulates on the bottom, could become a chronic source; moderate to high risk of contamination of benthic species because of coating and persistence of submerged oil

2.6.2 Impacts on sea birds

Sea bird casualties probably attract the greatest public concern; it is often difficult to assess the bird mortalities resulting from a spill because it was observed that there is little relation between the size of a spill and the number of sea bird casualties as shown in table 2.2 For example over 35,000 carcasses were recovered after the Exxon Valdez spilled 35,000 tones of oil. In the case of Braer only 1500 dead birds recovered even though the Braer spill (85,000 tons) was almost two and half times as large as that of Exxon Valdez (Kingston, 2002, p.56).

Table 2.2 comparison of the number of dead seabirds recovered following the Exxon Valdez and Braer spills (Kingeston, 2002).

Species Group	Alaskan Spill	Shetland Spill
Sea ducks	1440	167
Mergansers	121	1
Loons	395	14
Grebes	462	0
Heron	1	3
Geese / Swans	9	0
Gulls	696	74
Kittiwakes	1225	133
Cormorants	836	864
Shear waters	3399	0
Fulmars	870	31
Guillemots / Murres	20562	220
Other Auks	2174	29
Bald Eagles	125	N/A
Other birds	3152	0
Total	35467	1536

The high mortality rates are due to the reduction in feather insulating capacity due to direct oiling allowing cold water penetration and subsequent increase in the of the thermal conductance. Also records of bird deaths due to direct ingestion of oil exist. Direct exposure of eggs affects reproduction and has the greatest potential for damage especially in the early states of incubation. Adults that are exposed to sublethal doses of oil and then ingest it may produce fewer eggs or cease laying eggs all together.

2.6.3 Impacts on Coral Reefs

Corals are regarded as the most diverse and complex marine communities (a single reef may contain 300 species of coral), and play an important role in the geochemical mass balance of the oceans. Coral reefs are also an important for the fishery as they provide food and shelter to many species. Coral reefs are also a barrier for coastal erosion, and their amenity value is often the basis of tourist economies (IPIECA, 1992, P.4). All these factors should be highlighted to decision makers.

Laboratory studies on the effects of oil on corals revealed decrease of growth decrease in reproductive and colonization capacity, and also negative effects on feeding and behavior. On the other hand a long-term field study of corals in the Gulf of Aqaba with persistent exposure to oil from nearby terminal operations caused more detrimental effects than one time exposure even though the one time exposure is more visible. Chronic oil pollution can make corals more venerable to natural phenomena. For example data on the re-colonization of a coral reef after a very low astronomical tide in the Gulf of Aqaba showed that after 10 years the corals re-established well in a relatively clean environment but those corals on a chronically polluted beach did not.

2.6.4 Impacts on Salt Marshes

Salt marches occur along many coasts and fulfill many important functions, which are not always known. For example salt marches provide nursery areas and food web support for fish and shellfish. In addition they play an important role in coastal protection. In some parts of the world they are used by livestock and they are an important habitat for wading birds. Because of ignorance legislators sometimes de-prioritize marches claiming that they are of no human use importance which proved to be a wrong trend from the lessons learned from marsh oiling in the last two decades.

The facts are that marsh environments are highly sensitive to oiling and should receive high priority for protection; if protection fails and marches are oiled, decision makers should carefully consider the advantages and disadvantages of clean up (as shown in table 2.3) in this sensitive habitats. A starting point would be assessing the severity of the impact and attempting to estimate the timeframe for recovery. With information about the likely timeframe for recovery it is possible to assess whether cleanup is likely to speedup the natural recovery process or to impede it (Hoff, 1995, pp.2-5).

Table 2.3 Cleanup techniques used in marshes and their advantages and disadvantages. Source (Hazmat report 96-2 NOAA)

Advantages	Disadvantages
No response minimal impact (if oil degrades quickly) no physical impact	potential oiling of birds or wildlife oil may impact adjacent areas heavy oils may degrade slowly or form asphalt
Vacuum/pumping can remove large quantities of oil	access /deployment of equipment physical impacts
Low pressure flushing assists in removal by herding oil lifts oil off sediment surface	requires careful monitoring pressure must be controlled physical impacts
Burning potential to remove oil quickly can minimize impacts from trampling	potential damage to plant roots and rhizomes little known about impacts due to season, inundation of marsh, species composition, air pollution, regulatory concerns
Sediment removal may be only remediation possible for heavily oiled sediments	"destroy marsh to save it" increased erosion potential elevation changes may impede regrowth of plants replanting necessary
Vegetation cutting leaves most of plant intact prevents oiling of birds	may kill plant potential for increased erosion must be carefully monitored
Bioremediation great theoretical potential low impact	few case studies available potential for nutrient enrichment oxygen may be limiting

2.6.5 Impacts on Mangroves[3]

Mangroves coastal forests are notorious oil traps, the trees usually die when coming in contact with oil endangering coastal stabilization and food chain support for near-shore fisheries. Therefore it is important for decision makers to address habitat protection options by understanding the adverse effects on these sensitive plants.

Oil slicks usually enter mangrove forests at high tide and deposits on the aerial roots, as the tide recedes lots of oil patches are left behind each according to its own tidal height which makes it very difficult to assess the extent of oiling especially in dense forests. Aerial surveillance is only useful at a very late stage when the trees are actually killed by the oil, which could not be visible before 30 days in most cases.

Response Considerations:

- Oiled wrack[4] can be removed once the threat of oiling has passed. Wrack can actually protect the trees from direct oil contact during the acute phase of the spill.
- Sorbent booms can be placed in front of oiled forests to recover oil released naturally.
- In most cases, no other cleanup activities are recommended.
- Where thick oil accumulations are not being naturally removed, low-pressure flushing or vacuum may be attempted at the outer fringe.
- No attempt should be made to clean interior mangroves, except where access to the oil is possible from terrestrial areas.
- It is extremely important to prevent disturbance of the substrate by foot traffic; thus most activities should be conducted from boats.

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[3] The term “mangrove” refers to salt-tolerant species of tree or shrub which grow on sheltered shores and in estuaries in the tropics and some sub-tropical regions.
[4] Wrack refers to debris of seaweed and algae washed out with the oil slick.

It is vitally important that decision makers know that it was proven through field and laboratory experiments that mangrove trees have the ability to tolerate dispersed oil better than untreated oil as shown in fig 2.5. Hence considering the use of chemical dispersion may be an effective measure only after considering all other affected resources within the context of the contingency plan (IPECA, 1993). The issue of using chemical dispersants is discussed in more detail in the next chapter.

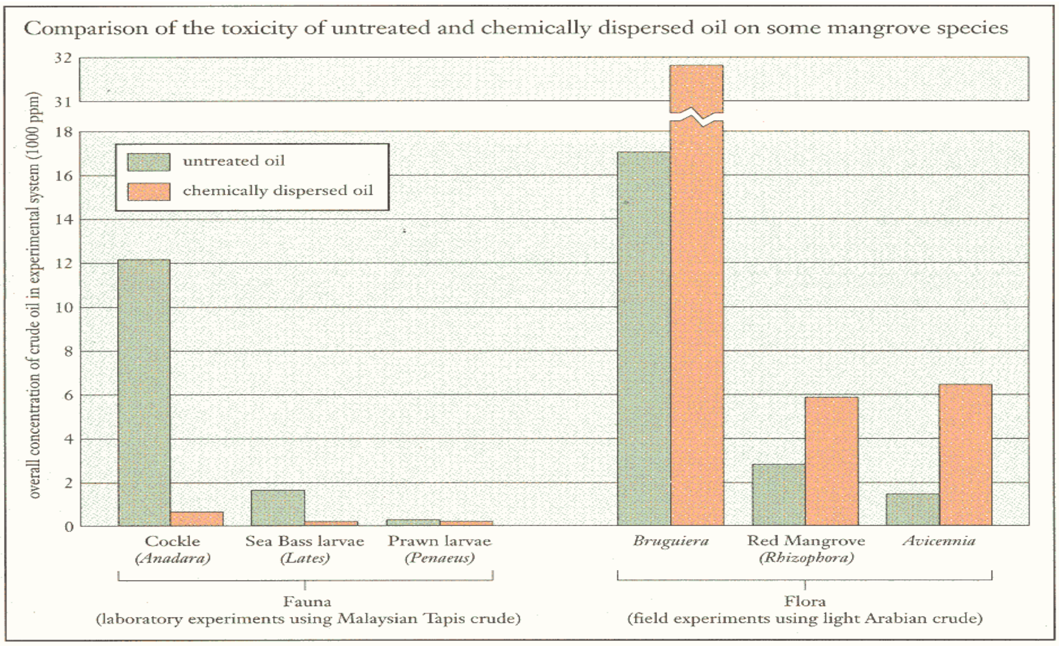

FIG.2.5 Comparison of the toxicity of untreated oil on some mangrove species. The histogram shows LC_{50} [5] values (in the case of fauna, after 96 hours, in the case of mangrove saplings after 30 days) the lower the LC_{50} value the lower the tolerance. Source (IPIECA VOL.4,1993).

2.7 The Economic Impacts of Oil Spills

Ideally all those various biological impacts would mainly be transformed later on to economical impacts, posing the usual pressure on higher-level decision-makers(political masters). However some of the data reaching them could be

[5] . LC50 means the lethal concentration, which is an estimate of the concentration of a substance which, within the specified time (generally 96 hours), kills 50% of the exposed group of test organisms.

exaggerated while other data could be misinterpreted causing the outcome to be faulty decisions.

Reviewing the economic implications of the “Sea Empress” spillage in South Wales as a major spill where over 70,000 tons of oil was lost. How could such a major disaster translated in to money was always a controversial issue, there is always some difficulty in establishing a causal relationship between oil spilled and damage caused to resources that are not owned which is an indirect economic effect. In this case it was clear that parties who had relied upon the continued availability of the damaged asset suffered most, those parties include fishermen, owners of fish processing factories and their employees, and tourist related industries that rely on recreational attractions of the beach resource (Bryan & Hill 1997).

Another obvious expenditure affecting the economy was the costs of the clean up operation itself, table 2.4 clarifies such impacts and concluding that the “Sea Empress” spill have reduced spending by 14.3 million sterling pounds, with the majority of this impact being on wages incomes. The study also revealed 1100 job loses in the aftermath of the spill mostly in tourist businesses.

Table 2.3 Estimated direct effects of spillage on the 1996 Pembroke shire[6] spending in (£m).

Pembrokeshire sector	Cleanup	Fishing	Tourism	Net effect
Agriculture, forestry, and fishing	+0.3	−0.2	—	+0.1
Manufacturing, energy, and construction	—	−0.3	—	−0.3
Other services	+4.7	—	−3.5	+1.2
Local wages	+0.5	−2.6	−10.0	−12.1
Subtotal	**+5.5**	**−3.1**	**−13.5**	**−11.1**
Imports	+5.5	−1.6	−7.1	−3.2
Net spending change	**+11.0**	**−4.7**	**−20.6**	**−14.3**
Associated direct jobs (Ftes)	+25	−147	−835	−957

Source: (Bryan & Hill, 1997)

[6] Pembroke shire is the local county that the port of Milford haven belongs to,

2.8 Conclusion

It is clear that decision makers have to decide on priorities, but do they have access to all information needed? Is it clear to them that oil emulsions viscosity may raise up to 1000 times of the original spilled oil before deciding to use mechanical recovery systems and deploy skimmers to the spill site? Do they know that emulsified oil may contain up to 80% of water before deciding on using the in-situ burning technique? Are they fully aware that the bio-degradation process is considerably slowed down in higher aromatic oils when taking the leave alone option?

Moreover when predicting the spill trajectory do they seek meteorological forecasts and know that gusting winds over 20 knots would be the prime mover of the slick not the usual idea that current is? Do they really consider how different types of oils could affect the seafood and public health? Have they justly prioritized salt marches as more than unused land and guarded against oil reaching any coral reef areas? Are they able to understand the tidal changes and the increased risk of oil entering the mangrove forests? Are they ready to use new generations of chemical dispersants on appropriate spills or still reluctant to do so? Do they still think that mechanical methods are the golden key in all cases? An attempt to answer and discuss some of those controversial issues will be discussed in the following chapters.

Chapter Three

Chemical Combating Methods: Myths and Mysteries

3.1 Introduction:

In this chapter the author will focus on the facts regarding validity and limitations of chemical combating methods. The issues concerning common myths and misunderstandings about oil spill dispersants will also be discussed.

3.2 Chemical Dispersants, the action?

Dispersants are a class of compounds composed of surfactants (surface active agents) and solvents. The surfactants are the key components of chemical dispersants; they contain both water and oil compatible constituents that enable the surfactant molecules to position themselves at the oil-water interfaces, thereby lowering the interfacial tension and also significantly lowering the energy required to generate oil droplets in water. This enables the oil slick to breakup into finely dispersed oil droplets as shown in fig.3.1 (Fiocco & Lewis, 1999).

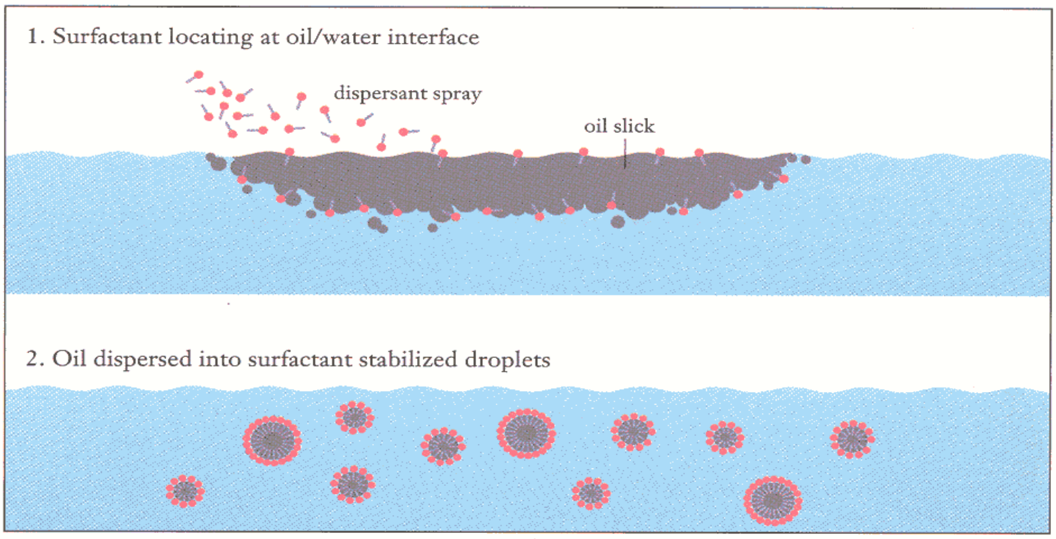

Fig 3.1 shows dispersion process. Surfactant locating at oil/water interface (1), and (2) oil dispersed into surfactant –stabilized droplets.

Source: IPIECA Report serious vol.5

3.2.1 The Debate?

The first generation of chemical dispersants was clearly toxic to many marine organisms. In addition they were in some well-studied cases applied under the wrong conditions, and consequently they usually caused additional damage. This explains why the ongoing debate on dispersant use usually reaches to the simplistic view “save the fish or save the birds and shorelines” implying that dispersants favor sea birds and shorelines whilst threatening fish. In fact the issue is more complex and there are lots of perception barriers that decision makers need to remove. An example of arguments that have been used for and against are summarized in table 3.1.

Table 3.1 the dispersant debate

Those opposed to dispersant use argue:	**Those in favor of dispersant use argue:**
- Using dispersants hides the problem rather than solving it.	- The problems are enhanced with oil reaching shore lines.
- The addition of chemicals to the environment is undesirable.	- The toxic effects of oil already exist even when dispersed naturally.
- Oil will be broken down naturally given enough time.	- Natural dispersion almost stops when oil is emulsified.
- Dispersants are an unreliable technique because they do not always work.	- Dispersants, provided they are applied using the correct technique, are effective in most cases.
- It is better to remove spilled oil from the surface of the sea rather than forcing it into the water.	- If the oil is spilled, the damage cannot be reversed, but can be minimized by rapid action. The total removal by mechanical means is rarely feasible.
-Dispersants are toxic; their use causes the oil to have greater toxic effects than if dispersants are not used.	- Modern dispersants have low toxicity and do not add measurably to the environmental effects caused by the oil alone.

Source: (modified from Decola., 1999)

3.2.2 The choice?

A growing number of countries are now approving the use of chemical dispersants and publishing lists of approved types, however it is noticed that the majority require the "authorities" approval on case-by-case basis. Table 3.2 summarizes the dispersants approved by various countries.

Table 3.2 Overview of permitted dispersants in various countries. (Lindgren, 2001)

Dispersant	Permitted in
Corexit 9500	France, Canada, Norway, UK, USA
Corexit 9527	Canada, Norway, USA, UK
Corexit 9550	Canada
Corexit CRX-8	Canada
Dasic Slickgone LTSW	Norway, UK
Dasic Slickgone NS	France, Norway, UK
Dispersit SPC 1000	USA
Dispolene 36S	France, Norway, UK
Dispolene 38S	France, UK
Drew dispersant LT	Canada
Enersperse 700	Canada
Enersperse 1037	Norway, UK
Enersperse 2000	Canada
Finasol OSR 52	France, UK
Gamelin 2000	Canada
Gamlen OD 4000 (PE 998)	France, Norway, UK
Inipol IP 80	France, UK
Inipol IP 90	France, UK
Inipol IPC	France, UK
Mare clean 200	USA
Neos As 3000	USA
JD-109	USA
Oilsperse 43	Canada
OSR 5	Norway
Slickgone LT	Canada

The following discussion focuses on scientific evidence that decision makers need to understand how different resources will be affected by chemically dispersed oil. There are situations when the use of dispersants can be appropriate and ecologically beneficial. The question is what are those situations?

3.3 Factors affecting the dispersant use decision

The effectiveness of a dispersant is determined by measuring the amount of oil that it puts into the water column and comparing it to the amount of oil that remains on the water surface. Effectiveness is influenced by the answers of the next three key questions that decision makers should ask.

3.3.1 Is this type of oil dispersable?

The information needed to answer this question would be whether the type, viscosity, and weathering characteristics of oil would aid in the dispersion process or not. Oils containing large amounts of saturate, such as diesel oil, disperse more effectively, while oils containing high amounts of resigns, asphaltines and waxes will disperse poorly and will only separate to some degree and may remain on the surface (Fingas, 2001).

3.3.2 Is dispersion acceptable in these environmental conditions?

The information needed to answer this question relates directly to conducting a net environmental benefit analysis (NEBA) to weigh the advantages and disadvantages of dispersant spraying in relation to the location of a spill and the existence of sensitive resources (Lunel, et al.1997). In conducting such analysis many factors need to be considered for example:

- The concentrations of dispersed oil in the water column after application of dispersants.
- The toxicity of the likely concentrations of dispersed oil to local flora and fauna.

- The distribution, fate and biological effects of the oil if it is not treated with dispersants.
- The amount of mixing energy needed for effective dispersion.

As a result of such considerations many countries have defined zones along their coastlines where dispersion use is restricted. This may be based on water depth or distance from the shore or a combination of both.

3.3.3 Is dispersion feasible?

The information needed to answer this question is related directly to the quantity of oil spilled and the available dispersant. Another important factor would be the available spraying systems ranging from boat-based systems to helicopters and fixed wing specialized aircraft.

3.4 What has been done to date?

In order to answer the latter key questions, extensive research work has been done either by laboratory testing or field experiments in an attempt to verify the effectiveness of chemical dispersants on different types of oils and their biological and ecological impacts.

3.4.1 Laboratory studies and experiments

a) Generalized dispersants performance test

Comprehensive laboratory tests have been carried out by a number of national agencies, oil companies etc., in several countries. The purpose of these tests is to measure the effectiveness of the most commonly approved dispersants world wide on two types of crude oils – Prudhoe Bay crude oil and south Louisiana crude oil (EPA, 2001). The test also compared the effectiveness percent with other lab tests done by the manufacturer. The comparison showed that tests carried out by the manufacturer generally show a higher effectiveness of the dispersant than the EPA’s test (table 3.3). The variation in results suggests that judgment of dispersants is not always so representative.

Table 3.3 Comparison of the effectiveness (%) of four dispersants on two different crude oils (Prudhoe Bay Crude Oil and South Louisiana Crude Oil) as found by the EPA and the manufacturer (EPA, 2001)

Oil	Corexit 9500		Corexit 9527		Disperit 1000		JD-109	
	Dispersant's effectiveness (%)							
	Manuf-acturer	EPA	Manuf-acturer	EPA	Manuf-acturer	EPA	Manuf-acturer	EPA
Prudhoe Bay Crude Oil	45,3	49,4	37,4	51	40	52	29	30,02
South Louisiana Crude Oil	54,7	45,4	63,4	31	105	47,9	91	52,84
Mean value	50,0	47,4	50,4	41	73	51	58,5	41,43

Source: EPA 2001

b) Testing of weathering effects

The Environmental Technology Center in Canada has carried out similar laboratory testing on dispersant effectiveness with a wider variety of oils with the most commonly used dispersant (Corexit 9500)[7]. Tests were also carried out oils under different weathering conditions to track the dispersant performance in each case (Refer to appendix 4 for a more detailed overview).

The results show a great fluctuation in dispersant effectiveness but clearly reveal that for weathered oils the effectiveness drops off significantly (Fingas, et al, 2001). The tests also revealed one very important observation, that this pattern of effectiveness is oil specific and not correlated with simple oil properties such as density, viscosity or maximum weathering percentage. This is a point, which should be closely reviewed by decision makers.

c) Tests on salinity effects

The effects of receiving water salinity on the effectiveness of two oil dispersants were studied by the University of California. The dispersants chosen were Corexits 9527 and 9500; the dispersants were applied to ten different types of oils with

[7] Corexit 9500 is a product of EXXON chemical USA and one of the most widely used dispersants in the marine environment and approved by the majority of countries allowing the use of chemical dispersion.

different physical and chemical properties. Test salinities ranged from 0 to 35 ppt, with the temperature held constant at 15^{0}C. Three examples of mean effectiveness of both dispersants on Forcados, Arabian light and Kuwait crud oils are shown in figs 3.2, 3.3 and 3.4.

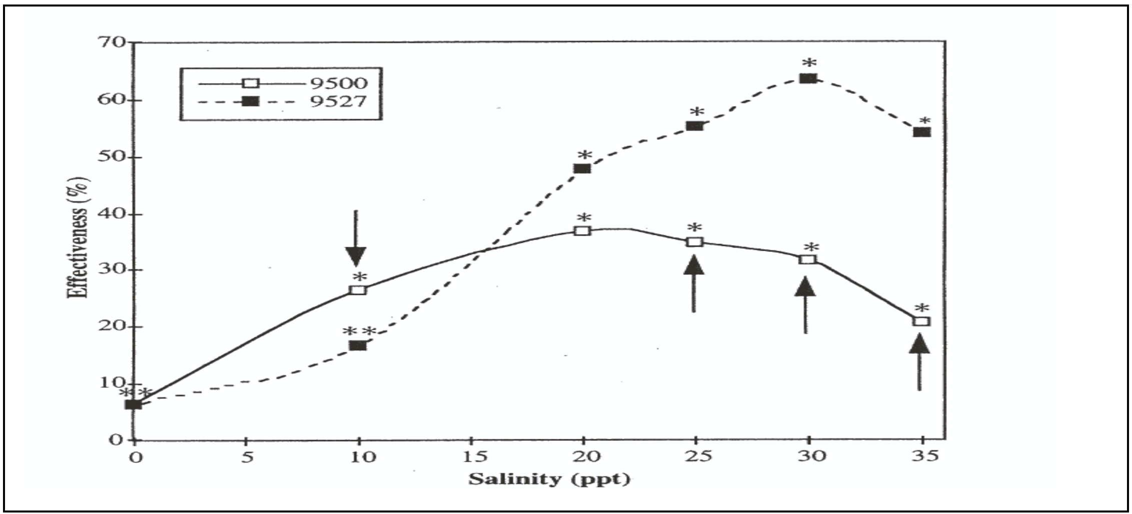

Fig.3.2 Mean effectiveness of Corexits 9527 and 9500 on Forcados crude oil. Arrows denote salinities at which effectiveness of the two agents was significantly different. source:(Blondina et.al. 1999)

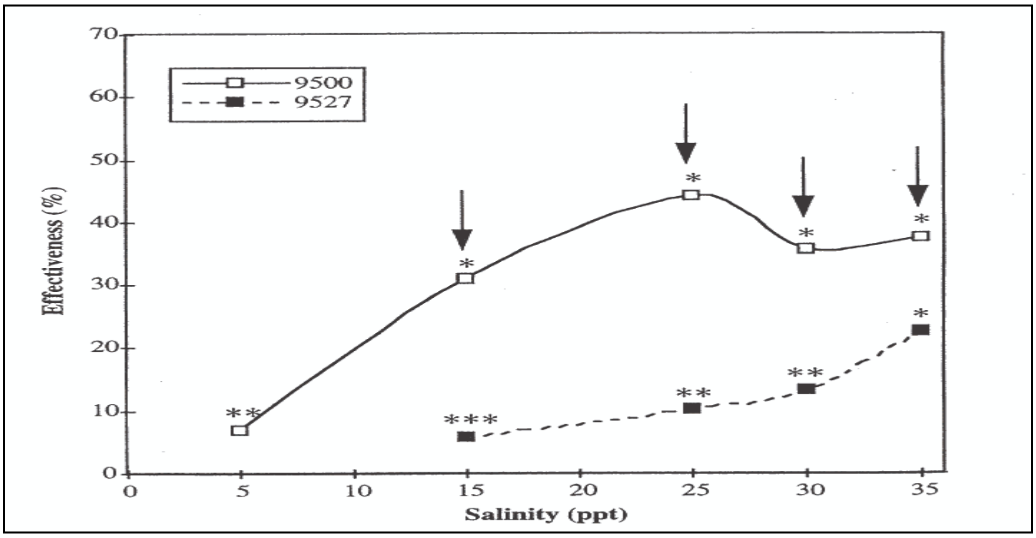

Fig 3.3 Mean effectiveness of Corexits 9527 and 9500 on Arabian light crude oil. Arrows denote salinities at which effectiveness of the two agents was significantly different. source:(Blondina et.al. 1999)

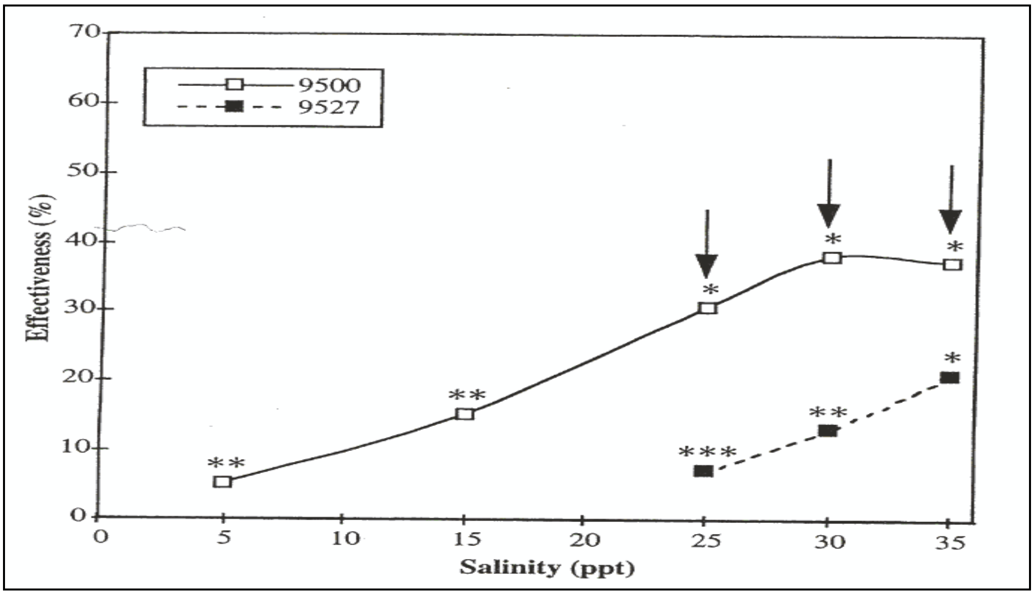

Fig. 3.4 Mean effectiveness of Corexits 9527 and 9500 on Kuwait crude oil. Arrows denote salinities at which effectiveness of the two agents was significantly different. source:(Blondina et.al. 1999).

The tests clearly show that performance of both dispersants was significantly affected by salinity. The best performance was at salinities above 25 ppt, mainly best at oceanic salinities (33-35 ppt) with sharp declines outside this range being recorded (Blondina, et al, 1999). It should be noted that this study also demonstrated that the interaction between receiving water salinity and the ability of dispersants to enhance petroleum accommodation into the water column could be both oil and dispersant specific. This implies that in the field, decision makers should consider the situation on a case-by-case basis.

d) Tests on temperature effects

The US EPA conducted a research as a part of developing a simulation model in which they used three test oils, South Louisiana Crude Oil (SLC), Prudhoe Bay Crude (PBC) and Number 2 Fuel oil. The dispersant used was Corexit 9500. The results clearly show that lower water temperatures increase the viscosity of both the oil and the dispersant and consequently increase the energy requirement for mixing the dispersant and oil. Higher water temperatures reduce oil viscosity and increase the solubility of dispersants in water (*Subhashini, et al, 2003)*. Table 3.4 shows the temperature related results of such a test.

Table 3.4 Corexit 9500 Effectiveness at different temperatures.

Oil (Weathering)	% Effectiveness at 5 °C	% Effectiveness at 22 °C	% Effectiveness at 35 °C
SLC (0%)	89.7	97.3	98.2
SLC (10%)	85.9	89.8	97.4
SLC (20%)	84.1	92.9	90.7
PBC (0%)	69.7	96.0	75.9
PBC (10%)	65.8	97.9	72.8
PBC (20%)	64.0	90.6	71.7
2FO (0%)	79.3	95.5	89.8
2FO (3.8%)	77.9	97.9	76.9
2FO (7.6%)	73.8	98.8	75.6

Source: (EPA 2003)

3.4.1.2 Open field experiments

To verify the results of laboratory studies field trials are essential. Even though faced with many legal, technical and logistical difficulties some countries like Norway, UK and the United States have succeeded in carrying out those vitally important field trials.

a) Dispersant field trials in Norway

These trials were carried out in the Norwegian sector of the North Sea in June 1994. In this field trial two oil slicks (2x20 m^3 of sture blend North Sea crude) were released. One slick (Tango) was treated with corexit 9500 after 3 and 7 hours weathering, while the second (Charlie) slick was left as a control. The dispersants were applied from a helicopter. The spraying was focused on the thick emulsified parts of the slick with a very low dispersant to emulsion dosage ratio (DER 1:300-1:700). The effect was a significant reduction in water content and viscosity of the emulsion after the first dose. Fig 3.5 presents the lifetime of the treated slick “Tango” compared to the control slick “Charlie”. The life time of the treated slick was not more than 13 hours and no trace was visible on the water surface after this (Daling, et al, 2002).

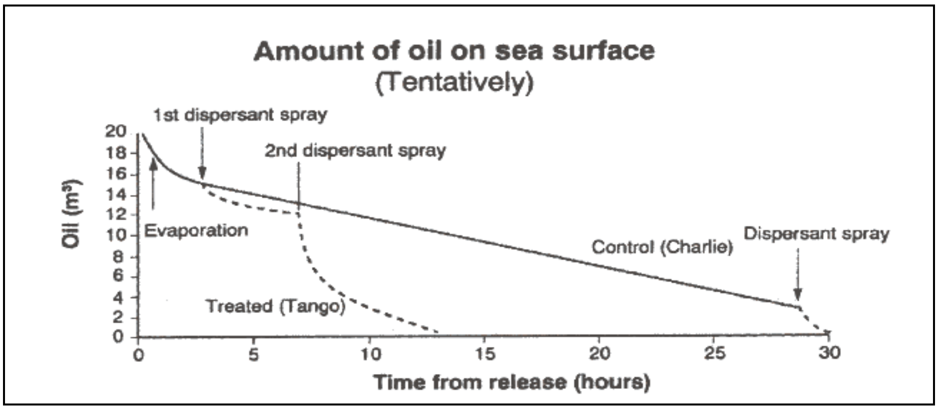

Fig 3.6 lifetime of surface oil slick, slick treated with dispersant (Tango) versus control slick (Charlie). Source: (Daling, et al, 2002)

b) Dispersant field trials in the UK

The trial was carried out in September 1993 in the UK sector of the North Sea. Two 20 ton slicks of medium fuel oil/gas oil mix (50:50 mix) were released; one of them was sprayed with Slickgone NS (Type III) dispersant by a fixed wing spray aircraft. The second slick was kept as a control. Another specialized remote sensing air craft equipped with SLAR (sideways looking airborne radar) and video, Ultra Violet (UV) and Infra Red (IR) cameras attended the operation for positioning and sensing.

Two tonnes of the dispersant was sprayed onto the slick with dispersant to oil ratio (DOR) 1:10 at 09:30 (1.5 hours after the release of the slick) during 10 spray runs along the length of the slick. The slick was monitored for 6 hours and another two tonnes was sprayed at 16:00 on the oil remaining on the surface of the treated slick. The first dispersant application showed initially an increased spreading of the surface slick, followed by a reduction in surface area after the second spraying. By monitoring the sub-surface oil concentrations it was observed that they were initially higher under the treated slick than under the un-treated slick. As dilution occurred over time it was observed that the maximum dispersed oil concentrations under the treated slick were no higher than under the untreated one (Lunel, 1995).

The results of such trials clearly give evidence to the decision makers of the dispersion ratio and the time span needed to disperse medium fuel oils. Also they show that in open sea and deep waters the increased total volume of oil dispersed into the sea is distributed over a larger volume of water and diluted over time without any significant concentrations resulting from the dispersion process. Refer to appendix 4 for an over view of the results of recent dispersant effectiveness measurements.

3.4.2 What about dispersants toxicity?

As this is the usual primary question asked by most stake holders, major field and laboratory experiments were carried out over the years to verify the effects of chemically dispersed oils on the human food chain and biological resources.

3.4.2.1 Dispersants Toxicity and long-term impacts

One well known long-term field testing program known as the TROPICS study which started in 1984 by treating sites containing mangroves, sea grasses and coral environments with either oil or chemically dispersed oil. The long term effects of different treatments were studied. This experiment was designed to allow examination of the possible trade offs between impacts on inter-tidal and sub-tidal tropical ecosystems .The site was studied for two years and revealed that the un-dispersed oil had major effects on the survival of mangroves and associated fauna, but relatively minor effects on the sea grass and the coral communities. Chemically dispersed oil caused declines in the majority of corals, sea urchins and other reef organisms, reduced coral growth in one species, and had minor or no effects on sea grasses and mangroves (Knap, et al, 1995.pp.262-270).

The site was revisited after 10 years in 1994. At the oil site (where un-dispersed oil was added), the additional mortality of mangrove tress was obvious, being only 17% at the end of short-term studies and reached 46% after 10 years. At the dispersed oil site the mangroves showed only sub-lethal effects[8]. For corals at the dispersed oil site long-term recovery has progressed as no significant differences between

[8] Sub-lethal effects were in the form of root deformations and less growth rates.

sites were observed. The site was recently visited twice in 2001 & 2002 to confirm the latest findings; the details have not been published to date. The findings of this study relating to the chemically dispersed site are summarized in tables 3.5 and 3.6.

Table 3.5 summaries of TROPICS parameters and findings

Year site sampled	Habitats Sampled and Tested		
	Corals and associated organisms	Mangroves and associated fauna	Sea grasses
1984-1986	Major effects Declines in growth rates	Minor effects	Minor effects
1996 (10 years after)	Sub-lethal effects Recovering rates of growth	Minor effects	Minor effects
2001-2002	Almost normal growth rates	Almost normal growth rates	Almost normal growth rates

Table 3.6 Survival of mangrove trees and seedlings in 18 years of the TROPICS study.

Parameter	Year	Site R #	Site R %	Site O #	Site O %	Site D #	Site D %
Live Trees	1984	108	100	149	100	72	100
Live Trees	1994	108	100	80	54	70	97
Live Trees	2001	85	78	86	58	60	83
Live Seedlings	1984	26	100	13	100	33	100
Live Seedlings	1994	21	81	89	685	19	58
Live Seedlings	2001	21	81	75	577	13	39

R=reference site O= Oiled site D=Dispersed oil site.

Source (Ward, et al, 2003)

To summarize the outcome of these studies, decision makers should closely consider the tradeoffs between dispersant use and non-use. It is obvious that efficient dispersant use saved mangroves from destruction and long-term effects due to an oil spill. However, chemically dispersed oil is harmful to corals and associated fauna in the short run especially in shallow waters (Ward, et al, 2003).

3.5 Chemical Dispersants and Biodegradation, do they match?

The addition of chemical dispersants has been proven to stimulate the microbial colonization and biodegradation of dispersed oil even at the low nutrient levels. This finding was the conclusion of a study on the dispersion and biodegradation of chemically- dispersed weathered Forties Crude Oil under simulated marine conditions in laboratory microcosms[9] using various types of dispersants (Corexit 9500 – Finasol OSR-51 – Enersperse 1583 – Dasic Slickone LTSW), (Swannell & Daniel, 1999). The experiment showed that all the dispersants tested promoted high levels of oil dispersion within the experimental vessels. There was also some evidence that this stimulation was not only due to an increased bioavailability (surface area) of the oil, but also due to the composition of the dispersant in terms of its ability to promote the growth of indigenous hydrocarbon-degrading micro-organisms. Moreover, Varadaraj et al. (1995) noted that sorbitan surfactants found in nearly all chemical dispersants actually supplied nutrients to the micro-organisms stimulating the whole process.

Decision makers should consider the latter results, which suggest that dispersant application may have the dual environmental benefit of promoting both oil dispersion and oil biodegradation. Should these findings be verified in the field it seems that this will correct some of the misperceptions of chemical dispersants worldwide.

3.6 When, How, and How much to spray?

The basic four methods for dispersant applications are pressurized backpacks, boats, helicopters and fixed wing airplanes. Each method has its appropriate time and place for use. Usually availability and cost are the prime factors that decision makers have to consider. Below is a discussion regarding the benefits and draw-backs of the different methods.

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[9] Laboratory microcosms are three glass vessels filled with seawater with sampling and air inlet ports simulating marine conditions.

3.6.1 Vessels or aircraft?

Dispersant application from vessels is considered outdated and inappropriate for certain spill situations. The main complaint about vessels is that they are too slow, both in reaching spills and in treating them. Ross, (1998) argues that this opinion is biased and invalid in view of current knowledge. The current view which could be proven with modern remote sensing equipment is that marine spills do not spread uniformly, they are composed of thick patches (more than 1mm) that contain most of the spill volume (90% of spill's volume is contained in 5 to 10% its area) and these thick patches are surrounded by sheens (about 0.001 to .01 mm).

Decision makers planning for aerial application often assume that oil spills are uniformly very thin and very large in area so the one-pass concept of the air craft is enough to do the job. This is lately changing to the multi-pass approach, which would be the only possible way of completely dosing the thick portions of marine spills. This could amount to ten to twenty more passes by the aircraft consuming more fuel and time for repositioning over the thicker areas of the slick. Here considering the use of vessels would be reasonable. Assuming a $1000m^3$ spill, the thick portions would be 0.4 Km^2 approximately. A vessel sweeping the slick at 10 knots speed and a spray swath of 25 meters and a dispersant pump capacity of 760 L/min can totally dose a 2-mm thick slick in one pass with the recommended dispersant to oil ratio (DOR) of 1:20 in an estimate of 50 minutes. This is nearly the same time needed by aircraft to treat the same spill (Ross et al., 2001 PP.1195-1201).

One of the most frequently asked questions in dispersant application is whether to apply it neat or diluted and does this really relate to its effectiveness? To answer this wide scale laboratory tests were completed by Belore and Ross, (1999) who evaluated the performance of two dispersants, Corexit 9527 and 9500, on Alaska North Slope (ANS) crude oil when applied neat and diluted with salt water. The results indicated that the performance of Corexit 9527 was not affected when diluted with water at a ratio of 1:10. On the other hand the performance of Corexit 9500 on ANS crude was significantly reduced when applied diluted with water. Fig. 3.6 shows the results from two sets of experiments, one in which the dispersant was first diluted then sprayed onto the test slick (premix case) while the other was injected into the main water flow. The results still proved a reduced effectiveness to Corexit 9500.

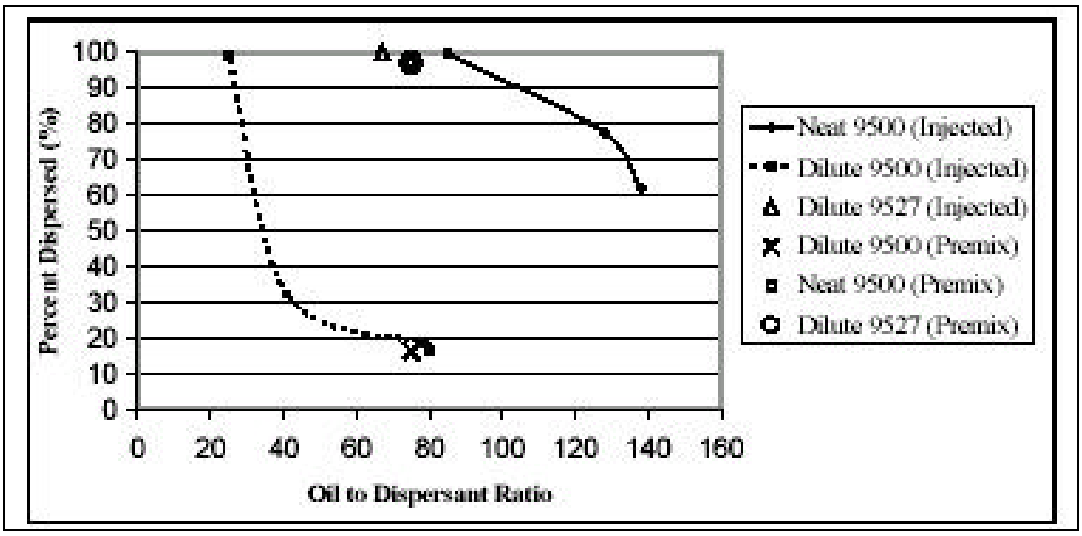


Fig.3.6 effects of dilution on dispersant effectiveness

Source (Ross et al., 2001)

This result clearly advises the decision makers to consider which types of dispersants they should use in relation to the application method. Many countries lack the existence of specialized spraying vessels or aircraft and instead use service tugs or supply vessels which usually utilize their fire and foam nozzles and diluting the dispersant may result in the failure of the whole operation.

3.7 Conclusion: To spray or not to spray?

"Are we going to add more chemicals to the environment?... we don't want to hide the problem we need to solve it…. ! No these dispersants are very toxic they will destroy all our fisheries industry ….. No we are not using dispersants again, we did that before and it didn't work."

These are some of the comments usually heard in the central operations room of a major spill incident, but the trend is changing and this is due to the following facts:

- Some oils are dispersable others are not (oil specific pattern of effectiveness).
- Fates of different types of oils differ, each should be investigated separately.
- The petroleum accommodation into the water column can be both oil and dispersant specific, which forces decision makers to consider each case separately.
- Cold water conditions significantly reduce the dispersant effectiveness as it increases the viscosity of both the oil and the dispersant.
- The possibility of the formation of lethal concentrations of dispersants in the water column is very remote in open waters.
- The dispersants would have negative impacts on corals initially but long-term recovery is possible while its impact on mangroves, associated fauna and sea grass is minimal.
- The biodegradation process is promoted by the introduction of dispersants.
- Neat and proper dispersion methods bring more success to the outcome of the dispersion process.

What if the final decision is not to use chemical dispersion? Or use in combination by all other available means. This is discussed in the next chapter.

Chapter Four

How to Contain? And can we Recover?

4.1 Introduction:

This chapter will try to focus on the means of improving oil containment and recovery in the marine environment, how to protect sensitive shorelines and the practical tools to enhance the quantity of recovered oil. It will also tackle the in- situ burning option, the use of sorbent materials and when they could be used.

4.2 Mechanical Equipment performance sheets. Do they tell us the truth?

The Mechanical response to oil spills has always had its limitations; the recovery equipment recording, at best, 30% of the initially spilled oil. However, after the *Erika* spill in December 1999, off the coast of Brittany, France, where about 10,000 m^3 of heavy fuel oil spilled into the ocean, less than 5% was recovered at sea before the oil reached the coast (Hvidbok, 2001, pp. 577-584).

Decision makers tend to go for politically attractive “performance sheets” of mechanical containment and recovery equipment. For example “Heavy duty Booms” which can be extremely large reaching up to three meters, which incorporates all sorts of problems for transport, deployment and towing? Another example could be “Recovery capacity of the skimmer (250 m^3/h)”, but for which type of spilled oil? Which viscosity? Can this happen in all weather conditions? Similar equipment has found its way to the inventories of many response organizations. The need to review the performance limitations of mechanical equipment remains pending and the work is still in progress.

4.3 Performance of Oil Containment Booms

There is no doubt that the handling and deployment of booms are still far from satisfactory. Their effectiveness is still considered very limited, even in normal ocean environments. The main problem areas are largely in the fast flowing waters[10] represented by entrainment of oil, drainage failures and planning of booms resulting in the potential failure of the containment, Protection or diversion operation. For these reasons a large number of tests and research papers have been conducted from 1975 to 1999 resulting in substantial amounts of literature. About 30 papers were reviewed and summarized lately by Schulze & Lane (2001) in an attempt to provide data predictive of boom performance for spill decision makers.

4.3.1 Main problem areas of boom performance:

a) Entrainment and Drainage of oil

The first signs of oil escape can be usually noticed when oil droplets starts surfacing on the water at the backside of the boom. The typical movements of the oil droplets separated from the oil layer are shown in fig.4.1. The droplet, “a” which is larger in size and higher in buoyancy, tends to float and reattaches itself to the oil layer above. Droplet “b” will be carried downstream and passing below the skirt of the boom. Droplet “c” is carried towards the boom, undergoes a circulatory motion for a while and eventually escapes beneath the boom. Such a leakage behavior is called entrainment failure. When this stream increases the entrainment will turn to a continuous drainage resulting in the loss of large amounts of contained oil (Lee & Kang, 1997).

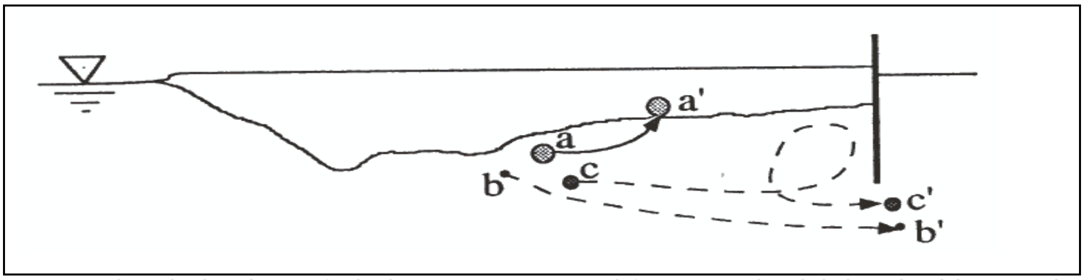


Fig. 4.1 typical behaviors of oil droplets separated from an oil slick blocked by an oil boom. Source: (Lee & Kang, 1997).

[10] Any water mass velocity in excess of 1 knot is considered fast flowing water for boom performance testing.

The question is when is this downstream formed and why? This stream is mainly because of the movement of water mass either by the currents and tidal streams or by the reverse current resulting from towing the boom in the water.

b) Splash over

This usually occurs in high seas when the waves are higher than the boom's freeboard so the contained oil on one side of the boom is able to splash to the other side as shown in fig.4.2

c) Submergence failure

This is one of the common failures and it occurs when water goes over some types of booms which are not buoyant and flexible enough to follow the wave motion so some of the boom length could occasionally sink and oil passes over it as shown in fig.4.2

d) Critical accumulation

This failure usually occurs with heavier oils, which tend to accumulate close to the leading edge of the boom and are swept underneath with the increase of current velocity as shown in fig. 4.2

e) Planning

Is a sign of mishandling or miss positioning. It occurs when the boom moves from the vertical to almost a horizontal plan allowing the oil to pass over or under it as shown in fig.4.2. This usually occurs if the boom is towed creating reverse currents in excess of the recommended velocities.

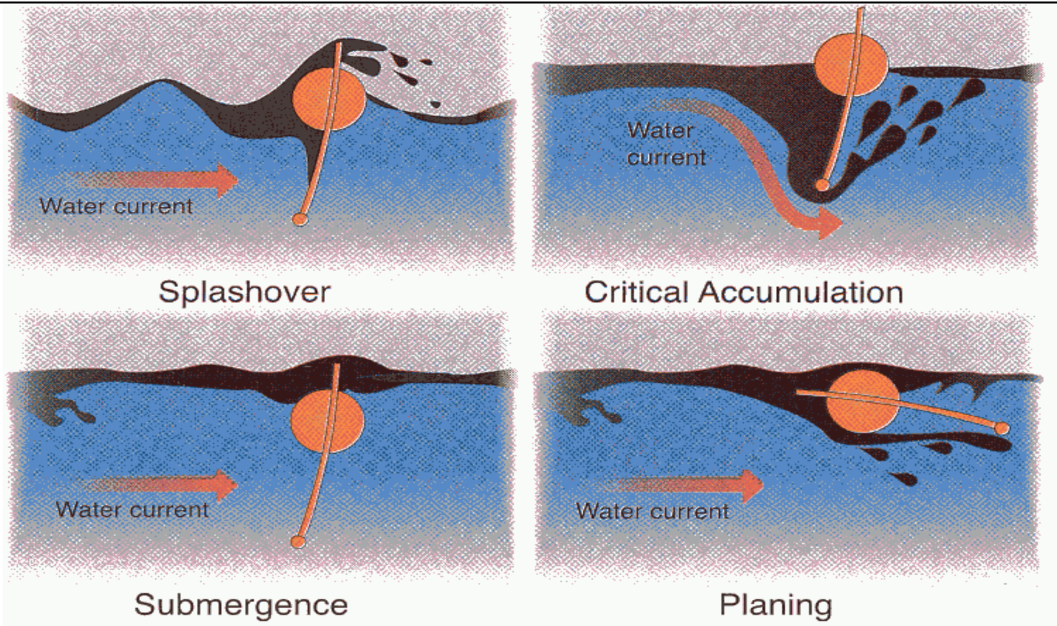


Fig.4.2 Boom failure modes. Source: (Fingas, 2001)

4.3.2 Uses of Booms

One of the key solutions for overcoming these failures is that the decision makers should change the conventional thought that Booms are only used to contain the oil slick in open waters. The Other alternative uses have proved to be more successful with less failure rates, namely:

a) Deflection booming

This is better used where the currents are likely to exceed 1 knot. The boom should be carefully deployed at a certain angle to the current according to the current's speed as recommended in table 4.1. Placing the boom at the wrong angle for the current speed and improper anchoring causes the boom to sag and a pocket forms. The pocket orients perpendicular to the flow at the point of highest current speeds, and usually results in boom failure (see fig. 4.3).

Table 4.1 Boom angles and critical current velocities.

Angle (degrees)	Velocity of Perpendicular Current Before Critical Velocity is Reached*
90	0.5
75	0.5
60	0.6
45	0.7
35	0.9
15	1.9

Source: Fingas 2001

Currents & Angles

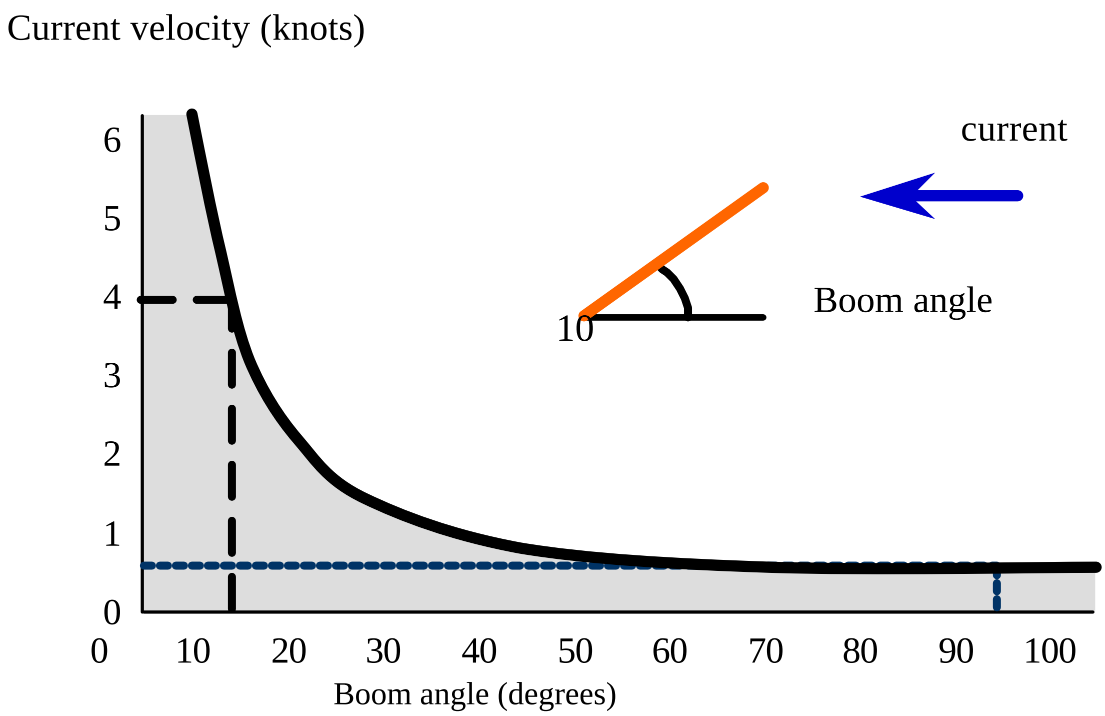


Fig. 4.3 currents and recommended boom angles.

b) Exclusion booming

Exclusion booming is effective only where the currents are relatively weak; otherwise entrainment under the boom is likely. Even so, deflection booming can be added as a backup in come cases. Multiple booms should be used to ensure effectiveness. It is imperative that the boom is well sealed to the shoreline to prevent leakage. Figure 4.4 shows examples of deflection and exclusion booming.

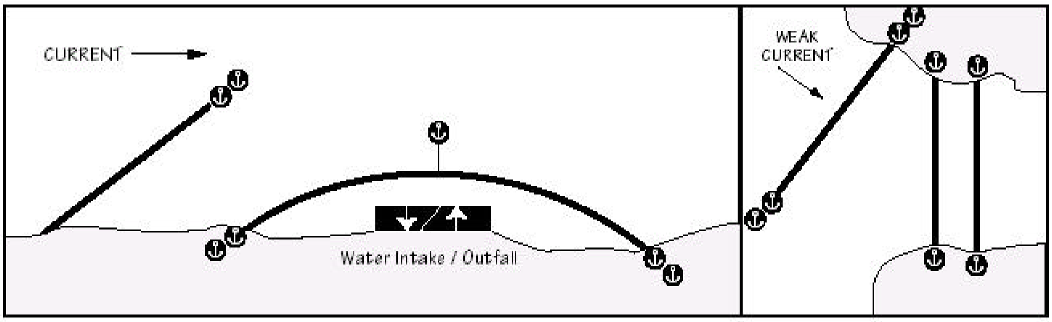


Fig. 4.4 Examples of deflection and exclusion booming configurations

Source: Michel et al. 1994

c) Cascading pattern

If the existence of strong currents prevents the proper positioning of the booms, several booms can be deployed in a cascading pattern towards areas of weaker currents for enhanced recovery as shown in fig 4.5. In this type of configuration decision-makers should prepare for the following:

- There must be adequate overlap between boom sections so more length of boom sections will be required.
- The booms may need securing with multiple anchors to guard against strong currents.
- Sites for collection along the shore must have access for personnel and equipment.

- Anchoring points, collection sites, and boom configuration will change with shifts in tidal current and wind directions, and so must be regularly tended (Michel et al.1994)

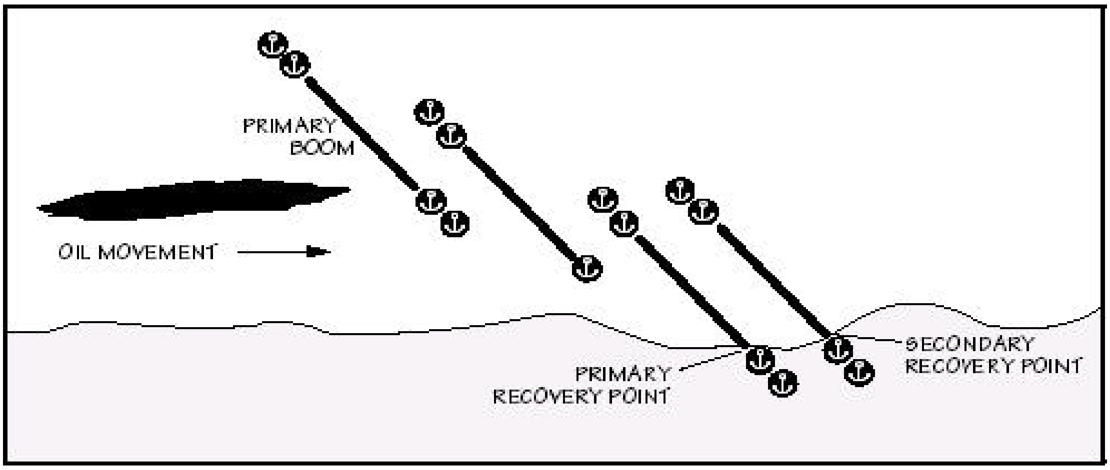


Fig.4.5 Cascade to collection points. Source: Michel et al. 1994

4.3.3 Improving boom performance

Knowing the limitations in boom performance, the key elements in avoidance of boom failure is choosing the right type of boom, in the right configuration and always considering the state of the sea and currents in the deployment area. The analysis of the previously mentioned 31 tests also supports the decision makers by high lighting that the factors contributing to better performance are either dynamic or physical.

The dynamic factors relate to the towing speed or the currents affecting the stationary booms. They reveal that:

- Booms can be towed in the catenary[11] mode in calm water up to 0.9 knots without losing oil. This performance is reduced to 0.7 knots in short regular waves or harbour breaking waves.

[11] Catenary mode refers to towing by two boats in a U or J configuration.

- In the diversionary mode and Vee sweep, towing speeds can be up to 1.2 knots and in some cases 2 or 3 knots without oil loss (Schulze & Lane, 2001 pp.285-293).

The most important physical factors that affect boom performance appear to be the following:

- The buoyancy to weight ratio or reserve buoyancy. This means that the float must balance the weight of the boom with the force exerted by currents and waves. The higher this reserve buoyancy the better the ability of the boom to rise and fall with the waves and remain on the surface of the water.
- The heave response, which is the boom's ability to follow the wave patterns. It is indicated by both the reserve buoyancy and the flexibility of the material of the boom structure. A boom with a good heave response will move with the waves on the water surface and not submerge alternately and thrust out of the water due to wave action.
- The roll response, which is the booms ability to remain upright with the least roll over movements. This is related directly to the design of the boom's tension member[12] (Fingas, 2001.pp.73-83).

4.4 Oil Skimmers: How effective are they?

Recovering oil on the water is mainly done with skimmers. It would appear to be an easy task to recover floating oil; in fact it is one of the most difficult operations to perform. It is true that effective recovery leaves less oil to be deposited on the shoreline but the task usually faces many obstacles, one of which is that skimming oil off the water surface frequently collects large amounts of water, which increases the volume of the waste to handle and dispose. Another obstacle which was clearly demonstrated in past oil spill experiences (Exxon Valdez, New Carrisa, Erika) is the

[12] Tension member is usually a galvanized chain or wire attached to the bottom of the boom to withhold the tension forces exerted on the boom in operation. It also acts as a ballast weight helping in keeping the boom floating upright at all times.

lack of ability to handle high viscosity oil. Failing to be able to transfer high viscosity recovered oil may be due to a limited understanding of the recovered oil viscosity influence on the pressure losses in the transfer system. This brings us back to the decision-maker's perception of the skimmer capacity and the efficiency of their performance.

4.4.1 Skimmer selection: one step ahead

Skimmers are classified in five different categories: weir, suction, centrifugal, submersion, and sorbent or oleophilic[13] skimmers. Key factors in selecting appropriate skimmers are the amount of debris present, the viscosity of the oil, the water depth and most important of all are the weather and sea conditions at the time of potential use (IMO, 1988).

4.4.2 Which skimmer? At what time? In which kind of oil?

a) Weir Skimmers

Weir skimmers with built-in transfer pumps for high viscosity oils are probably the most widely used skimmers for open sea skimming. They are based simply on gravity to drain the oil from the surface of the water to the weir well and to the holding tank. But what happens when they are actually deployed to recover oil?

- Responders tend to push or even shovel oil sludge into the hopper causing the pump to clog if it encounters any tar balls or debris.
- In swell and waves this skimmer tends to rock back and forth sucking air above the slick and water below which increases the amount of water, resulting in the rapid filling of the holding tank.

[13] Oleophilic materials are having greater affinity to oil than to water.

- Weir skimmers start losing efficiency when the viscosity of oil exceeds 30,000-40,000 cSt. It becomes almost impossible for the oil to pass the weir lip and flow to the hopper. Therefore other types of skimmers or recovery equipment should be used if the viscosity reaches these levels.

b) Suction or vacuum skimmers

This skimmer is only a suction head connected to an external source of a vacuum, such as a vacuum truck. It also tends to be susceptible to the same problems as weir skimmers, but despite this its compactness and shallow draft allows it to operate efficiently in shallow waters and confined areas.

c) Mechanical feeder skimmers

Mechanical feeding could be achieved by various means such as:

1. A set of ropes, bristles or brushes, gravity / scrapper feeding to a pump or a tank.
2. Various open or closed structure inclined belt types that convey the oil to a scraper, which gravity feeds into a tank or a pump.
3. Rotating a stretch metal net drum “snail shell” feeding by the concentrating geometry of the stretch into an oil trap, which, feeds into a pump.
4. Twin counter rotating drums with positive guides that lift and pressure-scraper feed the oil into a trap, which feeds a pump.
5. Conveyor belt with flap cups which gravity dumps into a tank or pump(fig 4.6)
6. Rotating discs with corrugated or rough teeth at the perimeter of the discs, gravity/scrapper feeding to a pump.

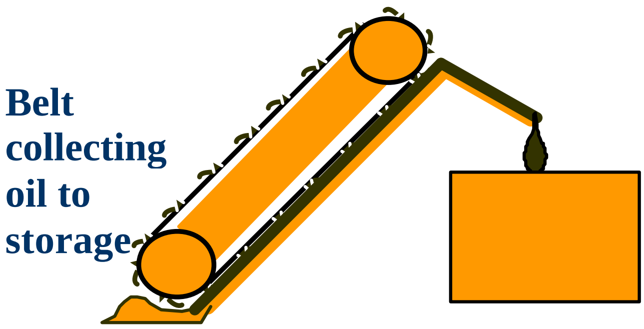


Fig. 4.6 mechanical belt skimmer

The above listed types were the best in performance in the field for highly viscous oils. Their ability to recover is based on combinations of adhering, grabbing, trapping and squeezing dependant on the type of oil being collected. They also are not sensitive to debris and in most cases recover minimal amounts of water even in choppy weather conditions. Decision makers should focus on one vital factor, which is the transfer pump's performance and its ability to pump the recovered oil and debris to storage. This may require the pumps discharge to be equipped with an additional lubricating system or a complete viscous oil pumping system (VOPS[14]), which greatly enhances the skimmer performance (Hvidbak, 2001).

D) Oleophilic Surface Skimmers

These types usually use an oleophilic surface to which oil can adhere. This surface may take the form of a disc, drum, belt, brush, or rope (see fig 4.7). The surface itself could be steel, aluminum, fabric or plastics such as polypropylene or polyvinyl chloride.

[14] This equipment consists of a water injection flange with a water injection pump, hydraulic hoses, fittings, hard pipe with pressure gauge and 400 meters of hydro tested six inch oil transfer hose.

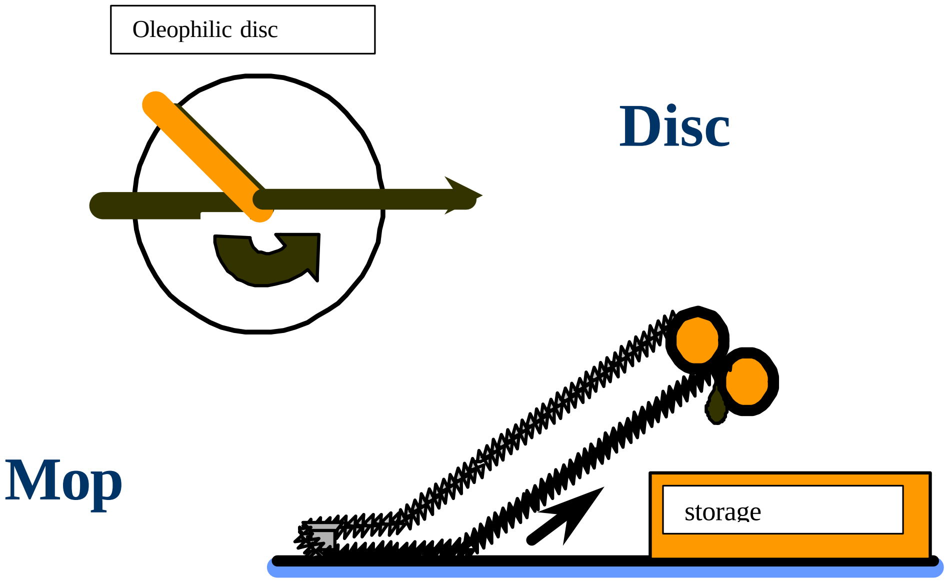


Fig.4.7 Oleophilic Rope Skimmer (Mop skimmer) & Disc Skimmer

These skimmers have high oil to water recovery ratio hence they work best with light crude oils and are well suited to working in waves and among weeds and debris. A summary of the operating range of various types of skimmers in relation to oil viscosity is shown in fig 4. 7.

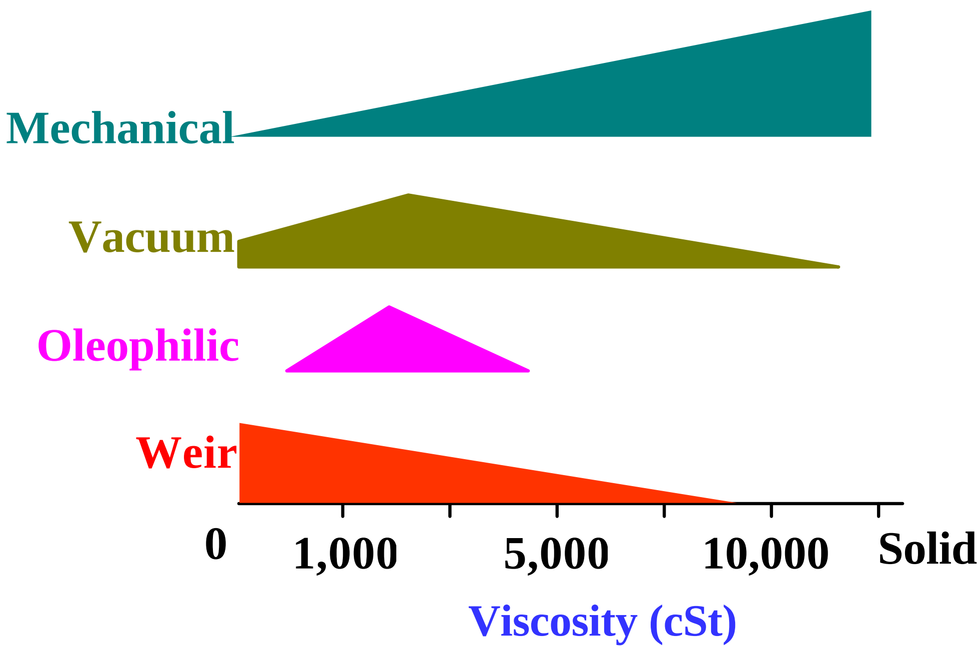


Fig.4. 7 Operating Range of Skimmer types

4.5. In Situ- Burning (ISB): when will it work?

Successful In- situ burning can remove oil from the water surface very efficiently and at very high rates in ideal conditions. Removal efficiency of thick slicks can easily exceed 90%. Removal rates of 2000 m^3/h can be achieved with a fire area of only about 100 m in diameter. The use of a towed fire containment boom to capture, thicken and isolate a portion of a spill, followed by ignition is in most cases less difficult than the operations involved in mechanical recovery, storage, treatment and disposal (Buist, 1999. pp. 21-28). However the success of ISB has a limited window of opportunity defined by two sets of factors relating to the characteristics of the oil, and the environmental conditions.

a) Thickness of the slick

The concentrating and thickening of the slick is vital during the ISB operation. The thickness of the oil must be maintained to avoid a heat sink effect that transfers the heat from the oil layer to the water and extinguishes the fire. Minimum thicknesses include two to three millimeters for fresh crude oil, three to five millimeters for diesel and weathered crude, and five to ten millimeters for emulsions and bunker C.

b) Flash point of the spilled oil

The flash point is the lowest temperature at which ignitable vapors are formed which is capable of flaring up from an outside ignition source. Highly volatile oils, such as gasoline products with flash points near 40^0C, evaporate quickly which lessens the chances for a successful ISB as the slick ages. Heavy crude oils and residual products are only slightly volatile, with flash points greater than 65^0C and thus once ignited and flames start spreading will stand a better chance for a successful operation (Yoshioka et al. 1999 pp.2-19).

c) Emulsification formation

Emulsification of an oil spill negatively affects *in situ* ignition and burning. This is because of the water in the emulsion. Stable emulsion water contents are typically in the 60% to 80% range with some up to 90%. The oil in the emulsion cannot reach a temperature higher than 100 °C until the water is either boiled off or removed. This results in the significant decline in the burn rates of the slick which is summarized in the following:

- little effect on oil removal efficiency (i.e., residue thickness) for low water contents up to about 12.5% by volume;
- a noticeable decrease in burn efficiency with water contents above 12.5%, the decrease being more pronounced with weathered oils; and
- Zero burn efficiency for stable emulsion slicks having water contents of 25% or more.

Recent research carried out in US, UK and Norway on the addition of chemical emulsion breakers on the emulsified slicks to extend the window of opportunity of ISB prior to ignition shows great promise (Thornbourg, 1997.pp131-136 and Guenette et al.1995.pp 115-123). It resulted in a strong evidence that the technique is highly oil specific and surfactant dependant. Another recently completed study of emulsion burning with Alaskan oils is summarized below (see table 4.1) to illustrate the potential for chemical treatment to extend the window of opportunity for *in situ* burning and the challenges remaining. Four oils were selected for an initial set of laboratory test burns (40 cm diameter) and the mid-scale (1.7 m diameter) burn tests. They were also subjected to various weathering conditions in conjunction with the ISB process in an attempt to simulate field conditions.

Table 4.2 Efficacy of emulsion breaker addition summary

Oil Type	Maximum Ignitable (% weathered/% water)	Maximum Ignitable with Emulsion Breaker Added (% weathered/% water)
Drift River crude	35.4% evap. / 25% H_2O	35.4% evap. / 60% H_2O
Endicott crude	fresh / 25% H_2O	9.1% evap. / 60% H_2O
Pt. McIntyre crude	fresh / 25% H_2O	fresh / 40% H_2O 18.2% evap. / 25% H_2O
IF-30 fuel oil	fresh / 25% H_2O	fresh / 40% H_2O
Milne Pt. crude - lab scale - mid scale	 40.7% evap. / 60% H_2O 27.6% evap. / 60% H_2O	 40.7% evap. / 60% H_2O 27.6% evap. / 60% H_2O
ANS crude - lab scale* - mid scale	 28% evap. / 25% H_2O 20.4% evap. / 25% H_2O	 28% evap. / 60% H_2O 20.4% evap. / 60% H_2O

Source: (Buist, 1999. pp.21-28)

It is clear from Table 4.2 that the efficacy of emulsion breaker addition in extending the limits of ignition and efficient burning appears to be oil related. Its use extends the limits for some oils but only had marginal effect on others. It is equally clear that some initially non-ignitable emulsions, due to their high water content are successfully ignited and burned easily. It is important to note that in one of the lab-scale burns, manually mixing the emulsion breaker chemical was found to be somewhat more effective than the natural mixing of the emulsion breaker with wave action alone. This indicates that the mixing energy supplied either manually or by the waves was necessary for the chemical to work (Buist, 1999).

d) Location of the spill

Each location can affect the feasibility of ISB in different ways. An offshore spill may pose minimum health and safety concerns, but would require containment of the slick and generally would involve more severe wind and wave conditions. Near shore wind and wave conditions may be more favorable than offshore conditions, but burning may be less suitable because of nearby populated areas. Many governments have delineated zones where burning is pre-authorized; these formalities will also affect the possible timeliness of an ISB operation.

The results from other laboratory investigations where 17 different types of crude oils were studied are shown in table 4.3. the oils were categorized according to their API gravity.

Table 4.3 summary of burn results by group.

Range of API Gravities	Emulsifies? (stability)	Unaided limit to ignition (% H_2O)	Breaker aids burning?
≥38°	When weathered or highly weathered (unstable)	No limit	Not needed
33° to 35°	Some when fresh; all when weathered (stable when weathered)	Fresh: 60% Weathered: 25%	Yes
23° to 30°	Some when fresh; all when weathered (most are stable)	Fresh: 0 to 60% Weathered: 0 to 25%	Sometimes
≤21°	When fresh (stable)	Fresh: 0% Weathered: 0%	No

Source: (McCourt et al.2001)

The oils in the first group, with API gravities = 38° were found to be very good candidates for ISB. They only formed unstable emulsions after extensive weathering processes, thus no emulsion breakers were needed. Ignition was possible even at high degrees of evaporation and emulsification. In the second group (API between 33-35), which is slightly heavier, the weathering took place for a day or two before stable emulsions were formed. These emulsions still ignited well after adding emulsion breakers.

The third group (API between 23-30) behaved erratically; some oils exhibited a high tendency to form stable emulsions but responded to breakers while others did not.

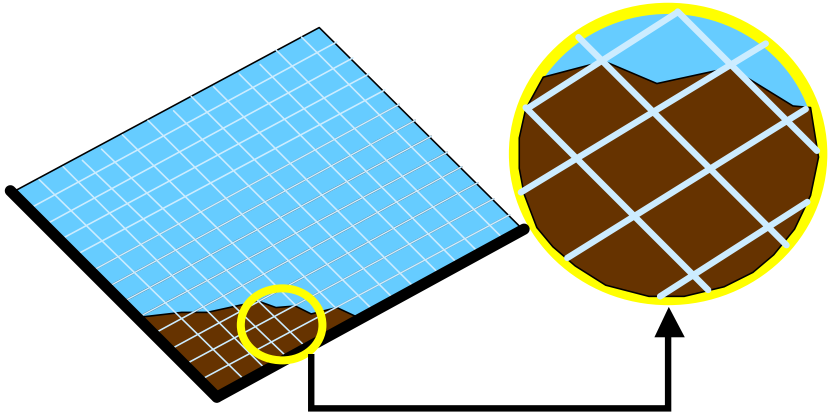
The oils in the final group, with API gravities = 21°, were the heaviest tested. They all proved to be poor candidates for ISB as they formed very stable unbreakable emulsions, even when they were fresh. No recommended further testing is to be done to those types (McCourt et al.2001 pp.529-532).

4.6 Oil Sorbents. How much can they absorb? Are they safe?

During many oil spills Sorbents are often used in the clean-up process as a first line of defense, the questions raised are: which type of Sorbent materials are they? Of what origin? Are there any Ecotoxicology tests carried out on such types? How much can they absorb? How are they going to be handled after getting soaked with oil? Where are they going to be disposed of?

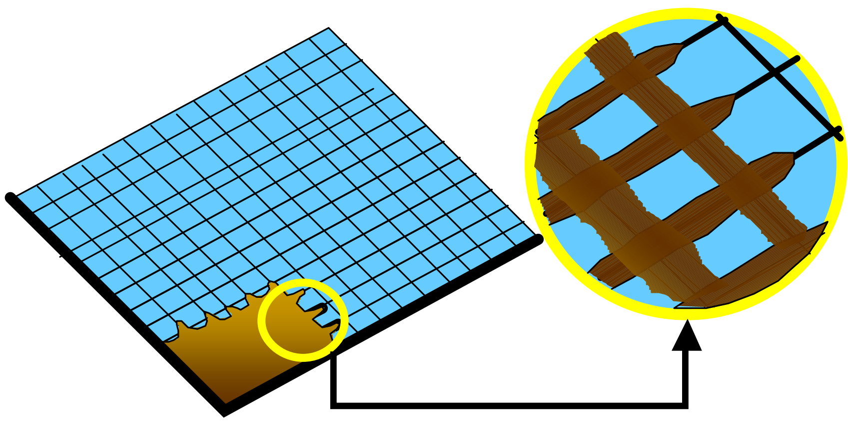
Sorbent means essentially inert and insoluble materials that are used to remove oil from water through adsorption, in which the oil is attracted to the Sorbent surface and then adheres to it (see fig. 4.9 a) or by absorption, in which the oil penetrates the pores of Sorbent material (see fig.4.9 b) or a combination of two. Sorbents are generally manufactured in particulate form for spreading over an oil slick or as sheets, rolls, pillows or booms. Sorbents are generally not listed among hazardous substances in many countries. However, Sorbents containing chemical or biological components, especially when made in lose form, may pose an ecological threat. Decision makers should consider the massive change in sorbent material weight after use. Moreover the oil retention capacity of absorbent versus adsorbent materials must be also considered to be prepared for the appropriate means of waste disposal.

Care should also be taken from leaving sorbent materials in temporary storage sites for long periods of time. This could cause the breakup of the containing material resulting in the spread of the particulate which may have toxic effects on some habitats in the surrounding environment.



Oil Adheres to the surface fibers

Fig.4.9 a . Adsorbent Material



Oil absorbed into the material

FIG.4.9 b Absorbent material.

some examples of sorbent materials that are mainly from organic origin (peat moss, bird feathers). Sorbent materials of mineral origin are for example volcanic ash and vermiculite. These materials do not pose high contamination threats. However caution should be taken when using Sorbent materials containing nonindegenous microbes, chemical solidifiers and synthetics such as polypropylene and polyester (*Nichols,* 2001 pp.1479-1843). The oil retention capacities of various Sorbent materials are summarized in table 4.4.

Table 4.4 Retention capacities of Sorbent materials

Oil retention capacities

Sorbent	Diesel	Crude Oil	HFO
Natural			
Natural Peat Moss	5	8	7
Straw	4	4	2
Saw Dust	3	4	3
Mineral			
Perlite / Vermiculite	5	4	3
Synthetic			
Polyurethane Foam	73	73	49
Polyethylene Wool	37	24	16
Polyethylene Sheets	19	15	11

Grams Oil per Gram Sorbent

Source: Environment Canada

4.7 Conclusion

By reviewing this chapter, it is clear that decision makers have some vital points to consider, have some actions to take and other actions they should refrain from doing. These are:

- Do not take the literature about performance rates of mechanical equipment for granted unless they investigate how they perform under actual working conditions in the field.
- They have to keep in mind that entrainment of oil under booms may occur at very low current or towing speeds (as low as 0.7 knots) in order to prepare for alternative deployment patterns which might need the extra length of boom sections to achieve a more successful operation.
- They must consider that booms once deployed at sea, should be tended at all times, especially when the tide and winds are changing.
- When deploying booms out in the open sea, decision makers usually choose the rigid stiff types of booms thinking they are the best for adverse weather conditions. This disregards the vital buoyancy to weight ration factor and is likely to result in the partial failure of the operation.
- During skimming operations, decision makers should not only know the viscosity of the spilled oil but also the emulsion's viscosity as the time lapses in order to prepare and deploy the type(s) of skimmer and associated pumping systems capable of handling such viscous oils.
- If an ISB decision is taken, spill mangers should instruct the crew on site (OSC) to focus on concentrating the slick with fire booms for a successful ignition and burning operation with the least residues.
- The growing promising signs of effectiveness of the addition of emulsion breakers in case the ISB equipment and crew cannot reach the site in the early stages of the spill should be considered by the decision makers.
- Decision makers should also bear in mind that a considerable amount of energy would be needed to fully mix such emulsion breakers with the slick

(by wave action or manually) to gain better ignition and a continued burning process.

- If sorbent materials are to be used their type and origin must be known. The location of use must also be considered as some types pose imminent ecological threats. In addition sorbents usually result in a massive amounts of bulky waste which needs to be disposed of.

The Decision makers, by knowing those technical limitations of various combating methods, can be prepared for the introduction of a decision supporting tool integrating all the input data to better handle the crisis. This tool can NOT be utilized effectively if there are misperceptions or a lack of knowledge about the limitations of technical oil spill countermeasures. This decision-making supporting tool in the context of a complete crisis management system will be discussed in the following chapter.

Chapter Five
The Decision Making Process

5.1 Introduction

This chapter discusses the process of formulating a sound decision. What are the prerequisites needed? What information could be offered to decision makers during a spill crisis? In what form is the information offered? Can the flow of information be integrated in a user-friendly software package? Can decision makers handle the complex flow of data and benefit from it?

5.2 What should be already on the table?

Most countries have already developed their own National Oil Spill Contingency Plans. However, in many cases such contingency plans are not updated and integrated with the available response capabilities. Frequently these plans fail to incorporate the most likely scenarios into the crisis management components. As an example the environmental risks for oil spill response are frequently not assessed. Furthermore a balanced, readable, and real-time risk communication to support decision-making is frequently lacking. Obviously there is a need for a scientifically based decision making tool which identifies and defines the windows of opportunity and effectiveness of different response methods and technologies (equipment) for specific oils under given environmental conditions considering a multitude of changing factors including, for example, the weathering of oil following the spill.

This scientifically based tool should be able to integrate oil spill trajectory models with environmental risk assessment with the Windows concept all together and provide policy decision makers with recommendations for how and when response methods should be used (Ornitz & Champ, 2002. pp.279-288). In order to build such tools the blocks needed to complete the full construction will be developed and collected from various sources:

- Existing National Oil Spill Contingency Plans (NOSCPs)
- Environmental Risk Assessment (ERA) analysis data

- Net Environmental Benefit Analysis data (NEBA)
- Historical meteorological data (prevailing winds and currents)
- Local tidal patterns and weather forecasts for input to trajectory models
- Data about weathering rates of different oils and the resulting changes in physical properties
- Available combating equipment and technologies
- Location of stockpiles of different types of equipment and material of relevance for successful combating
- Estimated timing for deployment of equipment at different sites
- Remote sensing facilities available
- Oil weathering model (prediction of changes in oil properties for oils commonly transported in the area)

From the list above it is obvious that this database needs to be dynamic and require constant updating. In addition, decision makers should keep themselves knowledgeable in most of its vital elements to be able to use it as an effective tool in spill response. One approach could be that they can actively contribute in carrying out the risk assessments and quantifying environmental benefits for their own countries along with the specialized risk assessors. This will give them better perception of risk and a wider understanding of the influence of how environmental conditions and changing physical conditions affect biological and socio-economic resources (Petersen, 1996, pp. 223-245). In the following sections more light will be shed on the main elements of these scientific tools and how decision makers could contribute actively in building up the database required.

5.3 Ecological Risk Assessment (ERA): The Role of Decision-Makers

ERA is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. The process is used is mainly used to evaluate and organize data, information, assumptions and uncertainties in order to help understand and predict the relationships between stressors and ecological effects in away that is useful for environmental decision making (US. EPA, 1998 PP. 17-28). This assessment process(s) may involve chemical, physical or biological parameters as discussed in earlier chapters of this paper. One or more parameter could be considered at the same time. The process is usually conducted in three phases: problem formulation, analysis, and risk characterization. The question here would be what is the role of decision makers in such a process?

The first step is to build up a team composed of both decision makers and risk assessors to provide the necessary breadth of expertise. The decision makers charged with protecting the environment can identify information they need to develop their decision while risk assessors can ensure that science is effectively used to address ecological concerns, and together they can evaluate the assessment and address identified problems. As the assessment process approaches its end point some vital questions have to be exchanged between decision makers and risk assessors.

Questions principally for risk assessors to ask decision makers are:
• Are the risks sufficiently well defined to support a risk management decision?
• Was the right problem analyzed?
• Was the problem adequately characterized?
(Adapted from U.S EPA, 1993 & Barnthouse and Brown, 1994)

Questions principally for decision makers to ask risk assessors:

• What effects might occur?
• How adverse are the effects?
• How likely is it that effects will occur?
• When and where do the effects occur?
• How confident are you in the conclusions of the risk assessment?
• What are the critical data gaps, and will information be available in the near future to fill these gaps?
• How could monitoring help evaluate the results of the risk management decision?
(Adapted from U.S EPA, 1993 and Barnthouse and Brown, 1994)

Decision makers contributing actively in ERA would be able to tightly couple the results reached to the contingency measures. Until recently the identification of high risk has not lead to major changes in preparedness concepts or adjustment of activity plans. Lately, however, contingency plans have been refined and redesigned, and the preparedness systems have been focused towards periods or geographic areas with increased risk, and priority resources. ERA thus forms the decision basis and provides the documentation for allocation of contingency efforts (Jodestol et al. 2001. pp.155-165).

The wide use and important advantages of ecological risk assessments do not mean they are the sole determinants of management decisions. Decision makers facing legal mandates and political, social and economic considerations may lead them to make decisions that are more or less protective. Reducing risk to the lowest level may be too expensive or not technically feasible. Thus, if ERA is complemented by another methodology that can accommodate those considerations we can get one more step closer to a sound decision.

5.4 Net Environmental Benefit Analysis (NEBA)

The ideal complimentary methodology to ERA would be the Net Environmental Benefit Analysis (NEBA). NEBA is increasingly used as a framework to assess the environmental benefits and disadvantages of a chosen response action. This analysis can be used to account for political and economic impacts as well as the effects on the natural environment (Lunel & Baker, 1999). If it is meant to be used after oil is stranded on the shore line the net environmental benefits would be the gains in environmental services or other ecological properties attained by remediation or ecological restoration[15], minus the environmental injuries caused by those actions (Efroymson, et al 2003).

[15] Restoration, as defined here, refers to actions that directly improve ecological services or other ecological properties. Ecological restoration encompasses restoration, rehabilitation, replacement or acquisition of the equivalent.

The elements (framework) of an effective NEBA as described by Baker (1999) includes but is not limited to: (see fig.5.1)

- Collection of information on ecology, physical characteristics and human use of environmental resources. (planning stage)
- Review of spill case studies that are relevant to the combating or remediation method being assessed.
- Prediction of likely environmental outcomes.
- Comparison of advantages and disadvantages of remediation and natural attenuation. (characterization of reference state)
- Balancing the advantages and disadvantages to proposed alternatives to arrive at a decision on the optimum combating or clean up response.

In this last point the contribution of decision makers is inevitable. The reason is that NEBA is a lengthy process, it takes time, which may be available if the oil has already impacted the shoreline, but definitely not available for typical coastal slicks scenarios (e.g. a slick moving over shallow water towards a tourist resort area or a mangrove swamp). In this case it is important to use NEBA as far as possible during the contingency planning process, before a spill occurs. The actions in every oil spill scenario will have to be re-evaluated, or adapted to the time of the spill, taking into consideration real time conditions. Now we can imagine what will happen if decision makers find themselves in the middle of the crisis having to adapt a plan or consider alternatives they never contributed in planning for in the first place!

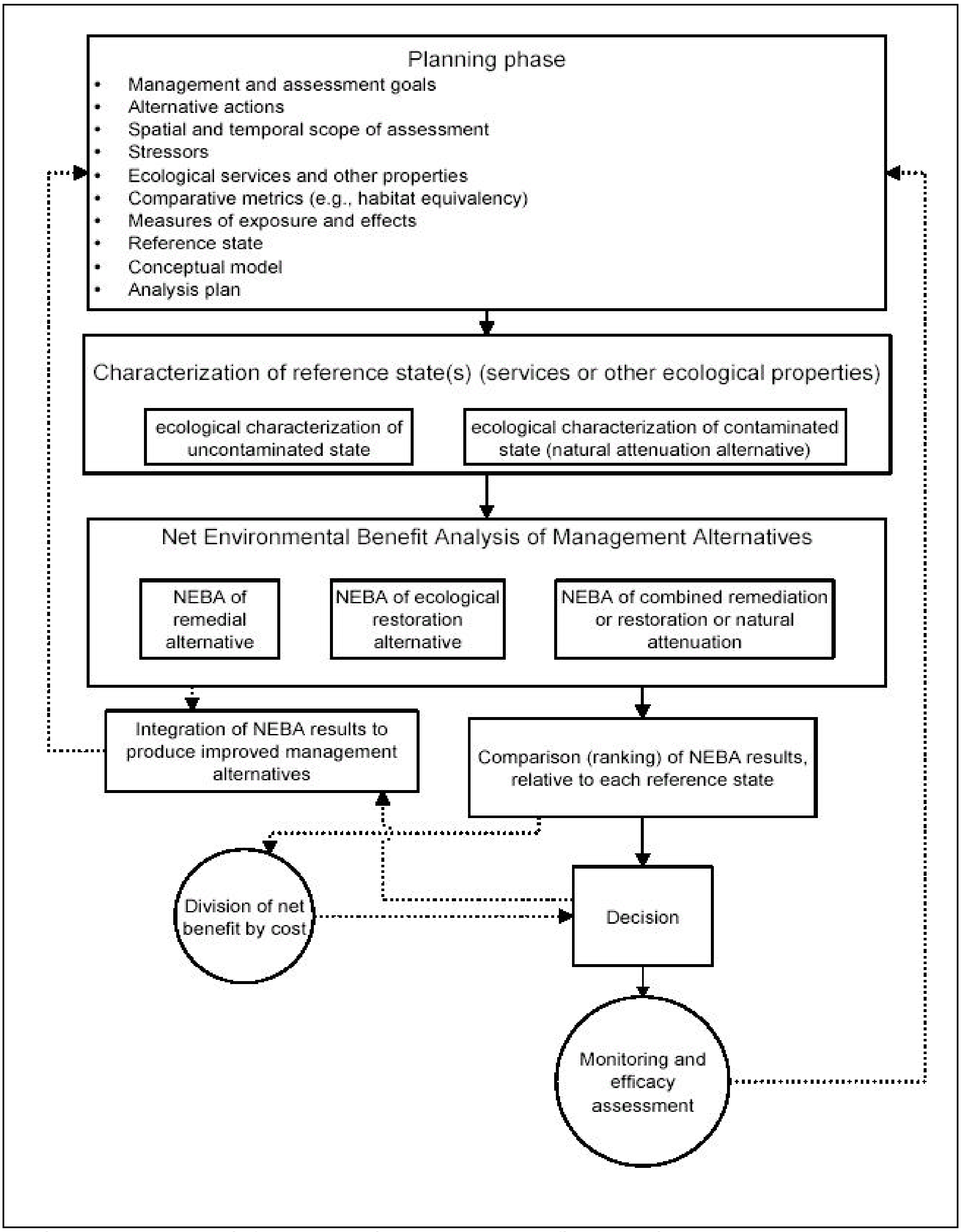


Fig 5.1 Frame work for Net Environmental Benefit Analysis

Source: Efroymson, et al 2003

The next step in the building up of the scientific decision support tool would be ensuring that a valid system of risk communication and crisis communication exists and all the data needed is available to all stake holders including, the decision makers within a real-time status.

5.5 Risk Communication and Crisis communication: Which Comes First?

Stressful situations of concern involving risk can produce barriers to effective communication and evoke strong emotions such as fear, anxiety, distrust, outrage, helplessness and frustration. In this environment the traditional approaches for communications may fall short or even worsen the situation, making necessary the use of risk and communication techniques (Roth, 2003 pp.1-10).

5.5.1 Risk communication

Risk communication is defined as: an interactive process of exchange of information and opinions among individuals, groups and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about the risk, that express concerns, opinions, or reactions to risk messages or to legal and institutional arrangements for risk management" (US National Research Council, 1989). An informal survey conducted by a team consisting of representatives of almost all stake holders shows that individuals or groups who make decisions about oil spills still lack sufficient access to up-to-date, balanced, readable communications that would support effective decision making (Pond, et al. 1997 pp.753-760).

It is clear that risk communication has to start in the contingency planning stage with the active contribution of decision makers to ensure that stakeholders concerns are listened to and considered. Decision makers in this process have to bear in mind that stake holders often are more concerned with issues to do with trust, credibility, competence, fairness, caring and compassion than about oil spill statistics and the details of quantitative risk assessment.

5.5.2 Crisis communication

When risk suddenly becomes a reality crisis communication takes precedence. The usual common mistake is that decision makers strictly stick to the risk communication set plans and tend to neglect public relations and communications. This leads to speculations from the media, more outrage from the stakeholders, and consequently a tenser atmosphere in the command and control team handling the crisis. On a large scale exercise carried out by France in the Mediterranean Sea some crisis communication difficulties were encountered internally (between on scene personnel and the central crisis handling room) and externally (in dealing with the media). The feed back process recommended that:

- To quickly release factual information;
- To centralize information before dispatch;
- To have more specific crisis management training for media officers and;
- To optimize organization and cooperation between media officers and operational personnel (Calonne & Rousseau, 1999).

However, the main problem experienced in this exercise was that decision makers obviously could not handle easily the massive flow of information from various sources while three types of operations were conducted simultaneously (equipment deployment, incident management and media handling). These three actions taking place in parallel appeared to have negative effects on the incident management exercise as decision makers complained that they could not keep up with the speed of events with an efficient response action (Kerstholt, 1997, pp. 185-192). The feedback process also recommended modifying the management structure to come closer to the Incident Command System (ICS) in the United States. (Refer to appendix 5 for an overview of the ICS).

Towards the final construction of our scientific decision support tool the growing demand and use of oil spill modeling by governments and industry cannot be overruled. However, this is still a highly controversial issue as it incorporates the chemical characteristics of oil, physical behavior, meteorological and hydrographic data. The next section will try to highlight the capabilities and limitations of such models as they highly contribute to the oil spill decision-making process worldwide.

5.6 Modeling spill impacts: a closer look.

The growing need for quantification of impacts resulting from oil spills is not only for the simple prediction of the movement of spilled oil but also for risk assessment, contingency planning and environmental benefit analysis. Historically, attempts at quantification were only available by trying to collect field data, which rarely existed. What could be feasible and cost effective is to estimate impacts using the existing knowledge of the physical and chemical properties of oils and their transport in the environment. The new generation of spill models can simulate the entrainment of oil into the water, subsurface transport, sedimentation or resurfacing as well as quantifying the impact of oil on biological resources, such as fish, shellfish, birds, and their food sources.

For the purpose of this research work the Author contacted SINTEF Applied Chemistry in Norway, Applied Science Associates (ASA) and the National Oceanic and Atmospheric Administration (NOAA) in the USA. They supplied restricted licensed copies of their latest models (OSCAR, SIMAP and ADIOS2). These models were studied closely to verify the scope of user-friendly features in contrast to the complexity of input and output data from the decision makers' standpoint. The questions asked during this study were as follows:

5.6.1 Trajectory models and Trajectory analysis: do we need one or both?

The three models use mathematical equations to predict the movement of spilled oil. The models are not as simple as taking three percent of the wind speed as the velocity of the center of the slick but much more complicated. It is clear that using the model trajectory as a stand alone system once a spill has occurred to predict where the slick will end up is an invalid simplification of the real world. The results, though, will depend on the value and accuracy of the input data, its software design and how the results are interpreted.

The process of making a trajectory analysis is of more use to decision makers as it constitutes running the model hundreds of times (stochastic modeling) for a variety of possible scenarios to try to get a more accurate idea about where the oil will end up and when. The stochastic model in SIMAP (French et al., 1999 pp.243-270) could be used to build up statistical data about the range of distances and directions oil spills are likely to travel from a particular site. This will be done with given historical wind and current speed and direction data for the area. For each model run the date is automatically randomized to provide a different probability distribution for wind and current conditions during the spill. The results are arranged according to their probability in a statistical form which provides a constructive support to decision makers.

5.6.2 Can remote sensing and trajectory analysis interact during a spill incident?

Remote sensing for oil spills can be done by over flights, collecting data from surface drifting buoys or satellite tracking. Initial reports are very helpful in calibrating the trajectory predictions, which can help to re-direct the expensive aircraft for aerial surveillance, and identify false-positive observations. During a spill running a trajectory model without real data collected from the field will soon become irrelevant. Another question arises about the time span needed to enter this updated data into the model (Hurford, 1988, pp. 7-17).

A valid example would be the choices the user has when entering vital current data in the OSCAR model (Reed et al, 2002). Clicking on the setup menu will open a dialogue as shown in Fig. 5.2. When the user selects New or Open a current grid will appear. This grid is variable in dimensions and can be adapted to the needs of the user. A grid size between 50x50 and 200x200 cells is normal; one may select a default current profile (if available) or create an optimal grid for the release area. The updated data from remote sensing can be drawn as vectors in each cell or in a few numbers only depending on the variety of data and time available of the user. The Spread function fills the grid based on the value in a few cells, which reduces the accuracy of the predicted spill location.

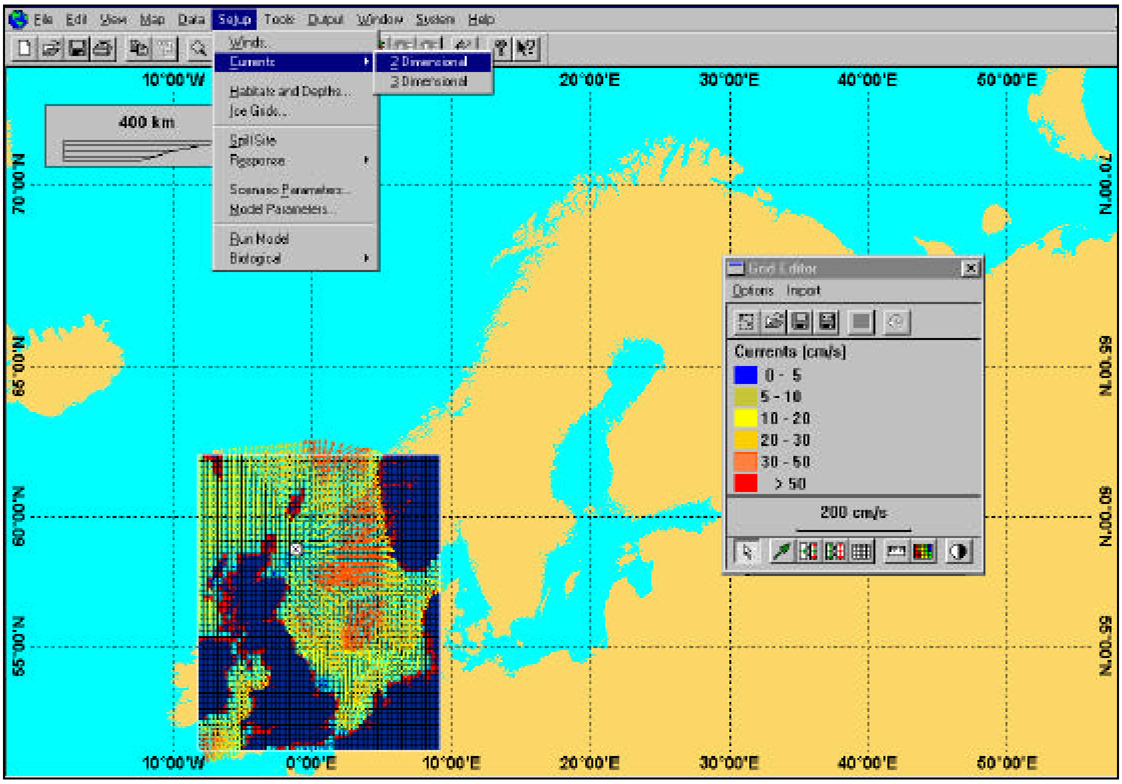


Fig.5.2 Example of a current grid display in OSCAR source :(Reed et al 2002)

The entry of the tidal currents data and the wind data in this model (OSCAR) follow a similar trend. It is clear that the more time utilized and the more reliable the remote sensing data the more accurate will be the results. However one relevant question may be if those two inputs (tidal currents and wind) will be available and could be fed into the model during the stressful situation of handling a spill crisis. Decision makers tend to apply the simplistic solutions of a constant wind and current in the models resulting in large deviations in the predicted fates and positions of oils.

5.6.3 Is it possible to run a spill model using uncertain information about the area and just "fill in" an estimate of the currents?

Many developing countries in the process of building up their oil spill contingency plan structure would purchase packages of spill modeling software to be used by decision making personnel in spill crisis. These packages may be complemented by

GIS[16] maps of the area of concern to the customer as a bonus from the maker. Users in the lack of minimum inputs would have no choice but to enter unreliable and unscientific data that will create incorrect outputs from the model.
Feeding the spill models with the correct data from current measurements is almost always the most difficult part in preparing a spill trajectory forecast. This difficulty was experienced in all three trajectory models reviewed.

The ADIOS2 model addressed the issue of uncertainty in fed data. This model gives the option to choose the uncertainty function for three input variables that are often uncertain in a real spill event (volume of oil spilled, wind speed and emulsification progress). Whenever the user selects one or more as uncertain, the model makes multiple runs to determine the output results considering this uncertainty. The function was further investigated by running the model several times without using the uncertainty function with exactly the same input data. The results showed that the area of the resulting slicks were different. The technical manual reasoned this to randomized small-scale gyres in the model, which slightly differs each time the model, is run.

5.6.4 Optimum use of spill modeling

In order to acquire optimum results from the current generation of spill models a defined strategy to deal with such models must be first defined. Many researchers in this area favor the “minimum regret” rather than the “maximum win” (Galt, 1998; Lehr et al. 1995; Jones, 1999). A maximum-win strategy would be one where the very best estimates of winds, currents, and initial quantity of oil spilled are fed into the model with the resulting forecast taken as “the” threat that needs to be responded to. A minimum-regret strategy on the other hand, would use all available analytical techniques to investigate the sensitivity of various estimates of errors in the input data and would explore the resulting implication by running different scenarios. For example, would a frontal system transiting over the spill area yesterday have a significant effect on the forecasted time of shore impact? Or does this affect the usable current pattern in the area of concern? What are the

[16] Geographic Information System

consequences of this transit on the planning of response options? Galt (1995) argues that this trend is significantly more difficult which could be a reason why most decision makers refrain from following this strategy. Decision makers, to carry out this type of analysis must, understand not only the full capabilities of the models, but also what they cannot provide.

Once decision makers reach this stage, they can create a comprehensive briefing material, which provides a “best guess” that covers alternate possibilities presenting any type of threat to different sensitive resources. The major difference between these two approaches is that the minimum-regret strategy can identify low probability, but extremely serious or expensive; scenarios that may require the development of alternate protection strategies while the maximum win strategy will only identify the most eminent threat (Galt & Payton, 1996).

5.6.4.1 The Trajectory Analysis Planner (TAP)

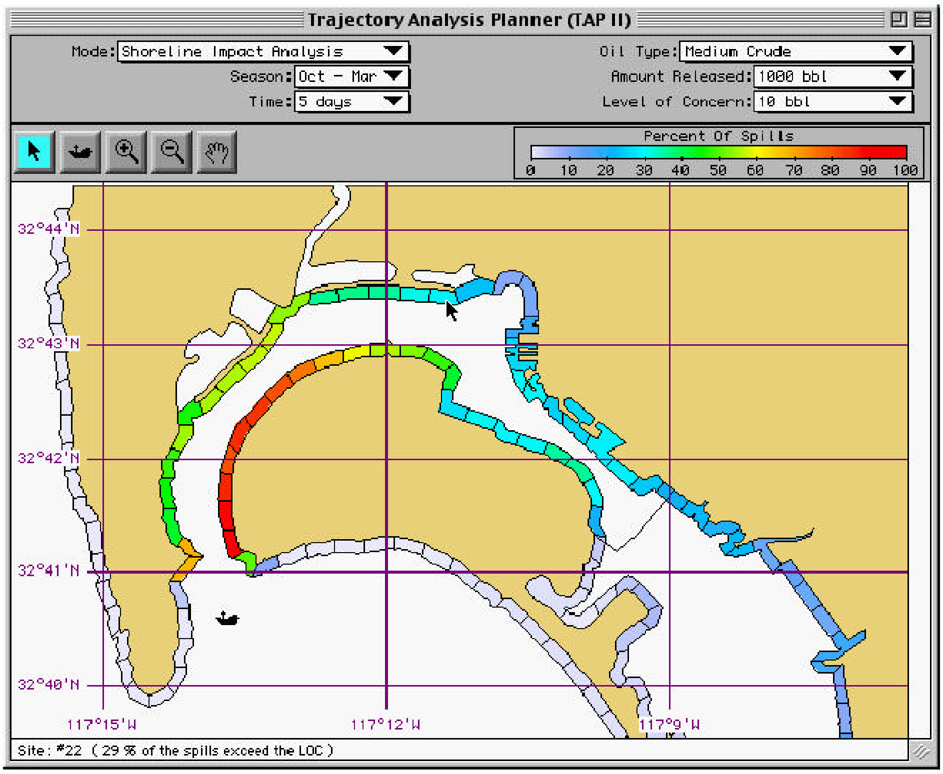
In the context of a “Minimum Regret” strategy a new tool was developed by NOAA to help decision makers assess their response effectiveness: the trajectory analysis planner TAP (Barker & Healy, 2001). TAP is an interface to a database of thousands of modeled oil spill trajectories that represent a compilation of all possible spills. This is based on the “worst case” scenario from a given spill at a given time. To generate these scenarios, sets of oceanographic and meteorological conditions are selected for the area of concern and the model is run repeatedly while results are recorded. The recorded results are transformed to statistical data that help decision makers quantify the behavior of oil spills in their own region.

A companion application to TAP called the resource manager is the tool to create and edit the resource files. This can be in a text-file format; the locations of the sites of concern can be entered into a GIS system to create resource files. If any environmental sensitivity index maps exist for this area they can be easily integrated into the system along with the level of concern LOC[17] for each site. To display data

[17] The level of concern LOC is the amount of oil that would be expected to significantly impact a particular site.

TAP provides five display modes each answering a different topic of interest to decision makers. One mode named Shore Line Impact Analysis helps to answer the usual questions when a spill is threatening a coast line, and which areas of the shoreline which are likely to be impacted. A source of the hypothetical spill is selected and the result will be displayed at the GIS map in color as shown in fig.5.3.

Fig 5.3 An example of shoreline impact analysis for a part of San Diego Bay



Colors indicate the percentage of modeled spills that exceeded the level of concern at each reception site five days after the spill. Source: (Barker & Healy, 2001)

The limitations of TAP are the very large amount of data that must be stored for each location (about 5 G.B) and the long processing time of such extensive database. This example illustrates the need of the continuity of processing of historical and actual data which could be done by many countries on a smaller scale to build up their own statistical data that could be used in upgrading their contingency plans.

5.7 Conclusion

Countries with well-established national oil spill contingency plans and seeking to build up a scientific tool for decision support need to consider the following:

- The process of building up the support tool is lengthy and needs the utilization of several types of expertise (technical, scientific and organizational).
- States are responsible for their own ERA; this process is by no means static. It requires frequent updates once a new stressor is introduced or a sensitive resource is identified (e.g. constructing a new off shore oil loading facility or building up a new beach resort area).
- Decision making personnel at the policy level may actively contribute in the update of the ERA. This will enable them to couple the results with oil spill planning & contingency measures.
- By integrating the NEBA with the existing ERA, further environmental damage could be avoided by the right choice of the clean-up technique. This is rather obvious in major spill cases.
- The distinction between the planned risk communication layout and the actual crisis communication is very important. Decision makers should try to deal with the needs and inquiries from various stake holders at the time of crisis handling.
- Dispatching quick, factual and centralized information to the media is actually reducing a main stress factor on the decision makers. If the media is left to speculate, the consequences may be more agitation of the public, and more demands reflected on the response organization.
- The structure of the crisis management team contributes directly in reducing the stress posed by the need to analyze the enormous amount of data pouring in during the spill crisis.
- The uncertainty factor in the in-put data for spill models cannot be eliminated even in the most advanced models.
- The integration of real-time remote sensing data with built-in physical and chemical fates models could lead to a more accurate trajectory forecast.

- By supporting the “minimum regret” strategy decision makers would become more familiar with spill models in-hand. This will allow them to run hundreds of potential scenarios during the planning stage, thus building-up comprehensive knowledge about capabilities and limitations of such models.
- Towards a sound decision, it is important to remember that the very best full-scale representation of the spill process is the actual spill itself. If decision makers cannot recognize this fact and endeavor to acquire remote sensing data and take advantage of it. The results will be substandard no matter how complex the logarithmic representations and colorful the model data presentation turn out to be.

Reviewing the above it is clear that decision-making personnel handling oil spill cases starting from the planning stage to the actual combating need extensive training and knowledge building. This is identified as the missing link in the decision support tools that most countries need to provide to their crisis managers. The next chapter will discuss how these personnel could be trained efficiently to be able to interpret the wide range of information introduced to them during a spill crisis and use them to the benefit of the decision making process.

Chapter Six

Training and Assessment of Decision Makers: The Missing Link

6.1 Introduction

Effective spill response requires trained and competent people, means for efficient training and assessing the competence of staff involved in the operation. This chapter will approach the area of training & assessment of decision makers using simulation and virtual reality techniques as well as tackle the subject of the role of Geographic Information Systems in facilitating such training and assessment tasks.

6.2 Simulator Training Approach

Given the nature of any oil spill crisis, the decision making process will often be carried out under time-constraint and stressful conditions; the challenge is how best to optimize the use of simulator training in preparing individuals and groups for the unpredictable? 0rasanu, (1997) suggests how training may be enhanced to prepare people for handling crisis under stress:

- Decision-making is a skill. Like all skills it may be learned through practice. By reducing the cognitive load through simulation practice, we can create experts who are less stressed than novices in stressful and threatening situations.
- The direct development of situational awareness that is done in most simulation scenarios might counteract the consequences of stress.
- Stress effects of decision-making may be reduced by sharing the process with the members of a team, which is usually the case in simulation training.

From these points we can deduce that the primary justification for simulation training in spill crisis is based on the belief that by exposing key individuals or spill management teams to a variety of spill scenarios, they will enrich their mental stores of situations, thus enhancing their repertories of decision making. Another justification is that by exposing people to such situations provides them with the self-confidence that they can handle future unknown situations.

6.2.1 Stress levels under simulated conditions

A research project was carried out during a critical incident management simulation to determine the degree of stress experienced by those involved in the exercise (Sharpley, 1994). Findings showed that participants spent much of the simulation in a low stress state and only spent brief intense periods under high psychological stress, indicated by high heart rates. To gain comparative data, the heart rates of the same participants were monitored in the real working environment. Similar patterns of stress were discovered, with sustained periods of relatively low heart activity, suggestive of low stress, punctuated by short periods of far more intense heart rate activity mirroring phases of intense decisional activity. These findings provided useful indicators of the range of psychological stresses participants could be subjected to in a simulated environment, which led to a re-appraisal of the appropriate design of the scenarios used in the training process. This in turn resulted in a high degree of operational fidelity[18] where the experience gained in the simulator was highly transferable to the working environment (Crego & Spinks, 1997) and (Hays & Singer, 1989).

6.3 Virtual reality training environments (VRTEs)

A Virtual Reality Training Environment (VRTE) is commonly considered to be a computer generated representation of a real world environment with which trainees can interact in order to achieve their training objectives. This technology has much in common with simulation technology, for at its simplest level it is a simulation with some aspect of reality. The existing oil spill crisis simulators provide some level of virtual reality according to their type (Harmon& Kenney, 1994). There are two main types of VRTEs:

a) Immersive VRTEs typically involve the user wearing a head mounted display, haptic and force feedback gloves…etc.

b) Cave in (non-immersive) VRTEs in which the trainee is either totally or partially surrounded by projection screens onto which the representation of the training

[18] Fidelity refers to how well the training environment represents reality

environment is displayed. The trainee usually interacts with the environment by means of joysticks, touch screen, or a high fidelity control console (Miller et al. 1996, pp. 39-48).

The second non-immersive type of VRTEs is the one commonly used for training of oil spill management personnel.

6.4 Considerations for using Simulation and VRTEs in Oil Spill Response Training

i) Safety

In cases where novice trainees are at risk in real life cases (Realia)[19], a simulation or VRTE eliminates the hazard. This is applicable to oil spill cases as the inappropriate use of spill countermeasures could aggravate the situation as discussed in earlier chapters.

ii) Cost

Simulations and VRTEs are considered when the cost of training with Realia is unaffordable. The mobilizing of all relevant resources engaged in combating a major oil spill is very expensive. In addition some of the resources used might need to be removed from productive service elsewhere in the society for the purpose of conducting a real exercise. The simulation facility establishment and its running costs would be significantly less expensive. The emerging trend of multiple applications of simulator facilities not only for training purposes for oil spill response but also for training on other types of crisis and for research and actual organizational use in oil spill cases have proved to be cost effective (Caird, 1996).

iii) Efficiency

Simulation and VRTEs are used when intentionally spilling large amounts of oil for training purposes is not considered an option for practical or environmental concerns. Both have the ability also to compress the time needed for training compared to Realia.

[19] Realia is a common term used in simulation terminology referring to real life training or “on the job training”

iv) Flexibility

In simulators and VRTEs trainees can get frequent practice dealing with problems that may seldom occur, if at all, in the real world, but are too critical to ignore. Different programming could change various parameters such as wind and current conditions, quantities of spilled oil, available technical resources etc.

v) Transfer

Training in simulators and VRTEs promote a high degree of transfer to real world situations more rapidly than traditional training methods (e.g. lecture or tutorial). Both also provide a certain degree of fidelity thus allowing a deeper, richer understanding of the task. This confirms well with training the managing staff handling a major spill as the system can easily transfer them almost completely to what is similar to a command centre handling the crisis.

Table 6.1 summarizes the considerations for the use of simulation and VRTEs

	Realia	Simulation	VRTEs
Cost	Very high	High	Relatively high
Safety	Low	High	Very high
Efficiency	Very low	High	Highest
Flexibility	Very low	Higher	Highest
Transfer	Highest	Relatively high	High

Source; modified from Harmon & Kenney, 1994.

6.5 Complexity of Simulated and VRTEs

Although simulated exercises for oil spill response training offer a number of benefits, it is important to point out the danger of overloading the simulated environment with too many parameters (Treu, 1996, pp. 162-169). The main problem in this approach to the spill management training is the degree of complexity the trainee may have to face during the exercise. It has been believed for a long time that the more a simulated environment approximates the real one, the more likely that the training in the former will transfer to the latter. Lately it has become clear that it is much more important to understand which aspects of an overall task need to be supported in the simulated environment, rather than the overall fidelity of the simulation system. There is some evidence from many simulation systems that higher levels of fidelity and complexity have little or no effect on skill transfer and reductions in fidelity actually improve training (Caird, 1996). To overcome this problem the simulation scenario representing the spill crisis should be structured to reduce the environment-task complexity until the trainees become familiarized with the system. Once some task proficiency occurs, complexity can incrementally be added into the training scenario.

6.6 **Global use of Oil Spill Management Simulators (OSMSs**)

Examining the current availability of OSMSs in training institutions worldwide, it is clear that they are still very scarce compared to the other types of simulators, as shown in table 6.2. It is noticed that the delivery of other types of simulators is an increasing trend recently, which indicates a high level of acceptance of the benefits of such systems especially in maritime communities (Muirhead, 1996).

Table.6.2 Estimates of marine simulator types at 1/6/96

Simulators with a visual ship handling facility	106
Radar and radar navigation	380
Engine room	110
Navigation instruments	60
Cargo and ballast control	45
Fisheries	30
GMDSS	60
Oil spill management trainer	4
VTS	10
High speed craft	2
River boat	3
Estimated total	810

Source: Muirhead, 1996

Table 6.2 Estimates of global marine simulator types at 1/10/02

Simulators with a visual ship handling facility	158
Radar and radar navigation	360
Engine room	100
Navigation instruments	60
Cargo and ballast control	50
Fisheries	35
GMDSS	320
Oil spill management trainer	5
VTS	10
High speed craft	5
River boat	3
Estimated total	1106

Source: Muirhead, 2003

It should be noted that the number of OSMSs has not increased in the last seven years (only one more system was installed see table.6.2), although some other simulators had a sharp rise such as GMDSS. The reason could be the difficulty in substituting a full OSMS with the widely spread part-task simulation tools, which are much cheaper and less sophisticated. This compromise especially in the area of oil spill management, may not present the needed training atmosphere for decision makers. However, many countries are still using the classic table top exercise aided with a standalone computer with an oil trajectory model.

6.7 The OPRC convention: Is a global standard for OSMSs in the pipeline?

The STCW 95 Convention stipulates minimum standards for the training using marine simulators, which already came into force on the 1st.February.2002. In the same year the OPRC[20] convention came into force on the 13th May 1995, defining a training program of three levels (IMO, 1995). The need for upgrading those three courses and developing a model course started with the establishment of the OPRC working group (OPRC WG) in 1992. Years of work and co-operation between IMO member states, non-governmental organizations and the industry produced three detailed and comprehensive model courses. Although the use of OSMSs was not mentioned in the course delivery methods, the issue of the development and standardization of the instructional materials was on the agenda (Slater, et al.1997). The hope is that this issue again is included in the agenda of future MEPC committee meetings as this would definitely be required considering the slow introduction of simulators in oil spill response training.

6.8 Competence Assessment of decision makers

There is currently no standard qualification for oil spill decision makers, technicians and first line responders. Should one be devised in the future the competencies required could only be derived from the feedback of training programs (Gair & Salt 2003). A fundamental problem in competence assessment for oil spill crisis decision makers is that real spill cases cannot be used and therefore simulations must be employed. For this purpose the assessment scenarios need to be carefully written and managed and should be as realistic as possible (Barnett, 1997, pp. 77-84). The assessment itself will often create a useful level of anxiety, which will produce relevant psychological and physiological symptoms. Assessors should be able to introduce an element of stress into scenarios and to judge the overall performance of the vital decision making process (Flin & Slaven, 1995). By having this ability to measure competence levels with the help of OSMSs, response organizations can develop plans and define training needs for their own staff.

[20] The International Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC) 1990.

6.9 The proposed model structure of OSMSs

This proposed structure was extracted and modified from the specifications of the oil spill crisis management simulator in the “Arab Academy for Science, Technology and Maritime Transport” (AASTMT) and the “Polaris” crisis management simulator. The former has been in use for more than five years to train the oil spill managers and on-scene commanders in Egypt, while the latter is actually used by Norway as a command center in actual oil spills.

Any proposed OSMS needs to fulfill the following points in order to achieve its goal in the most efficient and economic way:

- Function in accordance with the organizational structure and this country’s national oil spill contingency plan (NOSCP).
- Function as an exercise training and simulation system.
- Function as a tool to assist in risk management, spill mitigation and planning measures.
- Function for specific oil spill events or as generic over all-hazards system.
- Function in an exercise mode without information crossing between real world and exercise.
- Have the capability to upgrade/expand into handling real spill cases.

6.9.1 Proposed components of the OSMS system

For optimum training and assessment results the OSMS may contain the following units, noting that the layout may be modified according to the spill organizational structure of each country:-

a) Response room which incorporates a meeting table for at least 8 persons dedicated for the management team, PC work station, white board, VCD/VCR player, 4 assigned telephone lines and a CCTV camera system.
b) Emergency support room or command centre, which should incorporate at least 8 PC workstations, each with a separate telephone line, a facsimile machine, VHF radios and a projector screen.

c) Instructor control station, which should incorporate all equipment, required for the successful conduct, monitoring and control of the exercise or training.

d) At least three on-scene commander units, which could be, used either as floating units, helicopters or both (See fig. 6.1).

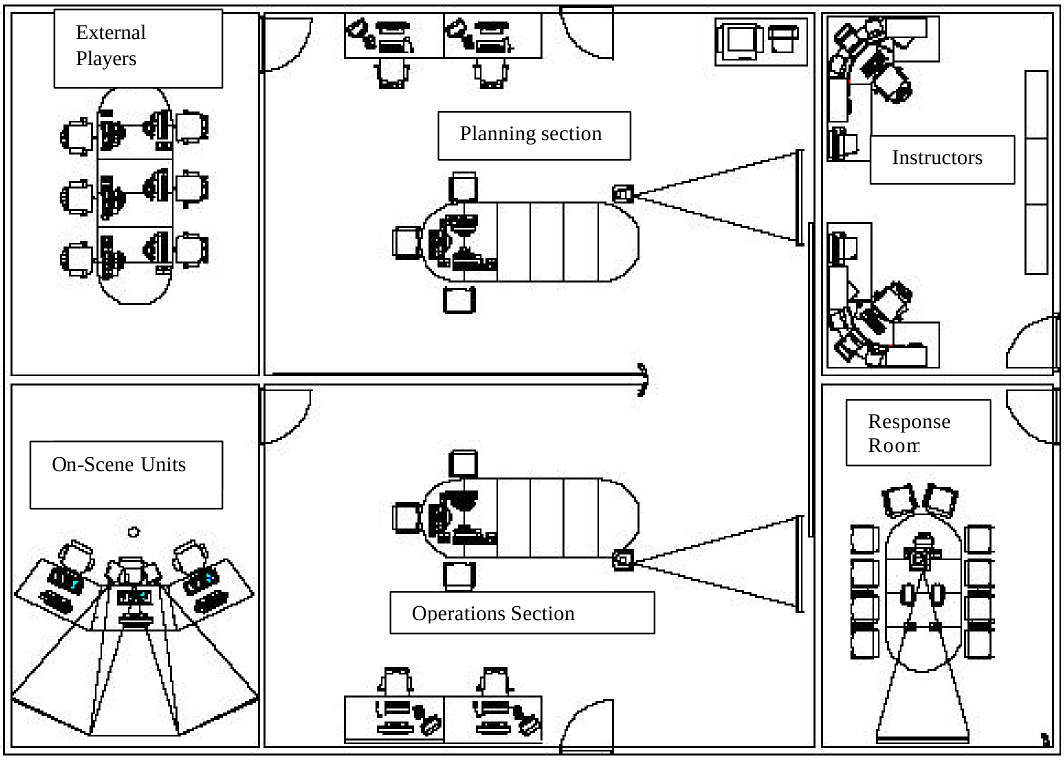


Fig. 6.1 possible lay out of an OSMS.

e) The system should have the ability to interface not less than 4 external players to the spill exercise.

6.9.2 System Architecture

The main aim of the OSMS is to train personnel involved in oil spill crisis management and response decision-making and enhance team skill building. It could also be used to develop and maintain a real management centre for actual spill response events. The simulation component must be able to simulate the spill itself and the countermeasure operations. This is usually done with the aid of built-in trajectory and physical fates models as described in the previous chapter.

6.9.2.1 Data Base Management System (DBMS)

The end-user interface to the system is required to be user friendly as the trainees could vary in their computer knowledge. This could be done under the widely known windows environment. (Windows NT). The different databases serving the system could be related by commercially available relational data base management systems (RDBMS), such as Oracle or Sybase.

The user access to the system should preferably be password protected. The failure of any individual windows workstation shall not in any way degrade or alter the performance or capabilities of the remainder of the system.

The data collected by the system during the exercise should be available in a central repository accessed by the instructors. This central repository is to be managed by the RDBMS, which contains all the information critical to the effective management of oil spill crisis response.

The RDBMS should time stamp and preserve all of the following data:

- Equipment procurement, activation and deactivation.
- User log in and logout actions.
- All procedure/checklist actions
- Personal notifications.
- Briefings / meetings (internal and public).
- Duty rosters and schedules.

6.9.2.2 Geographic information system (GIS)

The GIS is a system of computer software, hardware and data aiding personnel to control, analyze and present information that is tied up to a spatial location. The incorporation of GIS with the OSMS provides a vital contribution to the decision support tool discussed earlier (see fig.6.2)

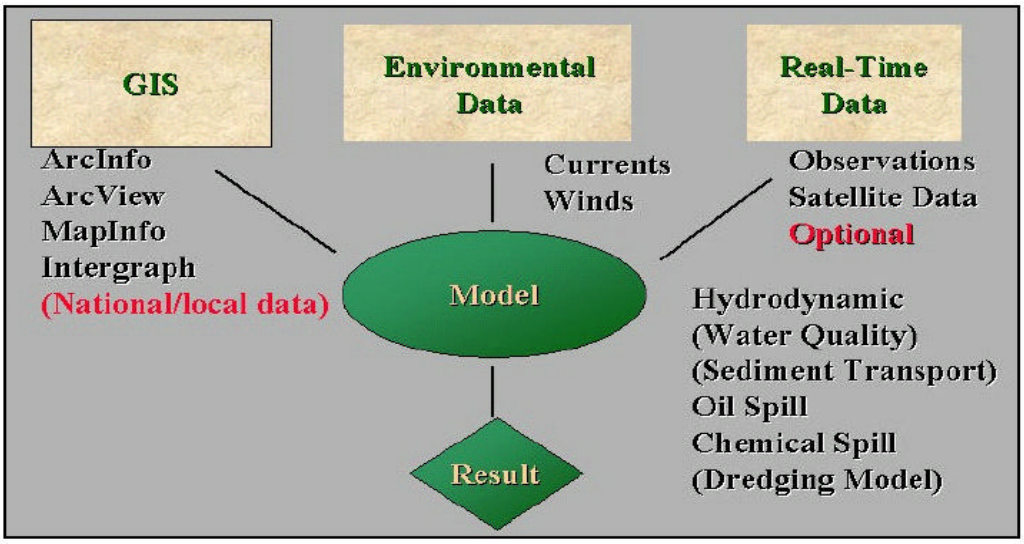
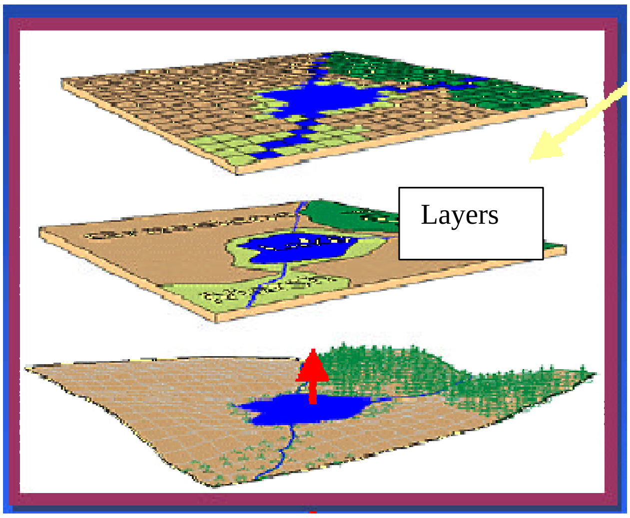


Fig. 6.2 Flow chart presenting various data inputs to the modeling system.

Source: "POLARIS" product description sheets.

The industry standard software usually includes a large layered map display, which should be available at each workstation. The specific GIS layers are usually determined by the functional position of the user. For example the user can display the layer indicating the area of the spill impact(s) along with the layer of sensitive resources in the same area (human, biological etc) see fig. 6.3.

Fig.7.3 Thematic layers in GIS display



. Source: WWW.GIS.COM

The main data of the concerned geographic area must be available on base maps that include vector based definitions of the coastal regions, scanned nautical charts, and digitized aerial and satellite photos. The base maps serve as the foundation, of the GIS displays, additional GIS data layers providing the trainees with an overview of the locations of environmental, economic and geographic attributes, as well as the locations of critical resources within and near the emergency or exercise area (Kerdany & Abou-elkawam, 2002, pp. 61-68). Where available such information shall include but is not limited to:

- General (marinas, beaches, hotels, ports…)
- Biology (fish, birds, mammals…)
- Physical (marsh grass, palm…)
- Channels / anchorages
- Navigation aids
- Satellite photos
- Shoreline features
- Populated places
- Roads & rail roads
- Airports

6.9.2.3 Logistics and resources

The proposed system should be able to track response assets (personnel, equipment and vehicles) during an oil spill or an exercise. It should be possible to completely control these assets by the simulation host; from their starting points, through staging areas, arrival at the spill site, and the start of the countermeasure operations. This control could be either in the hands of instructors or trainees during the exercise.

6.9.2.4 Financial tracking

The proposed system could be able to generate purchase orders and financial reports to be able to track expenditures over time. The system could display graphical descriptions of cost expenditures and report the total cost of the oil spill response to-date. Once an asset enters active simulation, information about the asset is available to controllers and trainees.

6.9.2.5 Communication

The system should have an adequate number of dedicated phone lines and at least one facsimile machine for external communication. The combating vessels and helicopter should be equipped with VHF[21] and UHF[22]radios to keep in continuous contact with the control room. It could prove to be practical to install satellite communication facilities (Inmarsat B, C & M) to have total independence from local failures in power or phone lines.

6.9.2.6 Message management / incident reports and logs

The system may incorporate some or all of the following features according to its intended use (training only or managing actual spills):

- Send messages through an approval point before transmission either inside or outside.
- Send and receive hard copy message traffic between members within the control center and outside to the on-scene responders and external players;
- Assign and track missions / tasks;
- Preserve message traffic for historical records;
- Sort / view and print messages;
- Sent pre-built messages at pre-determined times during exercises / training;
- Indicate the priority and type of message;
- Assign a unique number for each outgoing and incoming message.

The system should also be able to record “Actions” taken during the spill response or the exercise. These “Actions” may be logged automatically or manually, and become part of the permanent records of the exercise or training.

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[21] VHF stands for very high frequency radios.
[22] UHF stands for ultra high frequency hand held radios.

6.9.2.7 Reference material / personnel records

The system could be able to store various reference materials in the database such as chemical characteristics of various types of oils & products, trade names and synonyms. It could also provide specific information on health and safety hazards which response teams could be liable to while combating the pollution caused by these different types of oils and chemicals.

The reference section may also contain individual records on personnel assigned to various spill response duties including their specific skills and the previous training courses they have attended. The above information can be used in other parts of the database such as notification listings.

6.9.2.8 Environmental damage assessments

The system may be able to store and use the ERA forms and show the damaged areas on GIS maps. This could be done if the sensitivity data is captured and used to predict the quantitative levels of damage that might be caused to specific resources as a result of an oil spill. This information could be incorporated along with the spill trajectory model as explained before or as a stand-alone system.

6.9.2.9 Economic damages / compensation claims

The system may contain an economic damages assessment model which is able to provide an estimate of the effects caused by the spill incident on the natural or human resources. These types of models need identified “Targets” to work on. The data base containing the sensitive resources could be used in these models as the identified “Targets” such as commercial ports, beach resorts, marinas, fishing farms, public beaches and marine parks.

6.9.2.10 Instructor / exercise control functions

The proposed system should enable the instructors to design and develop an unlimited number of spill scenarios to confirm to training and competence assessment needs. Individual scenarios may be stored in a library to be used at various training levels. The instructor should be the initiator of the exercise from his workstation. He must be able to freeze, resume, play in-fast and reset the exercise to an earlier time. The instructors and external players should be able to use communication equipment to role-play external agencies in an exercise.

6.10 Conclusion

The skill of efficient decision making in stressful situations is vital. In an oil spill crisis DMs are subjected to variable stress levels. The on-job training of such personnel is always faced with difficulties ranging from logistical to safety. The importance of building up skills can never be ignored and the introduction of simulated and VRTEs deserves more focus and consideration from all nations.

While many other types of simulation systems are progressing considerably, especially in the maritime training field, only one OSMS has been established in the last seven years. Countries (developing and developed) need to re-consider the benefits of establishing such training facilities. Many countries are sceptical about the cost effectiveness of such establishments, which can prove more justifiable if the same facility could also be used in actual oil spills as a spill management center.

Having a closer look at what the proposed OSMS can offer, we can find some solutions for certain pending problems in the oil spill management area, one of which is the competence assessment of assigned & potential decision makers. This is solved by the sound structure of various spill scenarios, introducing elements of stress to provide a closer level to the reality needed. Assessment can then take place for those personnel under such conditions and feedback data can be collected to help upgrade and re-structure the scenarios to achieve optimum training levels.

Another problem is the known complexity and the huge amount of data that DMs have to deal with while handling the oil spill crisis. This is also solved by the incorporation of GIS with the various databases serving the system. The DMs through GIS, displayed on every workstation are able to view, analyze and scroll through huge amounts of data, which are presented in various visualized forms (e.g. maps, graphs, curves, bar and pie charts, satellite and remote sensing images etc.). DMs can also link any of the available databases (e.g. resources, logistics, finance, sensitivity, communication, risk assessment etc.) to the graphs or maps and obtain vitally needed data in limited time.

To sum-up, the whole construction of the personnel decision-making support tool must have a strong scientific foundation. This can only be achieved by having access to accurate input data and information and the efficient training of personnel handling the oil spill crisis. They can reach high competence standards only if they keep on developing their decision-making skills through continuous exercising under simulated conditions.

Chapter Seven

Conclusion, Recommendations and Further Research

7.1 Introduction:

The combating of oil spills is a complex undertaking that involves various actors at the international, regional, national and local levels. This study identified various cumulative gaps leading either to delays in the decision making process or to a decision leading to more destruction than a spill has already caused. Every time a major spill occurs biased decisions also occur, with destruction to the biological and human resources also occurring. On this matter Linden (1990, p.119) states that:

> The underlying problem is that, for too many years, environmental issues such as the threat of oil spills have been neglected. As a result, already won experience has been lost. When a new spill occurs, old mistakes are repeated.

7.2 Primary Findings

While decision makers exhibit some expertise in implementing the procedures of the previously set contingency plans, there is significant variability in individual decision makers' interpretations and understandings. This variability results in inconsistencies and disagreements among decision makers. Specific knowledge gaps, information needs, or misperceptions were discovered in the areas discussed below: -

- The study indicates that existing scientific information on the fates and effects of various types of oil in the marine environment has not been successfully communicated to decision makers. This was clearly displayed in the cases studied and the questionnaire results (see appendix one and two).

- Misconceptions in the area of mechanical combating are still common especially in the deployment methods of booms and skimmers, how to tend them and their technical limitations when used in the field.
- Some reluctance was noticed among decision makers to use new applied technologies such as the addition of emulsion breakers, considering the use of in-situ burning or bioremediation.
- Most decision makers are of the opinion that the use of simulators in general would be very beneficial to the training process. However, there is limited knowledge among them whether the use of oil spill management simulators (OSMSs) would be effective in enhancing the competence of spill managers. This could be due to the lack of experience because of the scarcity of such simulators worldwide.

7.3 Conclusions from studied areas in this Research

When these gaps and misperceptions were identified this study tried to focus on some of the most important areas where decision makers usually ask the question "how to?" which indicates either a lack of experience or knowledge or both. The following summarizes the findings deduced from the topics approached in this study:

- Decision-makers (DMs), when considering the fate of oil, have to differentiate between weathering processes and their effect on the physical and chemical characteristics of oils, and the movement of oil due to hydrographic and meteorological conditions. They should not focus on one neglecting the other.
- Safety precautions against volatile gases must be considered when working with oils having a higher evaporation rate.
- The emulsification process could incorporate up to 80% water in the "mousse" formed. DMs have to consider this before deciding which type of skimmers to use or if the ISB is an option.
- Low concentrations of aromatic hydrocarbons are usually dissolved in water. Soluble aromatic compounds are particularly toxic to fish and aquatic life only if occurring in shallow, protected waters with limited dilution capacity.

- The biodegradation and weathering processes are slower in oils with high aromatic and asphaltine content. This is to be carefully considered if the option of “leave alone” is chosen as those types could persist in the environment more than expected.
- The application method of chemical dispersants should be related directly to the distance of the spill site from the heliport or the airport if the arial application is chosen. The multi-pass approach over the spill is preferred for better results. This should be monitored by other high altitude craft to guide and verify the effectiveness of the operation.
- The use of dispersant vessels may prove to be more effective if the spill site is close to land and boat terminals. The remote sensing or aircraft monitoring should also be used to verify the effectiveness of the operation.
- The available scientific data resulting from the extensive research on the issue of chemical dispersants lately provides an aid to DMs as to where and when they can be used.
- Seafood tainting is minimal with light oil products while the risk is higher for pelagic fish with medium crude oils. Benthic organisms are more affected by heavy crude oils and fuel oils that easily sink to the bottom.
- Salt marches are sometimes considered wasteland of low or no value. However, they are often highly productive and have a key role in the food web chain. They are also very sensitive to most clean-up techniques. Once polluted, the clean-up process should proceed with caution.
- Corals are most sensitive to oil especially in the short term; they suffer decrease in growth rates & colonization capacity. However they tend to recover in the long term.
- Mangrove trees have the ability to tolerate dispersed oil better than untreated oil. If the mangrove area impact in unavoidable DMs could consider the use of dispersants to minimize damage.
- Translation of ecological losses into money in the aftermath of a major spill is not easy, but DMs handling a spill should be aware of this causal relationship when considering different countermeasures.
- The failures in Boom performance when used in containing, diverting or cascading patterns are not only due to winds and currents, but also are

related to the reserve buoyancy of this particular boom. The more buoyancy to weight ratio usually reflects better performance in all stationary and towed configurations.

- The performance of oil skimmers could be greatly enhanced when attention is given to the difficulties in pumping high viscous oils and emulsions. After recovery from the water, the additional viscous oil pumping systems (VOPS) may be the solution for many problems in this area.
- In-situ burning (ISB) can achieve high removal rates if the ignitable oil could be captured and isolated with fire booms to maintain the needed thickness for each specific oil type. The window of opportunity is extended by the addition of emulsion breakers. This may enhance the ignition process even in previously non-ignitable emulsions.
- Sorbent materials containing nonindegenous microbes, chemical solidifiers and synthetics should be used with caution in sensitive environments. The loose form of the chemical components they contain may pose an ecological threat.
- Although most countries have well-established national oil spill contingency plans, the need for building up a scientific supporting tool for DMs to execute those plans is an imminent task. The building up of this tool requires the integration of data and information from multiple sources.
- The active contribution of DMs in the ERA process will directly link the results of such analysis with the dynamic upgrading of the national contingency plans. This approach will achieve optimum results if complemented with NEBA as DMs will be able to balance the advantages and disadvantages of various combating or clean-up options.
- Risk communication procedures defined in the contingency plan need not to be followed strictly if a spill crisis occurs. Some flexibility in dealing with outside communications (stake holders and media) may ease-up the tense atmosphere on the DMs if the public are left to speculate on their own. The sound crisis communication process could optimize the cooperation between media officers and operational personnel.
- Oil spill models are often used only for tracking the location and distribution of oil. The new generation models address a wide range of environmental

impacts along with the usual trajectory. DMs need to familiarize themselves with the capabilities and limitations of the model in hand. This is done by running the model in stochastic mode and building-up their own statistical data. This data may prove to be viable in the decision-making process.

- Once staff knowledge is built-up about all the inputs relating to the spill management (physical, chemical, ecological, modeling, technical etc) attention should be diverted to the skill and competence of decision makers.
- The skill of decision making under the stress of an oil spill crisis needs competent personnel to handle it. Competence cannot be achieved without efficient and comprehensive training. Here the introduction of oil spill management simulators (OSMSs) is justified.
- OSMSs provide a safe, flexible virtual environment for training purposes. They promote a high degree of transfer to the real world situations. The investment in the establishment of OSMSs could be justified as they can be used as actual command and control centers in a real oil spill crisis.
- The OSMSs could improve the competence assessment problem of DMs handling oil spills. To examine competence the running of various potential scenarios and introducing stress elements during the exercise presents a useful feed back of data and identified personnel capabilities.

7.4 Recommendations

This study has introduced the build-up of a scientifically based support tool to oil spill DMs. The building-up of such a tool is a chain, which cannot afford a missing link. Many countries lack the dedicated staff that only deals with oil spills. Most of the time spill mangers are assigned other routine jobs and called in whenever the spill occurs. In most countries dedicated spill managers and responders do exist but with no professional cadre, meaning that they are not encouraged to dedicate their whole career to this job. Even some private spill contractors find it difficult to stay in business given the rarity of major spills.

To remedy this situation, it is recommended that countries with their different spill management structures (Authoritarian, Democratic, Central, Local) develop a designated professional cadre for all levels of spill handling staff. This could be done within governmental structures or even in the private sector. These personnel would base their whole career on dealing with spills around the country. Such a group could also be the core of the leading staff responding to all major spills as well as to provide advice and assistance for smaller spills. Rather than losing experience through rotation and reassignment a group of oil spill professionals would retain and build experience.

The wide range of knowledge, skills and experience might be enhanced further by sending this professional staff to advise or participate in responses to major spills elsewhere in the region. The OPRC convention strongly encourages this notion and many regional agreements are already in place (e.g. HELCOM, PERSIGA, and REMPEC). Countries, which took a similar approach, proved to exercise more sound decisions in cases of oil spills. (Personal contact. MCA May.2003), (Steen et al. 2003 & OSRL, 2003).

Although the triple leveled IMO model courses for oil spill staff has been delivered in many countries in recent years, it could so far ensure only a relatively low level of knowledge among the staff responsible for handling spill cases. It is highly recommended that the difference between knowledge and competence of oil spill professionals must be identified and handled. Taking the example of the STCW95 Convention for seafarers who clearly identifies that knowledge only is not enough but competence also must be practiced and assessed (IMO, 1995). The main problem area in exercising competence would be “on the job training” for spill staff. This could prove very difficult to achieve on regular basis due to various reasons (safety, logistics, preparedness, costs, permissions etc).

The OSMSs could be introduced as a mandatory tool for the training and assessment of such staff in the near future. Delegates of IMO member states may present this vital topic on the agenda of the future work of MEPC without waiting for the next major spill crisis. This action if decided could be a good example of the proactive approach IMO has been trying to take in recent years.

The establishment of such training facilities (OSMSs) requires large scale funding; this is a clear obstacle for developing countries. The large investment could be justified if the same facility can be used also for real oil spill combating as a command and control centre. This would only require that the internal communication systems used during the exercises are to be switched to the outside world. National spill response organizations in developing countries need to seek the support of national and international donor agencies highlighting the economic and environmental benefits of the implementation of such training and response methodology. IMO is also including the implementation of the model courses in project proposals being developed for support from multilateral funding sources. (Personal communication. TEC Committee- IMO head quarters. London. May 2003).

It is recommended that each country should generate a process whereby spill responders on various levels can communicate their experiences to the policy makers and contingency planners. The lessons learned from each minor spill could be of vital importance in a major one. For example, if contingency planners reviewed the characteristics and behaviors of heavy oils, this might lead them to strive to be ready for at sea-recovery but not to completely rely on it. Because the best and most meaningful chance to recover heavy oils from the sea is during favorable weather and calm seas, there is no need to invest in large stockpiles of overly sophisticated and specialized recovery equipment. Planning, simulated training, and using a mix of standard oil spill response equipment and locally available resources would seem to be the best approach.

In terms of equipment, decision-makers would be best advised to purchase booms, skimmers, pumps, and storage tanks and support equipment that can be used for the widest possible range of oils and conditions. In particular they should focus on those skimming systems that cope well with heavy oils and weathered emulsions. However, because both equipment budgets and storage space on vessels will always be limited, it is recommended to avoid dependency on overly-specialized devices as they need more training and are very sensitive to mishandling.

Given the uniqueness of each spill incident it is recommended that good contact should be maintained with key resource persons (e.g. biologists) with past spill experience who may no longer be actively in spill response. These people could serve as valuable advisors in the event of a spill. They should be integrated into the action command groups so they can provide advice to personnel in the field. They could also be consulted in the general contingency planning activities that occur outside actual spill response activities.

It is recommended that good contact with the media, environmental organizations, and local residents should be maintained during a spill response operation. These parties should be kept informed of clean-up activities and provided with information that can justify and defend the actions taken. A mechanism for the exchange of information between responders and the public is to be generated, and in particular allow for local residents to voice their concerns.

It is recommended that the previously mentioned GIS technology be best utilized to meet the demands of each country in protecting the biological and socio-economic resources of the marine and coastal environments. This could be done by the generation of a proposed GIS team in every spill response organization. The team may consist of a toxicologist, natural resource economist, biologist, a legal counsel, and a GIS expert delegated to collect, analyze and store such data in appropriate databases. The building-up of these databases in each country, as explained before, would be a valuable tool for the decision making process.

7.5 Future Research

Towards a better performance of spill response teams and more sound decisions in cases of oil spills the following could be considered:

- Laboratory tests and experiments concerning the effects of chemical dispersants, or boom and skimmer performance are vitally needed but still have some limitations. Only moderate dynamic conditions may be investigated in test tanks to simulate the real conditions. It was observed that test results are frequently de-rated according to assumptions of the environmental parameters, such as wave heights, current, temperature etc. there is limited knowledge to base such assumptions on. Future efforts should focus on identifying rules for scaling of laboratory tests to open water conditions.

- Many tests have been run using oils of widely varying viscosities, but none have related boom performance directly to oil viscosity with all other conditions remaining the same. Future tests could be performed with a boom of fixed dimensions and varying oil viscosities. These tests could be repeated with changing boom characteristics, specifically buoyancy to weight ratio and draft. These tests might be able to show if there is an optimum or minimum boom draft required for specific viscosity oils at various tow speeds.
- Future research areas should be identified that can provide decision makers with the information and facts they require to plan their response strategy and to justify their decisions to the media, the general public, local residents, and environmental organizations. As a start this could be done by revisiting old spill sites to evaluate the effectiveness of the clean-up methods used and to monitor the long-term fate and recovery of the oiled shorelines. This information could also be used to update the national oil spill contingency plans.
- Further research should focus on the evaluation of the performance of the new demulsifying dispersants. These new types of dispersants significantly increase the time window of opportunity of using chemical dispersants, which is usually a major concern for all spill response organizations. This could be done either by laboratory or field studies to assess the dosage and time relationships for both the demulsification and dispersion processes. For example, better dispersants would require lower dosage and/or less time to break emulsions and disperse oil.
- Oil spill response planners, insurers, and other stakeholders should direct their future research on developing an oil spill clean-up cost estimation methodology. This proposed methodology should be country-specific and

more precise than universal per-unit cost values that have been embedded in the commercially available environmental models. The proposed cost estimation model could be derived from studies of historical oil spill cost data. Such historical data, if integrated with current mechanical recovery and dispersant operation cost models, will provide an even better tool for estimating and predicting oil spill clean-up costs.

- Models to predict time windows of opportunity for the In-situ burning of oil spills are not currently available. Future research should be directed to testing of the ignition devices capability of raising oil surface temperatures to flash point temperatures and linking the results to the potential ignitability of floating oils. These results will help in developing such prediction models and help in predicting the feasibility of in-situ burning.

Finally many countries need to revise their environmental laws, especially those sections relating to marine pollution by oil. This could prove to be a contributing factor towards solving many organizational and technical problems in dealing with major oil spills. In conclusion, the words of Prof. P.K. Mukhrjee (2002) are particularly relevant and worth remembering:

> The subject of marine pollution is of prime importance in today's maritime world. In comparison with other areas of maritime law, many of which are deep rooted in history, marine pollution concerns arose only after oil was discovered in the early part of this century, and oil tankers entered the arena of shipping and ocean transportation. The problems relating to pollution of the seas are on going, as evidenced by frequent disasters of mammoth proportions; and the law appears to be continuously developing to cope with the consequences.

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Appendix One

Case Studies

Introduction:

In this appendix many in-famous oil spills are analyzed trying to detect where decision makers could have made a more sound decision. The cases are spread throughout two decades; nevertheless the similarity in the misperceptions and confusion exercised by decision makers can be easily detected.

Case one: ARAGON

Spill Date 12/29/89
Maderian Archipelago, Portugal
Location 33 34N Latitude Longitude 015 34 W
Oil Product: Mexican Maya crude oil
Tank Vessel
Oil quantity: 17500 Barrels

Incident Summary:

While under tow, the Spanish tank vessel Aragon suffered damage during a storm on December 29, 1989, approximately 360 miles off the coast of Morocco. The damage resulted in the release of approximately 175,000 barrels of Mexican Maya Crude Oil into the Atlantic Ocean, near the Maderian Archipelago. The Portuguese Navy was in charge of the response. They monitored the initial movement of the oil until it made landfall. Approximately three weeks after the spill, pollution occurred on the Portuguese Island of Porto Santo, with oil believed to have been from the Aragon. This was later confirmed when oil samples were taken from the vessel.

Observations:

Decision makers handling this spill incident could not decide on any chemical or mechanical countermeasure at sea possibly because of rough weather. The surprising observation is that although the Portuguese navy closely monitored the spill, no decision was taken to protect sensitive shorelines. The time was quite enough (three weeks) to try taking action.

Case two: NESTUCCA

Spill Date 12/23/88
Grays Harbor, Washington
Location: 46 55 N Latitude Longitude 124 15 W
Oil Product Bunker C
Tank Barge
Oil quantity: 5500 Barrels

Incident Summary:

In the early morning of December 23, 1988, the tug Ocean Service collided with its tow, the barge Nestucca, while trying to replace a broken tow line. Both the barge and tug were owned by Sause Brothers Ocean Towing Co. of Coos Bay, Oregon and were en route from Ferndale, Washington to Portland, Oregon when the collision occurred approximately 3 kilometers off the coast of Washington, near Grays Harbor. The barge was carrying over 69,000 barrels of Number 6 fuel oil. The tug punctured a cargo tank, releasing an estimated 5500 barrels of the heavy marine fuel into the ocean. It was an overcast, moonlit night and the vessels were reportedly rolling in 6 to 10 foot swells.

Observations:

The spill occurred in an area well known for its strong northerly currents. Decision makers in this incident are reported to have a totally wrong estimate of both the quantity of the spilled oil and the possible movement of oil. They observed some sheen only on the water surface at the first two days and had the wrong impression that the slick dispersed naturally. However it was later determined that a substantial slick was moving beneath the surface.

The first shore impact of oil was on December 31 at the sensitive west coast of Vancouver Island (8 days after the spill). It is clear that the time was also enough to consider alternative countermeasures at sea or trying to protect some sensitive resources along the 95 miles of shore line oiled. This delay and misperception caused mortalities around 10,000 among water fowls. Shellfish areas on Vancouver Island was at risk, so the Canadian Department of Fisheries and Oceans closed two shellfish areas to prevent possibly contaminated shel fish from reaching the market.

Case three: PATMOS

Name: Patmos
Spill Date 03/21/85
Straits of Messina, Sicily, Italy
Location: 38 15 N Latitude Longitude 015 35 E
Oil Product: Kirkuk Crude Oil
Tank Vessel
Oil quantity: 5300 Barrels

Incident Summary

On March 21, 1985, the Patmos and the Castillo de Monte-Aragon collided in the Straits of Messina. The Patmos was carrying 828,300 barrels of Kirkuk crude oil while the Castillo de Monte-Aragon was in ballast. The Patmos caught fire and was grounded on the beach of Villagio Torre Faro, Sicily. Firefighters subsequently towed the vessel off the beach to maneuver it for firefighting efforts. The fire was extinguished on March 23, and the Patmos was brought to dock at Messina, Sicily.

Observations:

"Patmos" spilled about 5,300 barrels of Kirkuk crude oil in the narrow strait of Messina which is known for variable currents. Oil moving south collected large amounts of garbage and remained near the coast near Taormina. Dispersant application was conducted in Messina on March 22 and 23. Operations were done from a variety of vessels outfitted with spray booms or fire monitors. There was no regular supervision by aircraft of the dispersant operations; hence a great deal of dispersants was applied ineffectively. About five skimming vessels were deployed at Messina, but also had little success in recovering oil because of the large amounts of garbage the slick collected.

Case four: PEURTO RICAN

Name Puerto Rican

Spill Date 10/31/84

San Francisco Bay, California

Location: 37 30 N Latitude Longitude 123 02 W

Oil Product Lube Oil, Lube Oil Additives, Bunker Fuel

Tank Vessel

Oil quantity: 38500 Barrels

Incident Summary

On October 31, 1984, at 0324, an explosion occurred on board the Tank Vessel Puerto Rican outside the SanFrancisco Bay Entrance Channel. The vessel was loaded with 91,984 barrels of lube oil and lube oil additives and 8,500 barrels of bunker fuel. Two crewmen and the pilot from the vessel were thrown into the water by the blast. The pilot and one crewman were recovered with serious burns. One crewman remained missing and was presumed dead after an extensive search. The explosion caused a relatively minor release of oil. Flames from the initial and subsequent explosions shot as high as 1000 feet into the sky. The fires on board the vessel were extinguished by late afternoon on November 1.

Following the explosion, the USCG On-Scene Coordinator (OSC) ordered the vessel towed out of the vicinity of S.Francisco Bay. The intent of the order was to minimize the potential for catastrophic environmental effect from a massive release of oil. On the basis of trajectory forecasts, the National Oceanic and Atmospheric Administration (NOAA) recommended that the vessel be towed to the vicinity of a nearby ocean dumping site (37 32 N, 122 59 W). This position is at the continental shelf break, 10 miles SE of the FarallonIslands. The ongoing firefighting and cooling efforts were hampered as the vessel moved farther from shore.

The weather worsened on November 2, with seas as high as 16 feet and wind speeds up to 35 knots. Salvage and inspection activities ceased for the day. On November 3 at 0000, the Puerto Rican broke in two, releasing 25,000-35,000 barrels of its cargo and an undetermined amount of the 8,500 barrels of bunker fuel onboard. The stern section sank one mile inside the boundary of the Point Reyes/Farallon Islands National Marine Sanctuary, taking most of the 8,500 barrels of bunker fuel with it.

<u>Observations:</u>

During the towing operation, oil was continuously leaking from the damaged vessel. The On-Scene Commander (OSC) insisted to continue the tow operation to the dumping site despite the adverse weather conditions encountered. The whole operation was not far from shore; however no attempt was made to enter a safe haven to be able to contain the leaking oil and recover it. No estimation that the hull of the vessel may not withstand these 16 feet high seas and these roaring winds. The decision makers tried to use various types of skimmers in this weather but obviously failed.

After the vessel broke-up the use of dispersants was finally approved (3 DAYS DELAY) but the late dispersant application dispersed only an estimate of none to 20% only of the slick. At the oil impacted beaches from Bodega head to Salmon creek, workers were unable to place containment and deflection booms across the mouths of many of the bays due to the swift currents.

Case five: SANKO HARVEST

Name: Sanko Harvest
Spill Date 02/13/91
Esperance, Western Australia
Location: 34 10 S Latitude Longitude 122 30 E
Oil Product: Fuel Oil
Non-Tank Vessel
Oil quantity: 4400 Barrels

Incident Summary:

On the night of February 13, 1991, the Panamanian bulk cargo carrier Sanko Harvest grounded on a submerged rock pinnacle 23 miles south of Esperance, Western Australia. The vessel, out of the shipping lane at the time of the incident, was loaded with 30,000 metric tons of fertilizer, phosphate, and triple super phosphate. The double hull of the vessel was ripped open in the grounding and the freighter began leaking its fuel oil. On February 18, the ship broke in two in a storm and sank with its entire cargo and bunker fuel. Approximately 3,500 barrels of fuel oil were spilled during the incident. The remaining 900 barrels of oil sank with the ship.

Observations:

The spill created a slick approximately 9 miles long and 1000 feet wide. The department of marine and harbors (DMH) deployed nearly 1,700 feet of containment boom around the ship in two rows. The sea and wind conditions at the time were very rough. More than two thirds of the boom was damaged at sea and lost.
The failure of the containment operation resulted in the heavy oiling of about 17 miles of the north east islands and the mainland of Australia with around 2,100 barrels of fuel oil. The sensitive beach of Cape Le Grande National Park was also contaminated. Around 200 seal pups were reportedly dead on hood island and seal rock. An unknown number of birds were also killed as a result of the spill.

Case six: SEA SPIRIT

Name: Sea Spirit
Spill Date 08/06/90
Strait of Gibraltar
Location: 35 53 N Latitude Longitude 005 58 W
Oil Product: Heavy Fuel Oil (HFO)
Tank Vessel
Oil quantity: 48875 Barrels

Incident Summary

On the evening of August 6, 1990, the Cypriot tanker “Sea Spirit” and the Norwegian Liquefied Petroleum Gas (LPG) carrier “Hesperus” collided in the Strait of Gibraltar. The Sea Spirit was holed on the starboard side above and below the waterline, causing approximately 48,875 barrels of oil to be spilled into the Mediterranean Sea.

Estimates of the total volume spilled ranged from 48,875 to 89,426 barrels. The bows of the Hesperus were destroyed, but the vessel was still capable of sailing and did not leak any of her cargo.

Prevailing currents drew the oil into the Mediterranean Sea. The oil was caught in the flow of a clockwise gyre between Morocco and Spain and made approximately two to three revolutions in the gyre over the following week, breaking up and dispersing naturally. As the main body of the oil moved in the gyre, it passed within a few miles of the Moroccan coast, near Punta de los Frailes.

The oil spread out with extensive sheen due to the warm, calm conditions at the time. Sheen and large patches of emulsified oil were visible from over flights, and reported by fishermen and observers in vessels in the waters off the coast.

Oil began to come ashore on the coasts of Spain and Morocco within a few days of the spill. The Moroccan province of Al Hoceim was the hardest hit area. The first impacts here were on August 13. Large slicks were observed in the bay and in nearby offshore areas of Al Hoceim. Most of the oiling along the Moroccan coastline consisted of a band of tar balls between two- and six feet wide. With the exception of a few sites, this band was nearly continuous for the approximately 600 kilometers of Moroccan coastline.

<u>Observations:</u>

Slicks were monitored and tracked as they neared the coast lines of Spain and Morocco. Although heavy fuel oil is known to be resistant to chemical dispersants, Spanish authorities actually used them but with very little success. Precautionary booming was used at tourist beaches in Al Hoceim but was reportedly not effective because the personnel on-scene did not have adequate training or experience to install or tend them properly. When the oil was reported to impact remote areas on the coasts of Spain, a very late request was sent to France, which contributed, by sending a monitoring aircraft. This aircraft was equipped with side loop airborne radar (SLAR) which was vitally needed since the beginning of the spill. (Arrived 4 days late). The spill occurred during the height of the tourist season along both the Spanish and Moroccan coast lines. There was a severe impact to the tuna fishing industry in morocco. Fishermen reported 70 to 80 percent reduction in their catches.

Case seven: TANIO

Name: Tanio
Spill Date 03/07/80
Brittany, France
Location: 49 10 N Latitude Longitude 004 16 W
Oil Product No. 6 Fuel Oil
Tank Vessel
Oil quantity: 98955 Barrels

Incident Summary

On March 7, 1980, the tanker Tanio, carrying 190,580 barrels of No. 6 fuel oil, broke in two off the coast of Brittany, France during a violent storm. The master and seven crew members died as a result of the accident. Approximately 98,955 barrels of oil spilled into the sea as a result of the breakup. The bow section, which still contained 36,650 barrels of oil, sank in 300 feet of water. Substantial amounts of oil continued to leak from the sunken bow until several small leaks in the bow were sealed in May. The stern remained afloat and was towed to the port of Le Havre where its remaining 54,975 barrels of oil were offloaded.

Strong northwest winds at the time of the incident moved the oil towards the Breton coast. Due to the high viscosity of the oil and severe weather conditions, containment or dispersal at sea was impossible. Because the spring tides in this region have an average tidal range of 26 feet, many areas along the coast could not be boomed effectively. Consequently, the Breton coast (which had already received major oil impacts from the Torrey Canyon spill in 1967 and the Amoco Cadiz in 1978), was again severely oiled. Approximately 45percent of the Amoco Cadiz spill area was affected by oil from the Tanio. Approximately 125 miles of the coastline of the two Departments of Finistere and Cotes-du-Nord were oiled.

Observations:

Ten priority areas were boomed & monitored. Strong currents generated by the large tidal range reduced the effectiveness of the booms, requiring the use of another stronger type of boom that took several days to deploy. At river estuaries an attempt was made to use vacuum systems, but did not work well because the hoses became blocked with stones and sea weed. The oil was also so viscous in cold days that the tractor- drawn vacuum trucks could not handle. In beach cleaning process the extensive use of bulldozers and front-end loaders pushed the oil to underlying sediments at a number of beaches. This sub-surface oiling required extensive restoration work to clean.

Case eight: ELENI V

Name: Eleni V
Spill Date 05/06/78
Norfolk, southeast coast of England
Location: 52 49 N Latitude Longitude 001 48 E
Oil Product Heavy Fuel Oil
Tank Vessel
Oil quantity: 52500 Barrels

Incident Summary

On the morning of May 6, 1978, the Greek tanker "Eleni V" was cut in two by the French vessel "Roseline" in foggy conditions off the southeast coast of England. The Eleni V was loaded with 117,280 barrels of Heavy Fuel Oil. The collision caused the release of approximately 52,500 barrels of oil. The aft section was towed to

Rotterdam by five Dutch tugs. The cargo remaining in the aft section was recovered by pumping it into storage tanks at Europort. The forward section of the vessel drifted away from the collision site. It went aground on May 8 on a sandbank near Lowestoft off the East Anglian coast with approximately 8000 barrels still on board. Attempts to salvage the forward part failed, and authorities decided to blow it up. The bow was towed to a position several miles offshore and blown up with two tons of explosives by Navy divers on May 30. Following the explosion, a large part of the remaining oil burned.

The heavy fuel oil had a viscosity of 5,000 centistokes at 20 degrees C. It formed a huge viscous slick that was brown to black in color. Oil washed ashore on the English and Dutch coasts. Oil on the shoreline formed pancakes between 0.25 and 12 inches in diameter. Oil was also reported as globules of thick mousse that appeared on the beaches. This became the worst case of marine pollution on the English coast since theTorrey Canyon spill, more than 11 years earlier.

Observations:

Although it had been predicted early in the response that this particular type of oil would not readily disperse. Nonetheless, 22 vessels were used over a period of three weeks spraying chemical dispersants on the oil?! Nearly 240,000 gallons of BP 1100D and Dasic LTD were used. The dispersant operation had virtually no effect on the oil, and almost all of it went ashore anyway.

Case nine: KHARK 5

Name: Khark 5

Spill Date 12/19/89

400 miles north of Las Palmas, Canary Islands

Location: 34 32 N Latitude Longitude 099 34 W

Oil Product Iranian Heavy crude oil

Tank Vessel

Oil quantity: 452400 Barrels

Incident Summary

On December 19, 1989, the Iranian tanker Khark 5 bound for refineries in Northern Europe exploded and caught fire approximately 400 miles north of the Canary Islands. An estimated 452,400 barrels (19 million gallons) of the 1,714,300 barrels (72 million gallons) on board spilled into the sea. The 35 crew members were rescued by the passing Soviet vessel Sarny.
Ocean currents carried the abandoned vessel south towards the Canary Islands. A Moroccan Government Response Task Force consisting of members from the Moroccan Royal Navy, Interior Ministry, Ministry of Fisheries, and the Civil Defense Force responded to the incident. According to a joint Spain/Morocco contingency plan, the Spanish government was prepared to provide aid if necessary. The Moroccan government sent a formal request to the U.S. Coast Guard for technical assistance in evaluating the situation.

An Atlantic Strike Team (AST) representative was sent to the scene on January 4, 1990. The International Tanker Owners Pollution Federation (ITOPF) provided cleanup equipment and an on-scene advisor. Smit Tak, a Dutch salvage company, repaired a 60 foot by 90 foot hole in the vessel's port side. Early efforts to tow the damaged vessel away from the shore were hampered by 8-foot waves and high winds. On January 1, a tug secured a line to the Khark 5 and began towing the vessel towards the Madeira Islands off Portugal as Morocco and Spain refused to allow the vessel close to their shores.

Observations:

During this combating operation, approximately 6,600 gallons of chemical dispersants were applied to the floating oil in the first week of January (two weeks after the spill?!). Over 1,500 gallons of Finasol OSR-2, made from hydrocarbon-based solvents were applied in two passes by six aircraft with spraying equipment. Another tug boat dispatched from Spain applied approximately 5,000 gallons of A-3 dispersants closer to shore. These dispersants were relatively ineffective, as they were applied after the oil had weathered.

Case ten: MEGA BORG

Name: Mega Borg
Spill Date 06/08/90
Gulf of Mexico, 57 miles southeast of Galveston, Texas
Location: 28 33 N Latitude Longitude 094 08 W
Oil Product Angolan Palanca crude oil
Tank Vessel
Oil quantity: 100000 Barrels

Incident Summary

On June 8, 1990 at approximately 2330, while the Italian tank vessel "Fraqmura" was lightering the Norwegian tank vessel Mega Borg, an explosion occurred in the pump room of the Mega Borg. The two ships were in the Gulf of Mexico, 57 miles southeast of Galveston Texas in international waters, but within the U.S. exclusive economic zone. As a result of the explosion, a fire started in the pump room and spread to the engine room.

An estimated 100,000 barrels of Angolan Palanca crude was burned or released into the water from the Mega Borg during the next seven days. Approximately 238 barrels of oil was discharged when the Fraqmura intentionally broke away from the Mega Borg. Explosions on the Mega Borg, caused the stern of the ship began to settle lower in the water and list to the port side. A continuous discharge of burning oil flowed over the aft port quarter of the ship. Less than an hour after the explosions on the Mega Borg, the U.S. Coast Guard (USCG) in Galveston dispatched two USCG cutters to the scene.

Observations:

Responders believed that abnormally high freshwater runoff from the Sabine River and other rivers in the area would have a tendency to keep the oil offshore. Initially the oil moved northwest toward Corpus Christi. By June 18, the leading edge of the oil slick approached the environmentally sensitive area of Sabine Pass, but was kept offshore by winds and currents. After a few days it began to move to the north and east and first came ashore on the Southwestern Louisiana coast on June 28 in the form of small tar balls scattered over a distance of 18 miles. Shorelines that suffered oiling included Holly Beach and Dung Beach in Texas, Peveto Beach in Louisiana, and the Mermentau River in Louisiana.

On June 10, four thousand gallons of Exxon Corexit 9527 were applied to part of the slick. Observers noted a definite change in the consistency of the oil slick after dispersant application but with very limited dispersion ratio. Following this another attempt was made with five aircraft sorties spraying a total of 11,300 gallons of dispersant. The results were still not prominent. It should be noted that the winds were very calm during & after the application which may not have provided enough mixing energy for maximum dispersion.

Conclusion:

It is apparent that many decision-makers have an oversimplified view in many areas and they are:

- The fate of oil in the marine environment.
- The physical and chemical characteristics of oil.
- The movement of oil on the water.
- The window of opportunity for dispersants.
- The limitations of various mechanical countermeasures.
- The remote sensing data and its role.
- The hull resistance damaged tank vessels.

The above mentioned problem areas are observed to have re-occurred along from the 70s till recent spills (e.g. ERIKA & PRESTIGE). In fact the author on purpose did not discuss those two major accidents as the media has done the job. However reading the final reports of both spills shows that the same mistakes are made again. This conclusion opened the door for many questions: Are those problems due to limited knowledge or incompetence in handling the crisis situation? Why do we keep applying massive amounts of dispersants while the oil is already weathered and non-dispersable anymore? Why do mistakes still occur about the movement of oil with the existence of trajectory models? Why are booms still used in fast flowing waters for containment and deflection purposes when they are liable to be damaged and lost without any benefit? Why do we lose precious time and money in deploying countermeasures, which sometimes are known to be ineffective in this particular spill? Why is the issue of pumping viscous oils not always considered and the whole recovery operation fails? Why is the remote sensing data not utilized properly to aid in quantifying the potential risks? Why do seal pups, birds, fisheries and tourist businesses have to pay every time a spill occurs?

This study tries to answer some of these questions in an attempt to provide a decision support tool for oil spill decision makers.

The cases studied were mainly selected from a book published by NOAA in September 1992 with the title of “oil spill case histories 1967 – 1991: summaries of significant U.S and international spills”.

APPENDIX TWO

QUESTIONNAIRE

This questionnaire is a part of research work seeking for better ways of providing information to decision makers who have to respond to oil spills. I am interested in your views regarding these issues. So your responses will be most helpful if you answer directly without referring to any material.

Please note that this is anonymous. No one is going to grade the results. None of the questions are designed to be tricky; many of the questions do not have a "right" or "wrong" answer. The answers will be analyzed on the basis of groups of decision makers. Results from your questionnaire will be kept strictly confidential.

The first section is related to oil spills in the marine environment unless stated otherwise.

The second section is related to oil spill management simulators (OSMS) unless stated otherwise.

(For section one)

- *The percentages mentioned represent the correct answers at the correct end of the scale (e.g. True or maybe True, if the correct answer was true).*
- *The correct answers are in Bold.*
- *The response rate was 38 / 80 or 47.5%.*
- *All figures are approximated.*
- *One person represents about 2.6 % of the sample.*
- *Data collected starting from July 2002 until August 2003.*

"*Result analysis is at the end of the Questionnaire*"

SECTION ONE:

1. Crude oils are often difficult to disperse chemically more than 10 hours after the spill.

   True---maybe true---don't know---maybe false---false (*correct 70%)*

2. Oil spilled on water tends to spread uniformly (horizontally in all directions at the same rate).
   True---maybe true---don't know---maybe false---**false** (*correct 50%)*

3. Under optimal conditions, chemical dispersants can remove over 60% of the oil from the ocean surface.
   True---maybe true---don't know---maybe false---false (*correct 50%)*

4. As oil weathers, its dispersability decreases rapidly.
   True---maybe true---don't know---maybe false---false (*correct 80%*)

5. Recovery of over 25% of spilled oil is common with mechanical response options.
   True---maybe true---don't know---maybe false---**false** (*correct 30%*)

6. Immediately after correct application, concentrations of dispersants in the top few meters of water may be high enough to cause lethal or sublethal effects on some organisms.
   True---maybe true---don't know---maybe false---false (*correct 40%)*

7. Evaporated oil oxidizes into environmentally safe compounds.
   True---maybe true---don't know---maybe false---false (*correct 20%)*

8. If the spilled oil's pour point is higher than the water temperature, dispersants are likely to be effective.
   True---maybe true---don't know---maybe false---false (*correct 30%)*

9. Within the normal range of operating dosage, ecological effects are due primarily to the dispersed oil, not the dispersant.
   True---maybe true---don't know---maybe false---false (*correct 50%)*

10. Assuming there are no strong currents or tides, wind will cause an oil spill to drift at a velocity equal to 3-4% of the wind speed.
   True---maybe true---don't know---maybe false---false (*correct 90%)*

11. Accurate predicting of the trajectory of a specific oil spill can be done by using the latest computer models.

    True---maybe true---don't know---maybe false---false (*correct 80%)*

12. Dispersants should be tested on a small area of the spill before they are applied to an entire spill.

    True---maybe true---don't know---maybe false---false (*no specific answer*)

13. Booms can be effective in containing spilled oil in currents up to 4 knots.

    True---maybe true---don't know---maybe false---**false** (*correct 40%)*

14. Reserve buoyancy of a boom is the prime factor affecting its performance.

    True---maybe true---don't know---maybe false---false (*correct 30%)*

15. Oil emulsion viscosity may raise up to 1000 times the original spilled oil viscosity.

    True---maybe true---don't know---maybe false---false (*correct 60%*)

16. The in-situ burning process of oil spills can be enhanced by using emulsion breakers.

    True---maybe true---don't know---maybe false---false (*correct 20%)*

17. Entrainment (escape) of oil under a boom occurs with higher rate in emulsified oils rather than in fresh ones.

    True---maybe true---don't know---maybe false---false (*no specific answer*)

18. Bio-degradation of physically and /or chemically dispersed oil is a minor mechanism for the elimination of petroleum pollutants from the marine environment.

    True---maybe true---don't know---maybe false---**false** *(correct 40%)*

19. Photolysis (breakdown due to exposure to UV) of physically and/or chemically dispersed oil is a minor mechanism for the elimination of petroleum pollutants from the marine environment.
    True---maybe true---don't know---maybe false---**false** *(correct 30%)*

20. "Effective" dispersant use implies that a minimum of 50% of oil has been removed from the ocean surface.
    True---maybe true---don't know---maybe false---false (*no specific answer*)

21. Some oil sorbent materials are listed among hazardous substances in many countries.
    True---maybe true---don't know---maybe false---false (*correct 50%)*

SECTION TWO:

- *The response rate for this section was 27 / 50 or 54%.*
- *All figures are approximated.*
- *One person represents about 3.7 % of the sample.*
- *Data collected starting from May until August 2003.*
- *Numbers from 1-3 are considered on the ineffective-not true-disagree side.*
- *Numbers from 5-7 are considered on the effective-true-agree side.*
- *The number 4 is considered either hybrid or the participant simply does not know any answer.*

1. How effective are oil spill management simulators (OSMSs) for training on the following topics:- (please circle your answer)

a) Communications in a team?
   Very effective 7 6 5 4 3 2 1 very ineffective
   (*Effective side 90%--- hybrid 0%---ineffective side 10%)*

b) Technical skills?
   Very effective 7 6 5 4 3 2 1 very ineffective
(*Effective side 80%--- hybrid 0%---ineffective side 20%)*

c) Emergency procedures?

Very effective 7 6 5 4 3 2 1 very ineffective

(*Effective side 60%--- hybrid 20%---ineffective side 20%)*

d) Coping with stress?

Very effective 7 6 5 4 3 2 1 very ineffective

(*Effective side 10%--- hybrid 70%---ineffective side 20%)*

e) Leadership qualities?

Very effective 7 6 5 4 3 2 1 very ineffective

(*Effective side 40%--- hybrid 40%---ineffective side 20%)*

f) General teamwork?

Very effective 7 6 5 4 3 2 1 very ineffective

(*Effective side 40%--- hybrid 30%---ineffective side 70%)*

g) Early error detection?

Very effective 7 6 5 4 3 2 1 very ineffective

(*Effective side 30%--- hybrid 50%---ineffective side 20%)*

2. To what extent do you agree with the following statements regarding the effectiveness of oil spill management simulators?

a) For a simulator to be effective it is important to establish that the trainee has better performance than before he or she started the training with the simulator.

Very true 7 6 5 4 3 2 1 Not at all true

(True side 10%---hybrid 40%---not true side 50%)

b) For a simulator to be effective it is important to establish that the trainee has better performance following use of the simulator than she or he would have had using a different method (e.g. lecture or text book)

Very true 7 6 5 4 3 2 1 Not at all true

(True side 60%---hybrid 20%---not true side 20%)

c) For a simulator to be effective it is important to establish that the trainee has better knowledge than before she or he started the training with the simulator.

Very true 7 6 5 4 3 2 1 Not at all true

(True side 20%---hybrid 0%---not true side 80%)

d) For a simulator to be effective it is important to establish that the trainee has better knowledge following use of the simulator than she or he would have had using a different method (e.g. lecture or text book).

Very true 7 6 5 4 3 2 1 Not at all true

(True side 20%---hybrid 10%---not true side 70%)

e) For a simulator to be effective it is important that the trainee has better skills than before she or he started the training with the simulator.

Very true 7 6 5 4 3 2 1 Not at all true

(True side 70%---hybrid 20%---not true side 10%)

f) For a simulator to be effective it is important to establish that the trainee has better skills following use of the simulator than she or he would have had using a different method (e.g. lecture or text book).

Very true 7 6 5 4 3 2 1 Not at all true

(True side 20%---hybrid 0%---not true side 80%)

3. To what extent do you agree with each of these statements: -

a) Individuals trained using simulators have a better standard of training than those without training on simulators.

Totally agree 7 6 5 4 3 2 1 totally disagree

(Agree side 80%---hybrid 0%---disagree side 20%)

b) Some individuals benefit a great deal more than others when being trained on simulators.

Totally agree 7 6 5 4 3 2 1 totally disagree

(Agree side 70%---hybrid 0%---disagree side 30%)

c) The usefulness of a simulator usually outweighs the cost of a simulator.

Totally agree 7 6 5 4 3 2 1 totally disagree

(Agree side 60%---hybrid 20%---disagree side 20%)

d) Most decision makers feel they learned a great deal more on simulators than By using other methods.

Totally agree 7 6 5 4 3 2 1 totally disagree

(Agree side 80%---hybrid 10%---disagree side 10%)

Result Analysis: (Section one)

-The questions in section one are divided into general oil spill knowledge questions (e.g. questions 1 to 6) and more technical questions (e.g. questions 7, 8 & 16).

- The highest percentage of correct answers obviously was in the general oil spill knowledge questions with a decreasing trend as the questions got more technical. However an exception was detected regarding question number 13, where 70% of the participants had the perception that Booms could contain oil in current rates up to 4 knots which is totally wrong even in optimum deployment conditions.

- The average percentage of correct answers for the general oil spill knowledge questions (questions: 1-2-3-4-5-6-9-10-11-13 &21) was 49%. This clearly indicates that almost half of the participants still have limited knowledge about general information about oil spills and countermeasures.

- The average percentage of correct answers for the more technical questions (questions: 7-8-14-16-18 & 19) was only 28% which further indicates the lack of adequate technical knowledge about fate of oil spills and the validity of various countermeasures.

- Questions which do not have specific answers (questions: 12-17 & 20) were answered either on the true or false side. However neither of the participants circled the “do not know” answer, which may indicate the tendency of oil spill decision makers to build up their own perceptions (which could be wrong) on some issues or a certain countermeasure.

- Another observation was the very low percentage of correct answers when the issue was related to a new applied technology (e.g. question 16). About 70% of the participants answered “do not know” which could indicate that the knowledge of such personnel needs continuous upgrading and familiarization with the latest trends in spill combating technologies.

- In the light of the above mentioned results (combined with observations from the cases studied) the author decided to investigate some of these technical aspects which produced the lowest percentage of correct answers in this questionnaire. Chapters two, three and four of this study are an attempt to clarify some of the indistinct technical areas which constitutes a vital pre-requisite to a more sound decision in oil spill crisis management.

Result Analysis (Section Two)

The questions in this section were initially meant to verify whether decision makers can differentiate between knowledge and competence issues in relation to oil spill combating. The questions also try to sense oil spill current and potential decision-makers (DMs) perceptions about using Oil Spill Management Simulators (OSMSs) in building up combating skills in the lack of field training.

There was consensus among DMs about the effectiveness of OSMSs in the areas of enhancing technical skills and communication in a team. However DMs remained skeptical about the ability of such simulators to provide the necessary levels of stress in training environments, or their role in enhancing teamwork skills.

There seem to be clear miss-understanding among DMs about the actual role of OSMSs. Most participants valued the simulator training approach in comparison to other means of obtaining knowledge, which is quite misleading. OSMSs should be assessed as a stand alone means of training (if available) as they mainly contribute in enhancing competence not knowledge.

DMs agreed that simulators in-general provide a high standard training tool and this could prove valid for training on oil spill crisis management. DMs also agreed that OSMSs usefulness for trainees outweighs their establishment expenses.

In the light of the above results the author decided to investigate the process of building up a sound decision and the outstanding training issues needed in chapters four and five of this study. This investigation is also meant to introduce such new training approach for oil spill decision makers and fill the identified gaps in their competence levels while handling oil spills.

This questionnaire and the correct answers were compiled from the following sources in addition to interviews carried out during field studies.

- Scientific and Environmental Associates, (1997). Ecological issues on dispersant use: decision-makers perceptions and information needs. Alexandria, VA.
- American petroleum institute, (1986). The Role of Chemical Dispersants in Oil Spill Control. American Petroleum Institute: Washington, DC.
- National Research Council, (1985). Oil in the Sea, Inputs, Fates and Effects. National Research Council: Washington, DC.
- Haberley,J., Barnett,M. & Gatfield, D. (2001). Simulator training for handling and escalating emergencies. MCA. SouthHampton.

Appendix Three

Field Studies Related to this Research

A.3.1 introduction

This appendix lists all the oil spill related institutes, factories or organizations visited during the field studies program of WMU. In each of these visits the author established communication with the spill responsible staff, either related to management of spill response, training of responders or manufacturing of training and combating equipment and software. Some personnel were interviewed and some agreed to answer the questionnaire (see appendix 5) but almost all stressed on their anonymity.

A.3.2 List of the visits

A.3.2.1 Norwegian Maritime Directorate in Oslo (Norway)

Date: 2nd. September 2002

The Environment Protection department staff was interviewed about the existing spill organization in cases of major spills to have an overall idea about the chain of command and the background of personnel involved in this organizational structure.

A.3.2.2 Det Norske Veritas (DNV) head quarters at Hovik (Norway)

Date: 3rd. September 2002

The certification staff was interviewed about the class surveys relating to hull integrity and how this could contribute in the future avoidance of major spills.

A.3.2.3 The Norwegian State Pollution Control Authority in Horten (Norway)

Date: 4th. September 2002

The staff delivered a briefing about the preparedness of this organization against acute pollution cases. They were later interviewed about the competence levels and expertise of members of command and control in cases of major spills. Some staff agreed to answer the questionnaire.

A.3.2.4 The Norwegian Ship owners' Association in Oslo (Norway)

Date: 5th. September 2002

The staff delivered a briefing about the role of such non-governmental organization (NGO) in environmental protection, later they were interviewed on their technical or financial support to other NGO's in developing countries to upgrade their ability to combat major oil spills.

A.3.2.5 M/V Gunnar Thorson (Denmark)

Date: 26th. September 2002

A small scale exercise to demonstrate the deployment of booms and skimmers in the Oresund by the Danish oil-spill combating staff. Some of the officers and crew were interviewed and one officer agreed to answer the questionnaire.

A.3.2.6 ChemControl and Ro-Clean Desmi (Denmark)

Date: 27th. September 2002

ChemControl is a chemical treatment plant, while Ro-Clean Desmi is a giant manufacturer for spill combating equipment (booms, skimmers, transfer pumps etc.). Some technical staff were interviewed about the research and development projects in-progress and how are they endeavoring to enhance the efficiency of their products. One of the training staff also answered the questionnaire.

A.3.2.7 Danish Maritime Authority (Copenhagen)

Date: 17th. November 2002

The DMA was visited; some oil spill management and training personnel delivered some lectures and was later interviewed by the author about decision-making strategies in cases of major oil spills. Some also agreed on answering the questionnaire.

A.3.2.8 Tanker terminal in Kalundborg (Denmark)

Date: 18th. March 2003

The terminal spill combating facilities were thoroughly studied and the pier Master was interviewed on procedures of crisis communication in cases of major spills.

A.3.2.9 Germanischer Lloyd, Head Office in Hamburg (Germany)

Date: 3rd. March 2003

Interviewed the classification society staff on their role in certifying local, regional and international spill combating organization and how do they contribute in promoting the standards of oil spill decision-makers.

A.3.2.10 Finnish Maritime Administration (FMA) in Helsinki (Finland)

Date:1st. To 3rd. April 2003

Various personnel in the environment section were interviewed in this lengthy visit on their views and opinions about the adequacy of the levels of training delivered to the spill combating and organizational staff in Finland and the role of the training institutes in this process.

A.3.2.10 Maritime and Coast Guard Agency (MCA) in Southampton (UK)

Date: 27th. May 2003

The central command center for handling oil spills in UK was situated in the same room. An interview was conducted with the counter pollution staff head on the training and competence issues of staff. The co-operation between MCA and the Oil Spill Response Limited (OSRL) was described as an example of successful links with NGOs. The command centre communication facilities were described by responsible staff and a briefing about technical facilities was delivered. Many of the staff agreed to answer the questionnaire and some copies were sent to OSRL as well.

A.3.2.11 International Maritime Organization (London)

Date: 30th. May 2003

The Technical Co-operation Division staff was interviewed about the role of IMO in providing vitally needed training courses in developing countries for spill combating and management staff. The interviews was extended also to some delegates and representatives of NGOs attending the MSC 77 plenary sessions in an attempt to verify the various views relating to training and competence of oil spill decision makers in various countries.

Appendix Four

Dispersant Effectiveness Measurements

Dispersant effectiveness is defined as the amount of oil that the dispersant puts into the water column versus that which remains on the surface. The results of these tests show the typical trends of decrease in effectiveness with weathering. One of the main findings of these extensive laboratory tests is that: this pattern of effectiveness decrease with increased weathering <u>is oil specific</u> and does not correlate with simple oil properties such as density, viscosity or maximum weathering conditions

Results of Recent Dispersant Effectiveness Measurements

Oil	Dispersant	Effectiveness %	Std. Dev.
Adgo	Corexit 9500	28.6	9.1
AEA Medium	Corexit 9500	47.8	2.0
AEA Medium	Corexit 9527	54.1	2.9
AEA Medium	Dasic Slickg.	48.7	4.9
Alaska North Slope	Corexit 9500	46.1	6.9
Alberta Sweet Mixed Blend	Corexit 9500	40.0	6.3
Alberta Sweet Mixed Blend	Corexit 9527	29.9	5.9
Alberta Sweet Mixed Blend	Enersperse700	22.5	4.0
Alberta Sweet Mixed Blend	Oriclean	1.1	1.0
Arabian Heavy (2000)	Corexit 9500	15	
Arabian Light	Corexit 9500	21.4	2.0
Arabian Light 12.04% Weathered	Corexit 9500	17.2	0.6
Arabian Light 24.20% Weathered	Corexit 9500	13.6	0.1
Arabian Medium	Corexit 9500	22.7	1.0
Arabian Medium 13.15% Weath.	Corexit 9500	17.2	0.3

Oil	Dispersant	Effectiveness %	Std Dev.
Dos Cuadras 11.17% Weathered	Corexit 9500	15.4	2.7
Dos Cuadras 11.17% Weathered	Corexit 9527	8.2	3.4
Dos Cuadras 11.17% Weathered	Dasic LTS	8.0	0.3
Dos Cuadras 11.17% Weathered	Enersperse700	10.4	1.2
Dos Cuadras 20.30% Weathered	Corexit 9500	6.9	0.3
Dos Cuadras 20.30% Weathered	Enersperse700	2.3	1.6
Empire	Corexit 9500	31.4	3.4
Eugene Island Block 32	Corexit 9500	17.9	2.3
Eugene Island Block 32	Corexit 9500	45.4	6.7
Eugene Island Block 32	Corexit 9500	44.4	2.3
Eugene Island Block 32	Corexit 9500	44	
Eugene Is B. (13 % weathered)	Corexit 9500	22	
Eugene Is B. (20% weathered)	Corexit 9500	18	
Eugene Island B. (6% weathered)	Corexit 9500	30	
Eugene Island Block 43	Corexit 9500	2	
Federated	Corexit 9500	39.0	54
Federated	Corexit 9527	20.4	2.5
Federated	Dasic LTS	19.3	3.0
Federated	Enersperse700	15.1	1.1
Federated 15.5% Weathered	Corexit 9500	38.3	2.2
Federated 15.5% Weathered	Enersper 700	12.6	1.s
Federated 28.5% Weathered	Corexit 9500	21.6	4.1
Federated 28.5% Weathered	Corexit 9527	4.0	1.4
Federated 28.5% Weathered	Dasic LTS	9.4	1.s
Federated 28.5% Weathered	Enersper 700	2.5	0.3

Oil	Dispersant	Effectiveness %	Std. Dev.
Granite Point	Enersper 700	27.3	3.1
Granite Point 45.3% Weathered	Corexit 9500	13.9	4.2
Green Canyon Block 184	Corexit 9500	47.2	4.5
G.C.B.184 12.12% Weathered	Corexit 9500	33.0	30
G.C.B.184 26.03% Weathered	Corexit 9500	25.2	2.0
G.C.B.184 38.21% Weathered	Corexit 9500	22.4	3.0
Hebron M-04	Corexit 9500	<10	
Hebron M-04 (9% weathered)	Corexit 9500	<10	
Hebron M-04 (16% weathered)	Corexit 9500	<10	
Hebron M-04 (23% weathered)	Corexit 9500	<10	
Hibemia (1999)	Corexit 9500	21	
Hibemia (1999) (10% weathered)	Corexit 9500	17	
Hibernia (1999) (20% weathered)	Corexit 9500	15	
Hibemia (1999) (32% weathered)	Corexit 9500	11	
High Viscosity Fuel Oil	Corexit 9500	0.0	0.0
Hondo	Corexit 9500	8.3	13
Hondo	Enersper 700	4.0	1.6
Hondo 12.38% Weathered	Corexit 9500	0.0	0.0
Hondo 12.38% Weathered	Corexit 9527	0.0	0.0
Hondo 12.38% Weathered	Dasic LTS	0.0	0.0
Hondo 12.38% Weathered	Enersper 700	0.0	0.0
Hondo 16.7% Weathered	Corexit 9500	6.3	5.0
Hondo 29.76% Weathered	Corexit 9500	0.0	0.0
Hondo 29.76% Weathered	Corexit 9527	0.0	0.0
Hondo 29.76% Weathered	Dasic LTS	0.0	0.0
Hondo 29.76% Weathered	Enersper 700	0.0	0.0
Hondo 32.2% Weathered	Corexit 9500	4.3	1.0

Port Hueneme 4.16% Weathered	Dasic LTS	2.3	0.9
Port Hueneme 4.16% Weathered	Enersper700	4.0	0.7
Port Hueneme 6.37% Weathered	Corexit 9500	1.9	1.3
Port Hueneme 6.37% Weathered	Corexit 9500	6.2	4.0
Port Hueneme 6.37% Weathered	Dasic LTS	1.0	0.8
Port Hueneme 6.37% Weathered	Enersper 700	6.8	2.6
Prudhoe Bay	Corexit 9500	17.9	3.3
Prudhoe Bay 18% Weathered	Corexit 9500	2.5	5.6
Prudhoe Bay 27% Weathered	Corexit 9500	0.0	0.0
Sakhalin	Corexit 9500	83.9	4.3
Sakhalin	Corexit 9527	78.5	5.1
Sakhalin 25.04 % Weathered	Corexit 9500	48.5	7.9
Sakhalin 45.19 % Weathered	Corexit 9500	31.0	0.8

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Source of this data was a paper presented to the 2001 Arctic and Marine Oil Spill Program (AMOP) Technical Seminar by : Merv Fingas, Ben Fieldhouse, Lise Sigouin, Zhendi Wang and Joseph V.Mullin.

Appendix Five

The Incident Command System

A.5.1 introduction

This appendix briefly describes the components and structure of the incident command system (ICS) and how can it be introduced in training oil spill decision makers.

A.5.2 Organization structure

The following out line of the full ICS system is illustrated in fig. A.5.1

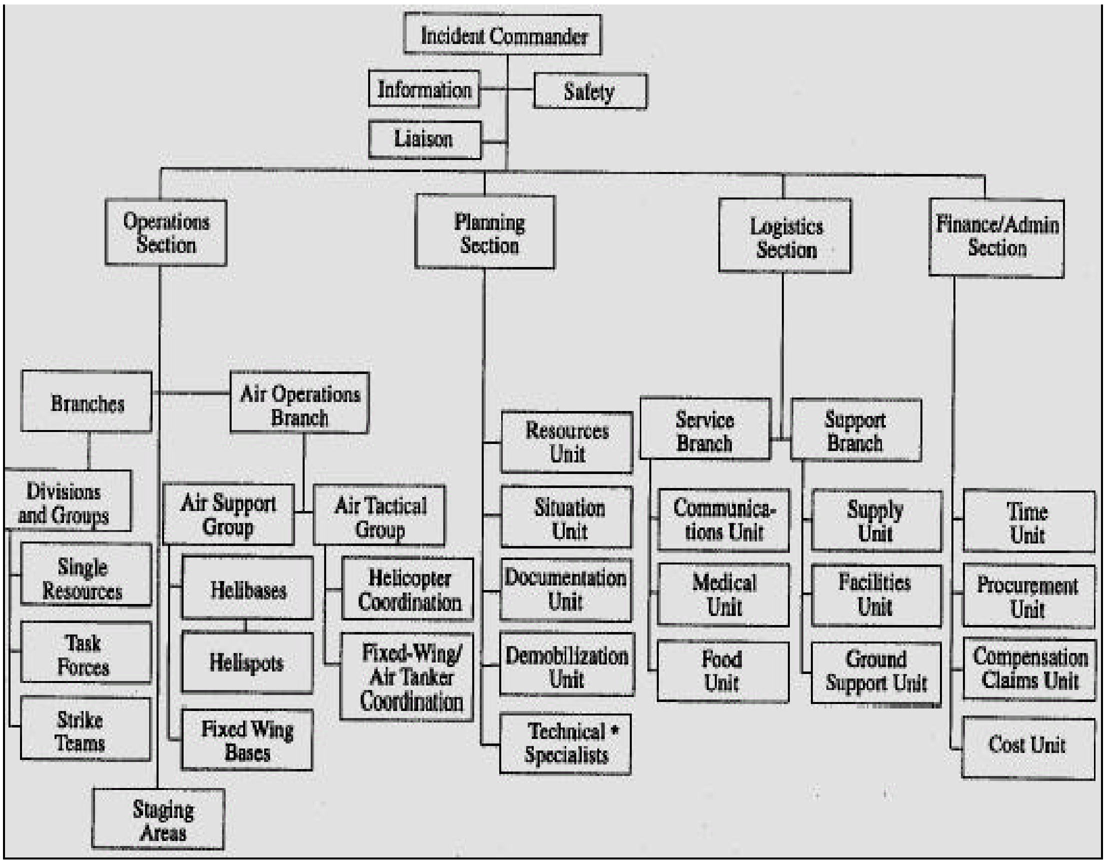

Fig.A.1 Full Incident Command Organizational chart

This full structure is mainly applicable to major spills on the national or international level, but it could be modified according to the scope and severity of each oil spill case. For training purposes the decision makers should be assigned the following duties (see fig.A.2) in order to qualify a team capable of handling a spill crisis using such command system.

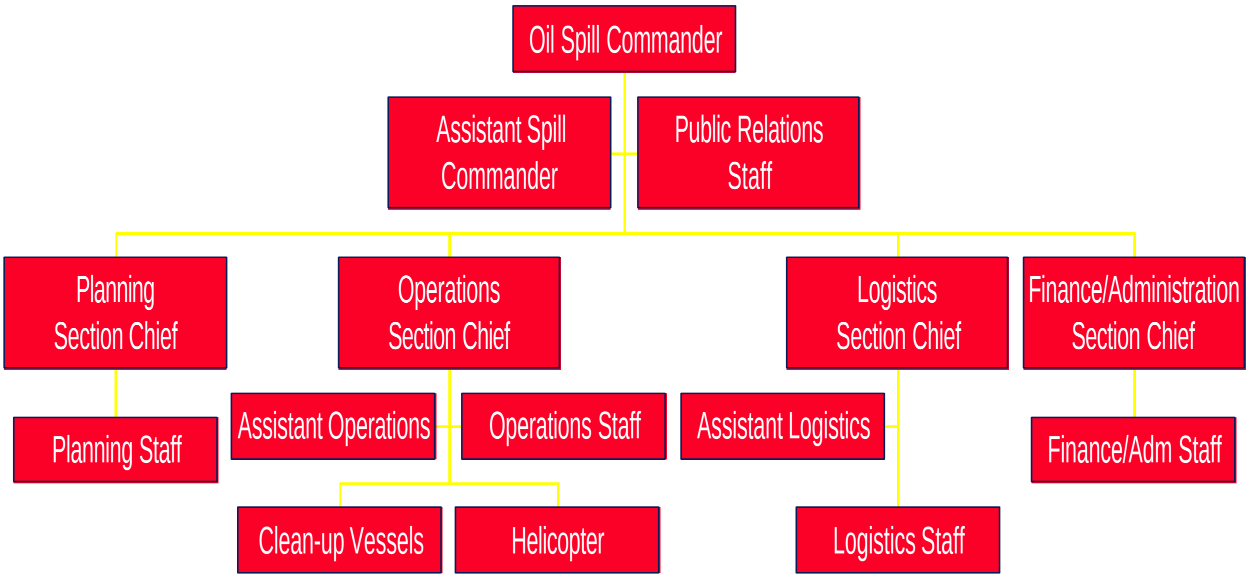

Fig. A.5.2 proposed training posts for ICS system

A.5.3 Responsibilities of the Command Team

The following responsibilities are applicable to actual spill cases as well as during simulated training exercises.

A.5.3.1 Incident Commander

- Assess the situation
- Determine Incident Objectives and strategy
- Establish the immediate priorities
- Establish an Incident Command Post
- Establish an appropriate organization
- Ensure planning meeting are scheduled as required
- Approve and authorize the implementation of an Incident Action Plan
- Ensure that adequate safety measures are in place
- Coordinate activity for all Command and General Staff
- Coordinate with key people and officials
- Approve requests for additional resources or for the release of resources
- Keep political powers informed of incident status
- Approve the use of trainees, volunteers, and auxiliary personnel
- Authorize release of information to the news media
- Order the demobilization of the incident when appropriate

A.5.3.2 Operations section Chief (On-scene Commander)

- Contain the incident
- Recover as much as possible
- Treat when possible
- Store and dispose the recovered products if there is any
- Maintain Unit Log

A.5.3.3 Planning section Chief

- Collect and process situation information about the incident (documentation)
- Supervise preparation of the Incident Action Plan
- Determine need for any specialized resources in support of the incident
- Provide periodic predictions on incident potential
- Collect current weather information
- Demobilization at the end of the incident
- Maintain Unit Log

A.5.3.3 Logistics section Chief

- Provide different types of transport
- Supply the operational team with
  - Treatment products
  - Working equipment
  - Fuel and other materials
- Assure the repair and maintenance of equipment
- Provide personnel's food and lodging
- Maintain Unit Log

A.5.3.4 Finance and Administration section Chief

- Keep records of operations (forms)
- Order for the necessary materials and equipment
- Prepare subsequent indemnity files
- Recruit reinforcements
- Prepare assistance contracts
- Maintain Unit Log

Finally it should be noted that this system can be also used by local response organizations for combating minor spills by compacting the structure and modifying the duties of the staff involved as needed.

> The information in his appendix was compiled from the USCG publication titled "Incident Management Hand Book" publication COMDTPUBP3120.17. Published in 2001.