Lessons and recommendations from the Prestige disaster

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Abstract

As usual, as was the case with the M/V *Prestige*, a serious catastrophe calls for major commitments of different social groups: first of all whose subsistence was directly menaced by the disaster, and then those thousands of anonymous volunteers, military, health workers, ecologists, and scientists. These are actually just a drop in the ocean.

As the disaster posed a serious challenge to us all, it also offered a breakthrough for the development of new methods and improvement of existing tools.

This paper will stress the main conclusions and recommendations of the Prestige Workshop within the Environment 2010 Conference held in Porto last May. This workshop was a forum to discuss model improvements, particularly concerning near surface, wind driven transport processes, data assimilation, operational approaches (including developing observational methods), subsurface horizontal transport and uprising of hydrocarbons from the deep. It was an opportunity to discuss methods of pollution containment and removal, both near shore and around the sunken wreck. Finally, the participants have discussed the ecological consequences of this kind of disasters, a subject that is far from gathering a wide consensus.

Keywords: Prestige disaster, environmental and biological aspects, prediction models, monitoring systems.

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)
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1 Introduction

On 13th November 2002, the tank ship Prestige-Nassau had an oil spill in front of coast of Galicia (NW Spain). It starts to travel to the north and continues spilling. After this, it changes its track to the south. The ship spills around 10000 Tm during its travel. The ship was sunk on 19th November in the Galician Bank, at 133 NM of Galicia coast and 3500 m depth, spilling about 10000 tm more, [1].

Afterward, the slick from the sunken time started to move towards the coast of Galicia. On 28th November 2002, many big oil patches appeared at the south of the main slick, when this was close to the slope of the sell. These slicks were not observed by over flights until then. It is supposed that this slick became under the water, so its movement is forced by Ekman layer. On 1st December, oil spill arrives to Cape Finisterra. After the 3rd December, wind from North East favoured the driving of the spill towards to the southwest. This drift is slower than in the first moment and the slick was situated in front of the coast of Portugal. From 14th December, wind changes again to be from the South and its intensity rises. The main area of patches starts to travel towards the north quickly such that on 30th December this slick is in the middle of the Cantabric Sea.

The sunken ship continued spilling oil at a rate of 150 Tm/day. A very light but big slick was placed from the sunken ship location to the middle of Cantabric Sea. This slick was forced with the wind, reaching French and North Spanish coast.

The *Prestige* disaster posed a serious challenge and offered a breakthrough for the development of new methods and improvement of existing tools.

Analysing the workshop presentations one can divide them in three main categories, each one related with one important area of work and research, concerned with oil spills. These categories are: the field work, the modelling issues (surface and underwater dispersion) and the biological aspects.

For this reason this report is divided in those main sections, finalized by general conclusions and recommendations that could be presented.

2 Analysis of field activities

According to the presentations from the three countries involved in this event, namely Portugal, Spain and France it’s possible to understand not only all the work that was carried out, but also some of the measures taken during the crisis period and that could give some important lessons and recommendations for future events.

Looking at the activities taken by the Portuguese Air Force, [13], it is important to stress the constant coordination between Squadron Operations and the Maritime Surveillance Cell (MSC), which is hosted in the Operational Command of the Air Force (COFA).

Any indication of pollution in the sensors was prompted investigated by the Navigator in order to obtain visual confirmation. It was then the OPAUX's responsibility to document the pollution and obtain proof with photographic, video and digital imagery. It was also necessary to determine the boundaries of

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

the pollution, characterize the type of pollution, as well as calculate both the area covered and the total volume. Observations regarding the current meteorological and sea conditions of the area were then transmitted on real time to oil pollution combat ships by radio, to guide the cleaning vessels to the polluted areas until they reached the areas affected by the oil slicks.

In the 18th November 2002, Air Force (AF) performed the detection and evaluation of M/V Prestige, who was towed out of Spanish coast to Portuguese waters. When the sinking took place, in the 19th November 2002 (am), data was collected with electronic sensor (SLAR – Side Looking Airborne Radar) and annotated. This sensor is too much sensitive and in some cases is difficult to distinguish the spills. For that reason the visual confirmation was also needed. In coordination with Portuguese Navy and Instituto Hidrográfico (IH) the AF performed electronic detection and evaluation of oil spills, data updating to support drifter's models generated by IH, collecting colour images (slide and video) and guiding oil pollution combat ships to oil spills in drift approaching the coast line.

The Oil Spill Polution Combat Service (*Serviço de Combate à Poluição no Mar por Hidrocarbonetos*) of the Portuguese Maritime General Authority (*Direcção-Geral da Autoridade Marítima*) is an operational pepartment alert. The department needs to collect the maximum available data regarding the problem, to consult national data bases and start a dialogue with international organizations dealing with these matters, [3].

It is also their duty to support the responsible for the Maritime Departments (*Chefes dos Departamentos Marítimos*) and the Port Captains (*Capitães dos Portos*) regarding the implementation of their Contingency Plans as well as to cooperate in the drills, in coordination with the Harbours' Responsible (*Capitanias do Porto de Leixões, Viana do Castelo e Caminha*), in order to reinforce the capacities of these local maritime authorities.

Another mission of the Department is to participate in the Maritime Authority Consulting Council (*Conselho Consultivo da Autoridade Marítima*). The tasks include technical advices and elaboration of possible scenarios to the operations during the evolution of each situation. According to the available information, several scenarios to the operations related to this incident were developed. All of them pointed out to an intervention at the sea. Thus, a special skimmer, the Transrec 250, was installed to store the recovered pollutants. In addition, navy and private vessels were used. They were equipped with booms, pumps, skimmers and storage tanks to support all tasks at the sea operations. On shore, there were also other resources.

The POLMAR plan (MARitime POLlution fight plan) was set up in France to face the pollution that arrives on the French coasts coming from the Prestige tanker wreck. In the following days after the disaster and in order to help the POLMAR aircrafts equipped with different kind of sensors, the French Navy decided to test the feasibility of an airborne hyper spectral survey to detect and map the pollution.

An aerial remote sensing campaign was mobilized by AvelMor (France) and Borstad (Canada), to obtain multispectral CASI imagery over the spill off the coasts of Portugal and Spain, [4]. The detection was made using the fluorency properties of oil slicks.

In spite of the poor weather the required images were acquired, calibrated, geometrically corrected and resampled on a ground station installed in Portugal. All of the images obtained were further analysed and accurate maps of oil extents were produced including large surface oil slicks, small tarry dispersed oil slicks (> 5 m^2), sheens of oil yellow slicks, and probably subsurface oil slicks. Visual confirmation was also needed.

The spatial and spectral signatures of the different kinds of oil slicks were obtained, as well as the optimal spatial and spectral configurations of the CASI images for cartographic mapping of the oil spills.

The Portuguese Naval Command usually requires Instituto Hidrográfico (IH) to compute forecasts of surface drifts to be used as tool to assist the Search and Rescue (SAR) operations. Winds are downloaded from a global meteorological model in order to force a very simple model of wind induced surface drift. A forecast was produced and an estimate of the area and time of impact at the coast was computed. As the ship was being towed new drift estimates were computed, guaranteeing that the spill posed no immediate danger to the Portuguese coast. Continued production of drift forecasts provided solid grounds for the operational and political decisions that were taken.

As the sinking took place a sound system was established where continuous monitoring of the spill drift by airborne and surface observations (including satellite tracking of surface drifters) was used to feed the predictions.

The concern was, however, expressed that processes other than surface response to wind forcing would have to be taken into account as the continental margin was approached. These included the adjustment of the ocean's interior to a rapidly sloping bottom, the input of river water giving rise to costal currents, and the effect of sea and swell, particularly in the generation of a littoral drift current obtained from a high-resolution model (Mocassim), capable of improving the predictions by adjusting them to the oceanographic fields, as they are observed. Data were obtained from basically two sources: satellite derived sea surface temperatures, and CTD data.

The predictions of the surface drifts were improved through the supply of indications about the surface current fields and the sea and swell conditions. As the wind drifts were forecasted they were, on the other hand, compared with the observed drifts of the fuel spill and the surface drifters. This led to improvement in the parameterisation of the simple model that, in turn, led to better predictions.

3 Prediction models and monitoring systems

In the frame of the French POLMAR plan already referred, the "Service Hydrographique et Océanographique de la Marine", France (SHOM), [2], implemented several actions and ran its general circulation oceanographic models in order to help forecasting surface oil slicks drifts, [5].

Environmental briefing dockets were supplied to the experts group, which took place in CEDRE (Centre d'Étude et de Documentation sur les Pollutions

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

Marines, France), whose aim was to provide a synthetic description of the general environmental conditions (geophysical, meteorological, oceanographical) of the polluted areas.

In coordination with CEDRE, series of surface and subsurface drifters (surface PTR, 15 m and 75 m depth SURDRIFT buoys) were deployed, in order to follow surface drifts of the main oil slicks. A report, analysing the observed buoys trajectories, was used to forecast the 24 h drift trends of oil slicks. Analysis of satellite observation data was also used, but the time-schedule of data reception seldom allowed the data to be effective.

Evaluation and forecasting oceanographic reports were also prepared, whose aim was to supply real time support decision aids for the coordination of the POLMAR aircrafts for the observation and detection of oil slicks and those relative to the ships on area for oil pumping actions.

Objectives of this modelling was to better understand, explain and reproduce which were the main processes participating on surface and sub-surface oil slicks drifts. The experts took a decision, taking into account the lack of good observational data.

Besides the oil spills, registered on the sea surface, the Prestige oil, after sinking, escaped by several tank breathers and cracks in the hull. The study of the oil filaments dynamics which have been seen above the holes and the oil spill process in the water depth is also very important. This study was performed using theoretical developments and Fluidyn software numerical simulations, [6].

The basic models normally used in the oil spill process model (OSPM) are a Lagrangian plume model or the numerical model of buoyant oil jet with many restrictive conditions. That implies a parametric study of the oil behaviour with the following scheme:

1) Oil filaments at the tanks' exits are modelled as connected cylindrical forms whose length and radius vary with time;
2) At a critical distance from the exits, geometrical shape changes will occur when the evolution of the fluid in the longitudinal direction becomes negligible compared to that of the transverse direction; blobs will appear;
3) During the rise, oil will mix with water (blobs' emulsification).

The effect of oil viscosity is neglected, and the variable included in the model represents the average value of the cross section and the change of the geometrical shape jet is not taken into account. In the case of the Prestige oil spill, various parameters can not be neglected, such as the temperature and viscosity. That implies a progressive study of the oil behaviour, each physical phenomenon at a time.

The theoretical model is the one of an axisymmetric liquid jet which is injected into another liquid; at a critical velocity the jet which has risen to a certain length breaks up into drops. These drops result in the creation of larger interfaces, which leads to enhanced mass transfer. It assumed that the flow in each phase is viscous and incompressible. The simulation took into account the instantaneous jet radius, the surface coefficient tension, the pressure of the ambient water, the oil velocity and the specific oil density.

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

By considering the various physical conditions related to the oil flow, the distance of the breaking jet against the nozzle, according to the bore as well as the size of the oil filaments coming from this rupture were calculated.

The results show that the jet is stable keeping its circular shape till a height of ~120 m, for radius higher than 20 cm. For small oil filaments and without any exchange of heat, the symmetrical filaments will be stretched some 10th of meters from the source, with some chances to be broken. If the fuel temperature is higher than 10°C, the filaments will be very unstable for jets whose diameters are more than 10 cm.

Many cases were analysed for different values of temperature, surface tension, buoyancy, viscosity. The effect of the initial speed as well as the heat exchanges between the two fluids is under investigation to model the first stage of the oil leaks from the cracks and breathers, by considering the various physical conditions related to the oil flow.

These studies seem to show that, above the oil tanks of the Prestige and at last at some 100 m height, the oil filaments have broken and the oil is finely divided. The upsurge of the oil to the surface was then analysed with currents' forecast computed with the Morane tidal and the Hycom models.

Another important problem is related to the fact that as oil density is slightly less than that of sea-water at all temperatures, the oil is bound to rise to the surface; but the damage to the environment will depend on how much time this ascent will take, and on the size of the resulting droplets or blobs.

CHAM (United Kingdom), Arco-Fluid (France) and the Service Hydrodynamique et Océanographique de la Marine (SHOM, France), have been using the general-purpose software package Phoenics in order to simulate the ascent process, [7].

Other questions have also been proposed for later stages of the computer simulation. One is: what would ensue if the tanker were destroyed by an explosion, as could almost certainly be contrived? Obviously, such an action would not be taken lightly; but it is possible that calculations would reveal that the oils would be so finely intermingled with the surrounding deep water that it would cease to be an environmental hazard. However 5 different regions are prone to be investigated, related with the 5 following issues:

- In the interior of the oil tanker, the possible effect of the internal temperature distribution of the tanker on the oil release rate.
- In the region just upstream, the effect of the aperture geometry through which the oil escapes, and the oil viscosity on its release rate.
- In the region just downstream of the aperture through which the oil escape, the fragmentation of oil filaments.
- In the region covering the ascending plume of water-oil mixture, the upsurge of the turbulent plume.
- In the layer beneath the sea surface (ocean mixed layer and seasonal thermocline), the possible effect of the temperature and density distribution in this layer and the effect of the horizontal current on the oil ascent.

Three work stages were established. In stage 1, whose objectives were to calculate the oil release rate based on hypothetical openings, the feasibility of

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

simulating the process quantitatively was established, and to calculate the time of ascension of the oil from the bottom of the sea in case of tanks' rupture, as well as the discharge rate and duration for various scenarios. Certain simplified assumptions were made, including:

1) that friction between the oil and the water caused the latter to rise also, forming a rising plume, similar to that of smoke above a bonfire;
2) that the relative velocity between the oil fragments and the water with which it was in contact was everywhere small compared with the velocity of the oil-water mixture itself (size of the oil fragments small compared to the width of the plume);
3) that that velocity was sufficient to cause the plume to be turbulent (distances are large, and the Reynolds Number likewise);
4) that the density difference between the oil and the water was independent of depth, that the Coriolis force had no impact in the oil-water dynamics.

It was found that the time of ascent, and the degree of dispersion of the oil at the surface, depends on the rate of discharge, which was varied between 20 and 70,000 tons per day.

The assumptions of this stage 1 are viable when the flow is turbulent, f.i. with a high concentration of fuel or a good mixing (small turbulence length or high volumetric two-phase interface). It allows carrying out single-phase calculations, the density of the oil-water mixture depending only on the mass fraction of the oil in the mixture.

The calculations show that the rise of 1125 tons of oil released in 14 min takes 8.5 hours for the maximum oil concentration to reach the surface arising in a parabolic pattern: the oil moves up fast at the first half of ascension time and slows down as it approaches the top. At the sea surface, the oil would cover a circle area of ~10^6 m^2 (a radius of some 500 m). The oil is rapidly mixed with water once released and as a result of turbulence break-up, the maximum oil concentration decreases to 10^{-5} at the sea surface. The maximum vertical velocity along the axis is ~10 cm/s and the maximum effective viscosity is around magnitude of 1. It also showed that the angle of the plume is independent of the oil release rate. It was also found that the time of ascent and the degree of dispersion of the oil at the surface depend on the rate of discharge and the volume of released oil, which was varied from 20 000 tons/hour to 30 tons/hour by changing the release aperture. The time of ascent from the wreck to the surface follows roughly a linear law. After the Prestige sinking, if the leakage of oil was small and the oil phase dispersed, it may have taken days for the released oil to reach the surface (from 5 to 30 days for a release of 20 to 130 tons/day).

In stage 2, calculations are steady with a uniform oil release rate using a parabolic mode for both economy and accuracy, and are performed over a wide range of flow rates, from 20 tons per day to 70,000 tons per day, even if is known that the hypothesis may not stand below 1000 tons/day of oil release rate. This residence time corresponds to the ratio between mass and mass fluxes. The residence time in the whole water column for a steady-state flow spans the range from 1 to 10 hours, which is much less than the time of ascent of an oil burst which is constrained by the existence of a forward front.

In stage 3, the uniform-temperature presumption was replaced by the allowance of 'thermoclines', *i.e.* the presence of layers of water which are appreciably warmer than that at greater depths.

Computer simulations incorporating a seasonal thermocline showed that the smaller density of the thermocline water prevented the oil-water plume from reaching the surface at all. Instead, having reached the level at which its density was no longer quite smaller than that of the undisturbed ocean, it spread horizontally. The water-oil mixture flows horizontally beneath the hotter layer through the domain boundaries: as the water-oil mixture approaches the ocean mixed layer which is warmer, the heavier plume will not be able to penetrate into the lighter layers. This conclusion can be regarded as rather agreeable as it can explain the lack of significant oil traces at the ocean surface above the wreck.

Computations have been made under the condition that the oil is sufficiently finely divided not to "slip" significantly relative to the surrounding water. This supposition is believed indeed to be correct for the upward rising plume; but, in the horizontally spreading near surface layer, in which the residence time will become very long, it may well not be.

Modelling activity, in cooperation with MeteoGalicia (Spanish Regional Meteorological Office), which provided most atmospheric forcing and checked the results using information gathered locally, was also made using Mohid model, [8].

The flow was forced by the wind and a vertical profile of density was assumed to be permanent. The surface model layer was 1 m thick. The effect of the wind on the fine surface layer where the oil is transported was accounted explicitly assuming a velocity equal to 2% of the wind velocity. This value was calibrated comparing plume forecasting and observations. The plume was simulated considering some thousand of lagrangean tracers.

The large volume of data available and the long duration of the spill permitted the introduction of some improvements in the model. The grid was refined at the surface using layers of 0.1, 0.2 and 0.5 meters. This allowed for the explicit simulation of the wind driven flow close to the surface, eliminating the need for parameterisation of "direct" effect of the wind over the plume. The contribution of the slope current for global transport has proven to be of secondary importance, except during periods of slow wind. The effect of oscillatory vertical movement of the plume associated to temperature oscillations was not simulated although observations suggest that they can be relevant.

Results have shown to be useful for management in the sense that date and locals where the plume hit the coast have been forecasted. The support to decision makers prior to the accidents require however a specific model exploitation policy. Simulation of preliminary scenarios and the evaluation of environmental and economic damage associated to each of them must be available to support quick decisions in emergency situations. Results of those simulations would allow for the selection of a few acceptable decisions during the phase "before the accident", e.g. should the ship be transported off the coast or inside a harbour? Then finer predictions should be done using the actual sea and atmospheric conditions.

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

This case study has shown that operational models are technically and economically affordable. Now the question is how should they be implemented and exploited. It is our opinion that regular users are required in order to assure (i) regular technical improvement and (ii) that they are run continuously, as meteorological models are. This is easier to achieve if they are interdisciplinary, especially if they are used for coastal water quality management, in particular in the framework of eutrophication and water quality (e.g. bathing water) monitoring programs.

A previous maritime pollution crisis, 4 years ago, set off a review of the French organisation for chronicle oil pollution monitoring (and penalisation of offenders) as well as for the intervention against oil spills. It leads to the publication of revised regulations for the “plan POLMAR” in order to cope with the expertise’s scattered state. A roadmap was also designed for decreasing the R&D lag with the endowment of a R&D fund and the onset of a network called RITMER (for "Pollutions Marines Accidentelles et Conséquences Écologiques”), [9].

Nonetheless, when the Prestige crisis occurred involving some risks for neighbouring regions and countries, it appeared that:

1) the information system and the decision aids were not fully available,
2) the use of the not-yet-fully developed tools was a necessity, and
3) other institutes than the ones quoted in the decrees should exceptionally be involved.

A group of representatives of 4 national institutes, i.e. CEDRE, IFREMER, Météo-France and SHOM, was gathered to assist the French authorities. The offer from SHOM, the French Hydrographic Office and French naval H/METOC centre, was eightfold:

a) Implementation of a temporary operational remote sensing data centre (radar and optics) with use of the last data fusion and data analysis algorithms,
b) Test of airborne equipments to detect and classify the oil spills (IR and hyperspectral radiometers ARIES & CASI) because of detection failures by the POLMAR planes with traditional sensors,
c) Measurement of the background pollution and the evolution after the oil spills,
d) Finalisation of the procedures design for the *in-situ* control of oil release by the Prestige wreck with fluorimeters and finalisation of the development of automatic sampling systems,
e) use of the French Navy (FN) oceanographic models for pollution drift’s forecasts (ship borne dedicated models or computer intensive models), with data assimilation or data control of the forecasts quality, taking into account simple hypothesis on the action of ocean waves, wind and ocean currents on the oil spills,
f) Statistical analysis of the paper cards drifts that was monitored during the 70’s and the 80’s from the coast of Portugal to the Norwegian straits, and statistical analysis of models hindcasts to help French authorities analyse the risks,

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

g) Modelling of the oil ascent process from the Prestige tanks; interpretation of the lack of oil at the sea-surface till blobs appear; interpretation of discrepancies between Mothy, Mercator, Hycom, and other models output and the effective drift of oil and buoys.

Points c and d did not catch attention, even if the equipment had already been supplied. Return of experience on point a is that the monitoring of pollution by satellite born sensors is still not tuned to operational need (the duration to order a view plus the time to get a rectified, filtered and segmented image with an oceanographic analysis is greater than the time allowed for decision).

If the b test was carried out and proved very conclusive, the cost of service was higher than the cost of regular POLMAR planes service because of data processing after the data acquisition (mapping of the area); in other respects, the data processing system fails and the French Navy did not follow and a new test is scheduled.

FN models which are usually used for oceanographic forecast dedicated to (anti)-submarine warfare were tuned to the new aim of oil drift forecast (point f) and run in parallel to the French official model MOTHY, but even if the discrepancies between the output and the marker buoys trajectories were reduced, a bias against the classical “3% of the wind speed at 10 m” remained. SHOM was obliged to apply theoretical work on ocean wave transport to erase it.

Point d is original, as the ascent was studied in 5 phases (5 slices in the water column) from the tanks to the surface in order to investigate thoroughly the oil dynamics, from the breakage of filaments (creation of oil fragments) to the spreading below the seasonal thermocline in the rising plume. Estimates of time of ascent and of oil sea residence were computed, they are in accordance with the few hints provided by the appearance of oil near the surface; but the results have to be confirmed. Moreover, with the oil’s speed of ascent, and because of the friction on the water, the rising plume may not be able to penetrate the upper mixed layer, which causes a lateral spreading.

Statistical analysis of drifters’ trajectories (point f) was the best tool for decision making at the highest level of the French Authorities.

4 Environmental and biological aspects

When crude oils or petroleum products are accidentally released to the marine environment, they are immediately submitted to a wide variety of weathering processes, including: evaporation, dissolution, dispersion, photochemical oxidation, water-oil emulsification, and microbial degradation, adsorption onto suspended particulate materials, sinking, sedimentation and accumulation in organisms. To search oil fingerprints in the ecosystem, selected groups of compounds are usually analysed.

Fauna, flora and sediment samples were analysed, [10], in order to evaluate the Prestige oil fingerprints in coastal resources. Higher hydrocarbon concentrations were observed in zooplankton and concentrations varied within the fish species. In spite of concentrations being low or moderate, the Prestige fuel signature was exhibited. The similarity of diagnostic ratios (proportion of

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

selected compounds) in biological samples and Prestige fuel, corroborate the fingerprint hypothesis.

Fuel oil data and direct submersible observations of the sunken ship show that the fuel a) is only loosely contained, b) remains fluid at seabed temperatures and c) remains less dense than sea water and once free will float to surface. The containment provided by the hull of the sunken ship will not last indefinitely, mainly because of corrosion and seismic activity (considerable in the area), [11].

There have been put forth two main proposals as remediation of the accident, 1) encapsulation of the hull or 2) removal of the oil by thinning followed by recovery, both via hoses attached to the hull by ROVs (Remotely Operated Vehicles).

A group of researchers from Portuguese institutions is testing the possibility that deep sea fauna found a) at hydrothermal vents, b) at methane cold seeps near the continents and c) attacking the hard parts of whale falls randomly dispersed on the ocean floors may be able to speed the biogenic degradation of the fuel oil, conceivably while it is still in the deep sea environment. The key to this test is the sulphur content of the Prestige fuel oil (more than 2%).

Impacts on the biota are many and cannot be addressed in an easy way, as each spill has its own characteristics, [12]. It can also be referred impacts over beach communities (fauna and flora), on the continental shelf, impacts on bird populations, with the death of thousands of animals, impacts in fisheries, in tourism and in public health are amongst the most important ones.

The immediate impacts should be distinguished from the medium and long-term impacts, as they have different results and are not perceived in the same way. Moreover, long-term impacts can be masked by other causes or even synergistic reactions can occur. The known impacts from the Prestige spill are important to predict what could happen in the northern Portuguese coast if a significative amount of the content of the tanker reaches the coast.

The impact of the spill on the continental shelf near the shoreline is related with the large amount of dense patches that are settled or combined with organic material and will remain for undetermined time span. There is also a direct impact on the exploitation of the marine living resources and suspension of activities.

The impact on juvenile fish, crustaceans and molluscs is not known as systematic monitoring of recruitment do not occurs. On the other hand, as the spill occurred before the spawning period for most species, the impact is far less important as if occurred in the first trimester of the year.

There's some knowledge about many of impacts due to accidents of other ships. From that, some of the Prestige accident consequences, in different fields, can also be predicted.

In spills, it was found the sediment contamination level as the major constraint for recovery. Other studies demonstrate low productivity or reproduction after small spills or chronic oil toxicity. Further health consequences are also common.

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

It is important to stress that long term trends in population abundance seems more important than oil spill effects, but these can produce synergistic effects and accelerate the rate of disappearance of some species.

5 Conclusions and recommendations

Earlier studies of oil dispersion in the marine environment have been concerned with spillages near the ocean surface, such as occur when a tanker runs aground on a rocky shore. Such spills give rise to oil slicks, which float on the surface of the water in the directions dictated by winds and currents. Although immediately after the hull of the Prestige was ruptured, some spillage of this kind must have occurred, the actual concern is with the vastly different process of dispersion from a wreck which lies 3500 meters below the surface.

The process of dispersion from such depths is dominated by the formation of a turbulent plume, having an approximately conical shape. The plume is impelled upwards by the slightly buoyant fragments of the oil carried within it, but, as it rises, it entrains water from the volume surrounding it. Fortunately, turbulent-plume processes have been subjected to extensive experimental and theoretical study during the past fifty years.

Because of the great distance separating the wreck from the surface, the amount of entrained water vastly exceeds the amount of the oil. As a consequence, the average concentration of oil in the plume, as it nears the surface, is less than one part per million. However, there is always a layer of warmer and therefore lighter water near the surface, of up to 100 meters in thickness. The plume water, by contrast, has the lower temperature corresponding to the depths from which it has emerged. As a consequence, the plume does not reach the surface at all. Instead it spreads horizontally, forming a second layer, perhaps half a kilometer thick having a radius of several kilometers, which increases with time.

This picture of the oil-dispersion process is, at first sight, highly agreeable, for it suggests that, by the time the oil-contaminated waters have reached the shore, the concentration of oil within them will be insignificant. However, there is another aspect which deserves attention, namely that of the sizes of the remaining particle fragments or, more properly, since fragments of many different sizes will be present, the fragment-size distribution function.

This function is important from two points of view. First even if the probability of finding a 10-centimeter-sized blob may be extremely small. Secondly, large blobs can escape from the plume, which transported them, by rising through both of the above-mentioned layers, and congregating at the surface. Conceivably, in the course of time, something akin to an oil slick could be formed after all.

This observation draws attention to a deficiency of most currently-employed models which, if they perform as they should, may accurately predict how rapidly the oil will travel. However these models are silent about its distribution into fragment-size bands. They therefore omit the feature which is of most practical importance.

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

Nevertheless, since similar deficiencies have been noted in other branches of applied fluid mechanics, for example chemical-reactor design, the conceptual framework and computational tools have been created which would enable to fragment-size distribution to be predicted. It's therefore recommend that the said framework and tools should be applied to the Prestige problem, with the dual aims of:

(a) Providing guidance to those who are seeking to anticipate, and so alleviate, its ill-effects on the environment; and
(b) Being available from the very start of the next disaster, for use by those who must take the optimal action.

The cost of such a fully-plannable model development would be negligible compared with the cost of operations, outlined during the Workshop, which are being envisaged for dealing with the Prestige disaster alone.

Moreover the model would enable alternative cheaper solutions to be at least investigated and perhaps thereafter applied. Two such are the following:

(1) A series of explosions, designed to ensure initial oil fragment sizes, which are too small to permit significant formation of large blobs.
(2) Discharge of the oil into the ocean via compressed-air-operated 'atomising injectors' attached to the hull, which would totally preclude the formation of blobs.

In summary, whereas responses to the environmental hazard presented by the Prestige wreck involve either:

(a) Containment (the cover-with-concrete solution) or
(b) Removal (the pump-it-all-out solution), and
(c) Dispersion (the break-it-into-tiny-droplets solution), that must surely be much cheaper than the other two.

Therefore it is recommended that further studies be made, directed towards:

- Estimating what proportion of the oil may consist of large lumps;
- Simulating the rise of such lumps through the near-surface water so as to reach the surface.

6 Future developments

As a consequence of some of the actions and studies carried out under this accident, several future developments were presented.

A controlled oil spill will be performed in France by the Navy. A hyperspectral airborne survey will be carried out, completed with in-situ measurements. The main objective of this project is to build an operational hyperspectral-based remote sensing system for an efficient fast detection and mapping of possible future oil spills. The main scientific challenges and objectives of the project are:

- to better understand the spectral signatures of the different kinds of slicks (sheens, tarry slicks, foams...),
- to identify the parameters that influence the spectral variability of oil (density, viscosity, in-depth penetration...),
- to determinate the lowest size bound of slicks that can be detected,

Geo-Environment, J. F. Martin-Duque, C. A. Brebbia, A. E. Godfrey & J. R. Diaz de Teran (Editors)

- to build robust algorithms for the detection of the slicks on the hyperspectral images.

However, before accepting this it is necessary to explore the extent to which it is dependent on assumption 2 above. Such explorations have been proposed for the not-yet-funded Stage 3 of the study, which will also require the creation of a mean of predicting the size distribution of the oil fragments. The reason is that, if any large blobs of oil are present in the rising plume, they will certainly in due course reach the surface; and so they may reach the shore.

CIMAR was commanded by the Oceanographic Intersectorial Commission of the Ministry of Science and Higher Education the building of a "Task Force" about the "ecological effects of Prestige's oil spill", and adequate financial support will be granted. The mission includes:

- Prepare a preliminary report about the reference situation based on published information and ongoing projects (3 months);
- Organise one Workshop to discuss the report, gathering the relevant Portuguese scientists
- Develop an Ecological Risk Assessment study (one year);
- Develop and maintain a network for communication about the problem.

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