Recuperation of Oil Trapped in Ship-Wrecks: the DIFIS Concept

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Abstract

A method for the prompt and cost-effective intervention and remediation of tanker wrecks dealing with eventual leaks and recuperating the fuel trapped in their tanks even at considerable depths is described. The method is of general applicability as long as the trapped pollutant does not dissolve and is of lower density than sea water. It relies on gravity to channel the flux of spilt fuel towards the surface. Instead of channeling the flux directly to the surface, the flux of fuel-water mix is channeled to a buffer reservoir/separator some 30-50 m below the sea surface so as not to be affected by rough weather. This is achieved by means of a light, quickly deployable flexible structure that should stay in place until all the tanks of the wreck are emptied and the pollution threat eliminated. The buffer reservoir, into which the spilt fuel is channeled, is provided with standard equipment through which shuttle vessels, weather permitting, can recuperate the fuel rapidly, using standard off-shore loading equipment and procedures.

Keywords

Ship-wreck; oil-spill; deep-sea intervention; pollution prevention

1. Introduction

Unfortunately, maritime disasters leading to major environmental pollution happen almost regularly every 2-3 years: AMOCO-GADIZ in 1978, TANIO in 1980, AEGEAN SEA in 1992 etc. In December 1999, the sinking of the tanker ERIKA caused a major pollution at the coasts of Brittany and triggered several measures aiming at the prevention of similar maritime catastrophes.

While a number of systems have been developed and deployed for containing, treating or eliminating the floating oil spills, in what regards the containment or the elimination of the pollution threat right at the sunken wreck, no proposal has ever gone further than the conceptual state. The last two actual interventions on ship wrecks (ERIKA and PRESTIGE) were planned and implemented under the pressure of the environmental emergency. They applied only to the specific conditions and, at least in the case of PRESTIGE, managed to collect only a small fraction[1] of the original fuel load.

Besides the threat that further accidental sinking of tanker and other vessels represent to the marine environment there already exist many wrecks lying on the sea bed all over the world, many of them having smaller or bigger quantities of hydrocarbons trapped in their tanks (cargo and/or fuel). Each one of these wrecks constitutes, according to the trapped hydro-carbons, the structural stability of the wreck and the environmental conditions, a more or less serious threat for the environment at a shorter or longer term.

On the aftermath of the PRESTIGE disaster, a novel concept for intervention directly at the ship wrecks was conceived at JRC[2]. The detailed study and laboratory validation of that concept is the objective of the DIFIS[3] project, partly financed by the European Commission under the Post-PRESTIGE package of the FP6-SST scheme.

2. State-of-the-art

On November 13th 2002, the tanker PRESTIGE loaded with 77.000 t of heavy fuel oil (typically used as bunker fuel) developed a 25^{o} starboard list while in heavy seas and high winds in the region of Cape Finisterre, 28 nautical miles off the coast of Galicia in northwest Spain. The vessel, after leaking some 3.000 t of fuel, was ordered to sail away from shore. On November 19, due to the severe structural overloading, it broke apart and, after having further leaked some 10.000 t, sunk 133 miles off Cape Finisterre. At the beginning of December 2002, the PRESTIGE wreck was leaking as much as 125 t of oil per day.

The ship wreck lays in two pieces, at 3.820 and 3.545 m deep, approximately 3,5 km apart. Some 20 leaking points were identified by NAUTILUS, the submersible of the French Institute IFREMER that was commissioned by the Spanish government to intervene on the wreck. Some of these leaks were stopped by NAUTILUS, albeit in a provisory manner. By mid January 2003, the leakage was reduced to 60-80 t daily and,

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[1] Less than 15% of the original fuel load has been recuperated; 25% leaked before sinking while 60% has been slowly dispersed in the ocean during the 22 months it took to plan and implement the intervention.

[2] Joint Research Centre of the European Commission

[3] Double Inverted Funnel for Intervention on Ship-wrecks

during the successive months, the leakage was further reduced to few tons daily.

By mid February 2003 the estimated quantity of fuel remnant on the wreck was estimated at 37.500 t. The Spanish commission of experts presented its final report on the remediation of the situation, proposing two alternative solutions:

1. Conventional pumping.
2. Confinement into a rigid sarcophagus

The Spanish government entrusted to REPSOL YPF the task of recovering the fuel from the PRESTIGE wreck. After detailed studies, REPSOL reconsidered the above mentioned recommendations and proposed two alternative solutions for extracting the remaining fuel: the "Shuttle Bag" and the "Confining Marquee" methods.

The Shuttle Bag method was retained. It consisted in opening large holes (Ø 80-90 cm) at each of the tanks, install valves and bring the fuel to surface in batches of 1.000 t through the use of special extensible "shuttle bags" as shown in Fig. 1 below. For an estimated quantity of remaining fuel of about 35.000 t, 35 such shuttle trips would be necessary, with the constant presence of ROV and mother ships above the wreck.

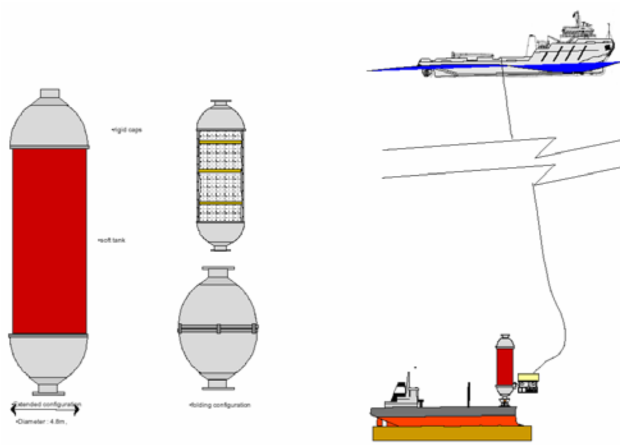

Fig. 1: "Shuttle bag" method foreseen for the PRESTIGE intervention, [Repsol YPF, Proyecto Prestige]

The Italian company SONSUB was assigned to study and implement the intervention.

By May 2003 the shuttle bag concept was finalized and on October 2003, almost a full year after the accident, the first 100 t of oil were recovered. Following this first pilot operation, the concept was modified and 350 m^3 capacity Aluminium shuttle tanks were used instead of the initially foreseen bags.

The operations completed on October 2004 with the recovery of about 13.400 t of oil. Slurry rich in microbiologic agents was pumped in the hold to speed up the breakdown of any remaining oil. The total estimated cost of the operations was well over 100 million €.

The PRESTIGE intervention put in evidence the lack of preparation for handling similar catastrophes. Despite the efforts of REPSOL, SONSUB and the rest of the contractors, despite the challenges faced, at the end almost 80% of the PRESTIGE heavy fuel oil cargo was dispersed to the ocean. The prime reason for that is the lack of reference methods and procedures for a prompt intervention. This is exactly the aim of the DIFIS project.

3. The DIFIS concept

3.1 Aim of the DIFIS project

The scope of the DIFIS project is the study, design (including costing, planning, deployment procedures etc.) and validation of an EU reference method for the prompt and cost-effective intervention and remediation of tanker wrecks dealing with eventual leaks and recuperation of fuel trapped in their tanks even at considerable depths. The proposed method is of general applicability as long as the trapped pollutant does not dissolve and is of lower density than sea water.

3.2 The system concept

The proposed solution, shown schematically in Figure 2, relies on gravitational forces to channel the flux of leaking fuel towards the surface. However, instead of channeling the flux directly to the surface, where the recovery operation would be greatly affected by adverse weather conditions, the flux of fuel-water mix is channeled to a buffer reservoir/separator some 30-50 m below the sea surface. In that way:

- Recovery operations can be performed when the weather permits it (depending on the buffer reservoir capacity) and
- The whole structure is not affected by rough weather (important dynamic loading due to waves).

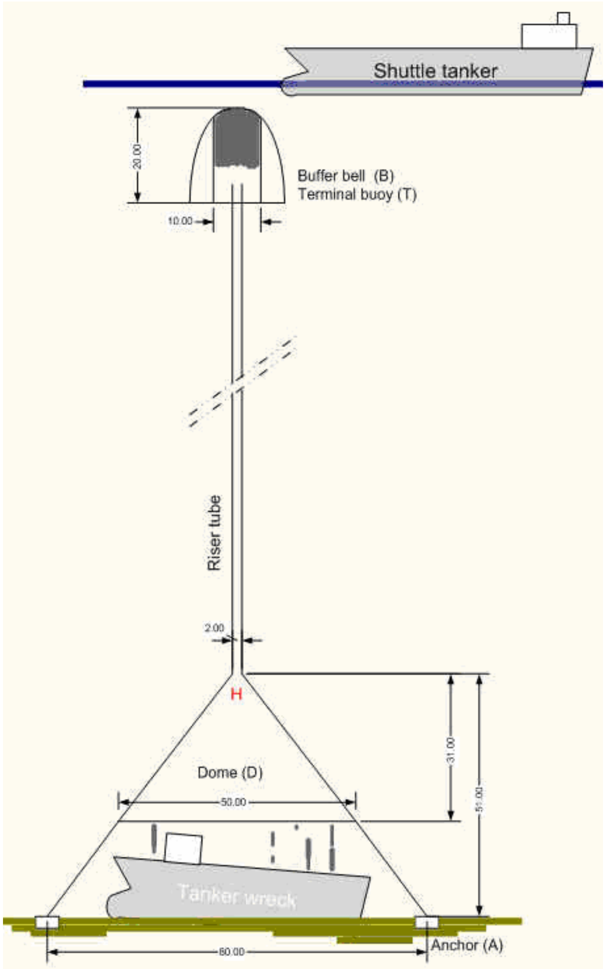

Fig. 2: **DIFIS system schematic layout**

The system consists of a light, quickly deployable flexible structure that should stay in place until all the tanks of the wreck are emptied and the pollution threat is eliminated. The buffer reservoir, into which the spilt fuel is channeled, is provided with standard equipment, so that shuttle vessels, weather permitting, can recuperate the fuel rapidly, using standard off-shore loading equipment and procedures.

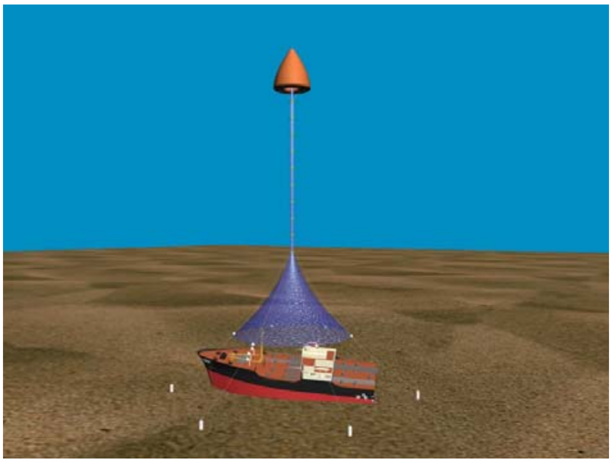

Fig. 3: **DIFIS system visualization**

The leaking fuel is collected by a kind of inverted funnel, consisting of fabric dome solidly anchored around and covering completely the wreck. The collected fuel is channelled, along with sea water, through a long, flexible riser tube (typical diameter: 1,5 – 2 meters) into a second inverted funnel close (30-50 m) to the sea surface. This second inverted funnel acts like separator and buffer reservoir (B). It is made of steel, like a bell, having a capacity of several hundred tons (typically 1.000 t or more). Fuel occupies the upper part of the bell while heavier sea water is forced out from the open bottom. The buffer bell, together with the necessary unloading equipment (standard off-shore technology), has the function of a terminal buoy T, which keeps the whole riser line in tension and provides for a rapid periodical unloading to a shuttle tanker.

The final outcome from the DIFIS project will be a reference method for the containment and recuperation of hydrocarbons or other fluid pollutants lighter than water from ship wrecks, validated from scale model experiments and extensive simulation studies. Design and deployment procedures will be tailored according two reference scenarios, so as to permit, in case of a future maritime disaster within a set of parameters covering most oil tanker deep-sea disasters to date, the prompt issue of a tender for the implementation of the specific DIFIS intervention system.

3.3 Main DIFIS components / subsystems

The DIFIS system, as outlined in Figure 4, consists of six (6) distinct major subsystems:

1. The Buffer Bell
2. The Riser tube stiffening lines
3. The Riser Tube
4. The Dome Housing Unit
5. The Dome
6. The Anchoring System

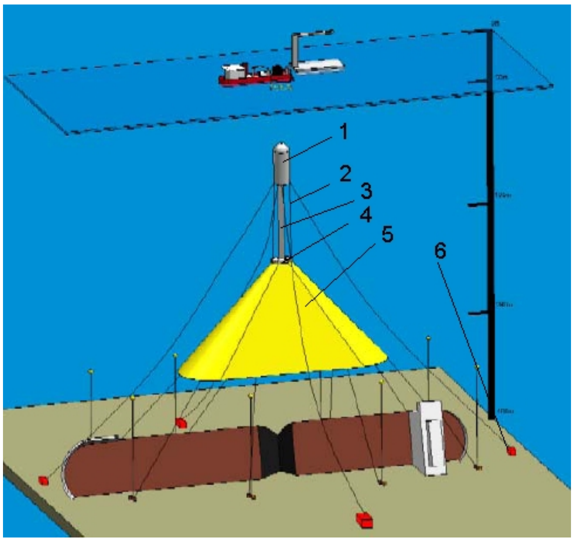

Fig. 4: **DIFIS subsystems, [Cybernetix]**

3.4 Buffer Bell (BB)

The Buffer Bell (BB), indicatively shown in Figure 5, plays the role of collecting the pollutant traveling through the riser tube from the wreck.

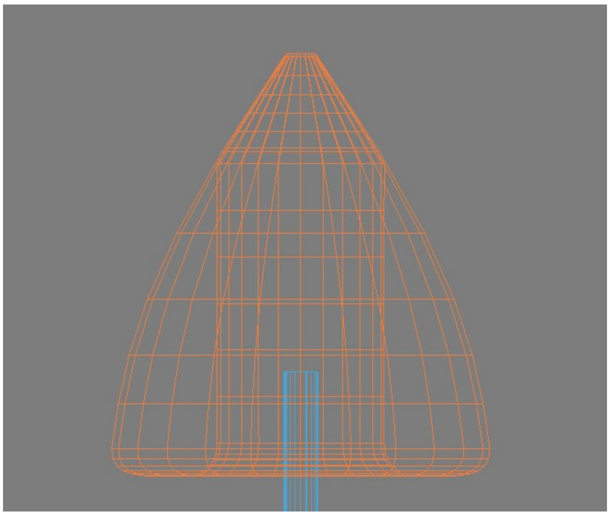

Fig. 5: Buffer Bell (BB)

Important parameters, concerning the BB, which comprise also Functional Specifications, are the following:

Operational depth: Adequate to “protect” the buffer bell from surface weather conditions (minimum 30 m, maximum depending on offloading interface configuration).

Survival Depth: Initial design considerations have shown a survival depth of 125 m to be acceptable.

Horizontal deflection: A maximum of 10% of total DIFIS system length, provided that the flow is not inhibited by the angle.

Capacity: Increase of capacity reduces logistics and transport costs, hence higher capacity must be feasible. A capacity of 6.250 m^3 seems technically reasonable.

Buoyancy: Is considered having a starting value of 1.000 t. Buoyancy must ensure adequate mooring lines and riser tube pretension, in order to avoid riser tube cross section reduction or excessive deformation vertical to its central axis.

Dimensions: A maximum total length of 42 m must be the upper limit (maximum length of on-deck transport). This limit can be overcome if the buffer is transferred on a barge.

Shape: A hydrodynamic shape vertical to the central axis of the DIFIS system will help reduce the cross-section and drag forces occurring for the water flow around the buffer bell (low drag coefficient).

Ballast: Since the BB must operate under different conditions and carrying different contents, a ballast system must be considered actively adjusting to different operational conditions.

Electronics: The electronics contained within the BB must include:

- A transponder revealing its position
- Digital Acquisition and Storage system for storing of monitoring system data
- An interface either to the shuttle tanker or a transmitter, transmitting data from the monitoring system to an administrative operator.
- A level sensor for the oil recuperated. If transmission to a central DIFIS station is selected, this level sensor will allow for the planning of shuttle tanker trips on a JiT basis. If no transmission of level sensor data is decided, then the level sensor will allow for actual flow rates calculation.
- A power source adequate to either :
    - Continuously transmit data revealing the mooring lines condition
    - Plainly support the electronics

Material: If weight and corrosion do not prove critical, steel seems a viable solution. But if those two factors are significant, GFRP composites are the most viable solution.

Stability: The BB must be designed in such a way that at the point of maximum horizontal deflection, no sloshing will occur.

3.5 Riser Tube stiffening lines

The riser tube stiffening lines are used during deployment to lower DIFIS components and additionally undertake part of the loads caused by Buffer Bell buoyancy and horizontal movement. In order to avoid torsional loading of the DIFIS system, their number is even. Depending on the existence or not of a BB mooring system, the material, required strength, and number of riser tube stiffening lines will vary.

3.6 Riser Tube (RT)

The Riser Tube (RT) plays the role of conducting the pollutant towards the Buffer Bell, through gravitational forces, as shown in Figure 6.

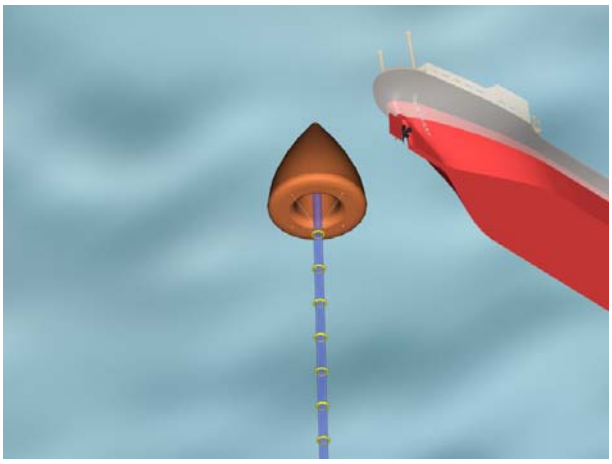

Fig. 6: Riser Tube, Buffer Bell and Shuttle tanker

The geometry and material of the RT must ensure that the possibility of clogs is minimal. This can be achieved by minimizing friction/adhesion of the pollutant on the RT walls. The factors that influence this are:

- Low surface roughness and material adhesion to oil
- A wide separation layer between the rising pollutant and the RT walls, assuring core annular flow
- RT deformed shape

Low surface roughness and material adhesion can be achieved by either the existence of an **oil repellent liner** or by **coating the tube** with specialized oil-repellent and flow amelioration coatings.

The need for a wide separation layer is satisfied by assuming a large diameter for the riser tube.

Although core - annular flow maybe unachievable, as a flow pattern is highly desirable, since little friction exists between the two phases and rising velocity is increased.

The deformed shape of the riser tube plays a role also in what concerns flow velocity. High deformations can cause oil sticking on the RT walls, loss of verticality and thus increase of clogs possibility.

The diameter of the riser tube is sufficiently large, in order to allow for achieving similar to core annular flow conditions. Furthermore, a large pipe diameter has the advantage of increased bending stiffness, additionally reducing deformation of the RT and thus minimizing the possibility of clogs.

The material of the riser tube must ensure resistance to creep that will occur during intervention, and should provide enough strength and stiffness (both axial and torsional) to withstand environmental and operational loads.

3.7 Dome Housing Unit (DHU)

The Dome Housing Unit (DHU) serves mainly for the deployment of the Dome, and after the deployment as:

1. A docking station for the riser tubes
2. A major structural reinforcement for the dome's upper part
3. An emergency docking station for filling bags such as the ones used on the Prestige wreck

The Dome Housing Unit design allows for the connection of different Riser Tube diameters via specialized interfaces, as shown indicatively in Figure 7.

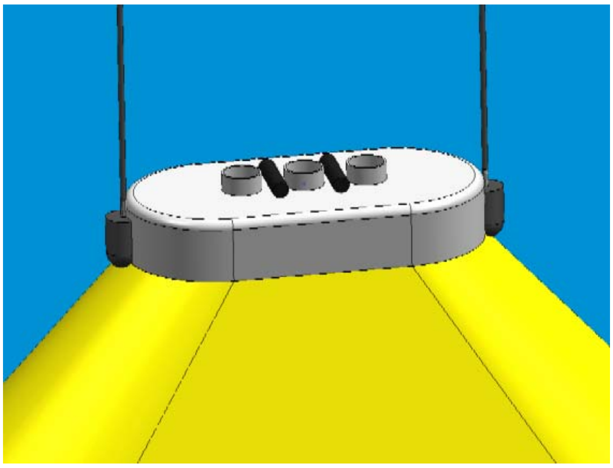

Fig. 7: Dome Housing Unit – DHU, [Cybernetix]

The docking station for the RTs must allow for connection with the biggest diameter RT considered during the design phases of the project. Furthermore, the DHU must be of sufficient strength for supporting the RT stiffening lines, partly undertaking the buoyancy forces of the Buffer Bell and the Dome's mooring system. Finally, a means of reducing stresses occurring due to the bending of the riser tube is installed in the docking station between the Dome Housing Unit and the Riser Tube.

3.8 Dome

The Dome is used for the "sealing" of the wreck and the collection of pollutant escaping from leaks either induced during the accident or intentionally created during intervention. Thus:

1. The Dome must be able to withstand the environmental loads
2. The size of the Dome is sufficient in order to cover half of a ULCC tanker
3. The Dome's configuration should allow a ROV to pass under the dome and perform any operations required
4. Although no independent system for monitoring the structural integrity of the Dome is implemented, optical inspections scheduled during every quarter of service life of the DIFIS setup or in case of a rising spill near the wreck site, should be conducted by ROVs

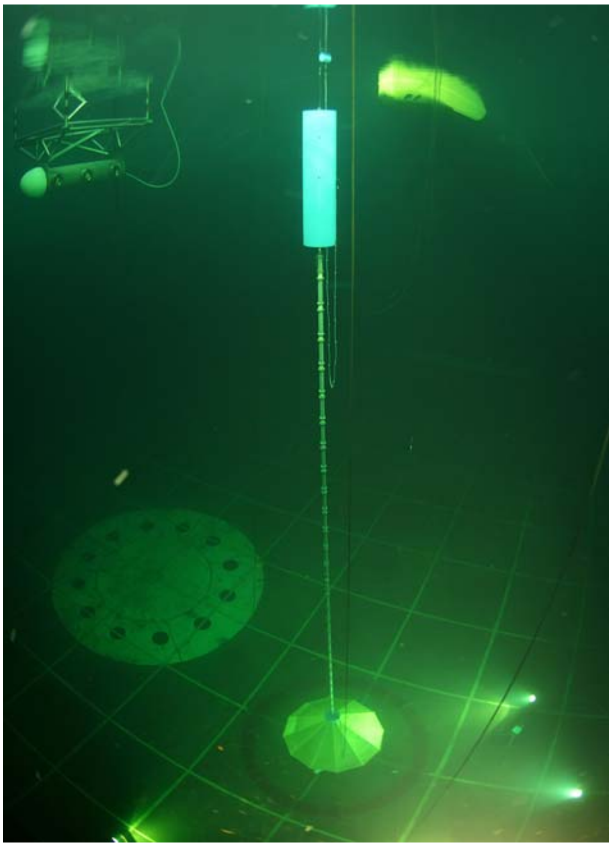

Fig. 8: DIFIS scale model at the MARIN's basin test facility, [Marin]

3.9 Anchoring System

The anchoring system plays the role of retaining the DIFIS system immobilized within the limits set by current off-shore practices.

The anchoring system mainly consists of:

- The mooring lines
- The anchors

Within the anchoring system, the mooring lines are the elements transferring forces to the anchors, whose role is to resist these environmental/operational forces and not allow the DIFIS structure to deviate excessively from its equilibrium position.

Some important parameters for the selection of the anchoring method are:

- Resistance to the environmental / operational loads in the accident area
- Fatigue life equal or larger to the service life of the whole structure
- A monitoring system

4. Operational Requirements

4.1 Methodology

In order to define the operational requirements for the DIFIS system, an extensive review of available literature and other resources was performed. Specifically:

1. An overview of the past maritime accidents involving hydrocarbon pollution hazards analyzed as to their location, causes and consequences, seeking to identify the most likely locations and type / pattern of maritime accidents during the next few decades.
2. An outlook to the parameters that are expected to have the major impact on the DIFIS design, including environmental factors (such as location, underwater and surface conditions) cargo type, properties and inventories, vessel size and type.
3. An outlook to the economical and ecological consequences of maritime accidents involving oil spills; the aim was a first insight as to the cost envelope for DIFIS.
4. A closer look at the ecological impact of 5 specific tanker disasters.
5. An outlook to the legislation and regulation applied after a severe maritime pollution accident.
6. A closer look at 5 specific tanker disasters from the liability and remediation point of view

The conclusions of all this work can be summarized as follows:

The projections elaborated from the analysis of past accidents, taking into consideration the projected routes and cargo, the type and condition of the vessels as well as the impact and remediation cost of such accidents, <u>fully justify the need for a system such as DIFIS,</u> with basic principles and functionalities to be confirmed.

4.2 Reference scenarios

Considerations on:

- Effects of the various environmental parameters (mainly bathymetry and sea current profiles) on the DIFIS design
- Existing and projected tanker routes, vessel traffic and cargo properties and inventories
- Environmental impact of past accidents
- Intervention and remediation cost

led to the adoption of two separate envelope scenarios (see Tables 1 and 2, below):

1. A <u>deep water</u> reference scenario based on the environmental conditions of the PRESTIGE accident: wreck lying at 4.000 m deep, slightly inclined seabed, low temperature, no sea current at sea-bed; strong currents near the surface and adverse sea conditions
2. A <u>shallow water</u> reference scenario based on the fact that a DIFIS system would be feasible in terms of design from around 400m, with the following environmental conditions

The <u>“PRESTIGE grade” heavy fuel oil</u> is the reference cargo in both scenarios. Moreover, in order to accurately define a range of oils, heaviest and lightest cases of oil cargo are included, to allow for a definition of multiple cargo scenarios.

In both scenarios, the wreck of <u>half of a standard double hull ULCC</u> was opted as the reference target.

In the case of an accident, the DIFIS system should be deployable <u>as soon as reasonably achievable</u>. Deployment time and simplicity of deployment operations is one of the key design criteria.

Analysis of past intervention costs and impacts from oil spills indicate a margin as to the total cost of DIFIS of the order of <u>several million €</u> for a relatively “easy” accident till several tens (possibly > 100) million € for a “difficult”, PRESTIGE like, accident.

Table 1: Deep water reference scenario

Depth	4 km
Sea Bottom Temperature	-2^{o}C
Significant Wave Height	11 m
Significant Mean Wave Period	9 s
Depth	Current velocity
0 m	2,5 knots
100 m	2,5 knots
200 m	1,5 knots
800 m	1,0 knots
Bottom (4 km)	0,0 knots

Table 2: Shallow water reference scenario

Depth	400 m
Sea Bottom Temperature	2^{o}C
Significant Wave Height	9,5 m
Significant Mean Wave Period	6,6 s ~ 8,8 s
Height above seabed	Current velocity
400 m	3,2 knots
300 m	3,2 knots
200 m	3,2 knots
100 m	2,9 knots
60 m	2,7 knots
20 m	2,3 knots
4 m	1,8 knots

5. The DIFIS Life Cycle

The life cycle of the DIFIS system is presented schematically in Figure 8. Each of these four phases is further analyzed in the following sections.

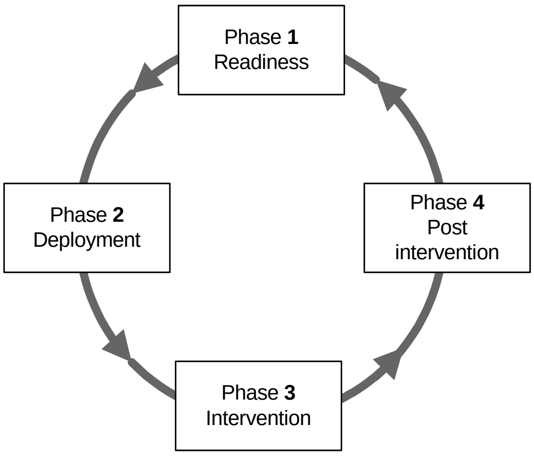

Fig. 8: The DIFIS system Life Cycle

5.1 Readiness

Phase #1 includes all the activities that regard DIFIS prior to an eventual accident (or manifestation of a need for a specific DIFIS intervention). It includes all the activities related to the readiness for intervention. The prime requirement during this phase is <u>preparedness</u> to intervene, within the DIFIS operational envelope, in:

- A time as short as possible, while
- Tying-down the less capital and human resources as possible

Activities like design, costing, deployment and tender procedures, eventual pre-fabrication and storage of components, integration of the system in emergency plans and contingency procedures and training of the personnel are included here.

5.2 Deployment

Phase #2 relates to all the pre-intervention activities after an accident has taken place (or a specific DIFIS intervention need has been manifested). It covers the time span immediately after the accident till the beginning of pollutant recuperation phase.

Six broad classes of deployment operations can be distinguished:

1. Planning and managing the whole project of the specific DIFIS intervention
2. On-site survey of the wreck (position, state, leakages), the sea-bottom and the other local environmental conditions (sea current profiles, waves, water temperature profile etc.)
3. Engineering and implementing the case specific aspects of the DIFIS intervention
4. On-site surface deployment operations: vessel positioning, deployment, assembly of submerged platform (SUP), ROV installation
5. On-site underwater deployment operations: anchoring, deployment, positioning, assembly riser tube, riser tube stiffening lines, dome unfolding, buffer bell installation
6. Eventual support operations: first operational test of the system

It is highly probable (but not necessary) that the same contractor undertakes more than one operation.

5.3 Intervention

Phase #3 covers the period after the deployment of the system, where the wreck is covered and all the trapped pollutants are channeled to the Buffer Bell.

The most important operation during this phase is the <u>periodic recuperation of the pollutant from the BB</u>, most likely by means of a small, suitably equipped shuttle tanker.

Another important class of operations performed during the intervention phase has to do with the monitoring activities (of the structure and wreck) and, eventually, maintenance of the DIFIS structure.

5.4 Post-intervention

Phase #4 covers the period after the end of the operation phase, when the pollution threat can be considered eliminated. It deals mainly with the recuperation of the system, the evaluation of the intervention as well as eventual feedback, changes and upgrading of the system and / or procedures.

Processing of recuperated pollutant is also a task that needs to be performed in this phase, but remains outside the scope of the DIFIS project. Processing of pollutant oil is most probable to take place on shore and it is something that is case specific, depending on each oil physical properties, oil/sea-water percentage mix and evaporation of oil components.

6. The DIFIS actors

The prime users of the DIFIS system are salvage companies. It is expected that, private salvage operators would use public funding to finance the ‘readiness’ phase of the life-cycle, the rest of the finances coming through tenders for the specific intervention (either public or private funds according to the specific case).

However, for the definition of the DIFIS user requirements the actors considered included all physical persons, companies or organizations that are related, directly or indirectly, to the DIFIS operations. Basically, 3 main classes of DIFIS actors were distinguished:

- The DIFIS operators: the actors that take part in the DIFIS operations during one or more phases of the DIFIS lifecycle; the DIFIS operators can be broken down in 3 further categories: the administrative (incl. design, planning etc.), the deployment (in-situ, surface & underwater) and the support (everything else) operators
- The regulators: the actors that take have to do with the regulatory framework within which DIFIS must be developed, deployed and operated

- The general public: the final beneficiaries from the DIFIS system

The main classes of actors involved during the DIFIS life cycle are presented in Table 3 below:

Table 3: Main DIFIS classes of actors

Symbol	Title	Phase	Description
A.REG	Regulatory authorities & decision makers	1, 4	International, EU or national authorities / bodies (i.e. IMO, EC, EMSA etc); Decision makers on if and who will intervene.
A.ADM	Administrative operator	all	DIFIS office/Ltd, overall readiness & operational responsibility
A.DPL	Deployment operator	2	All persons / companies involved with the DIFIS in-situ deployment.
A.SUP	Support operator	all	Site survey, fabrication & maintenance, monitoring & diagnostics etc
A.OWN	Owner	all	All actors that are involved in the incident with the role of ownership: the wreck owner, cargo owner
A.PUB	Public	4	The general public: it includes governmental and non-governmental organizations, associations, local authorities etc

7. Cost considerations

Analysis of past intervention costs and impacts from oil spills indicate a margin as to the total[4] cost of DIFIS of the order of several million € for a relatively "easy" accident till several tens (possibly > 100) million € for a difficult, PRESTIGE like, accident. A rough upper limit is the cost per ton retrieved (around 11k€/ton for the Prestige case). It should be noted that payable compensation by Fund Conventions approach an amount of about three hundred million US dollars ($300 million).

These initial, rough estimations derive from the cost intervention after past accidents as well as on the economical consequences and the magnitude of the compensation funds predicted for such accidents.

A more difficult question to be tackled during the course of the project is how this cost is financed. Society, in steady state conditions, is not willing to spend a lot on for "just-in-case" equipment. After severe accidents, pressure is exercised to authorities (local, national or EU) to react rapidly without sparing on expenses or resources. However, post – accidental interventions done under the pressure of the public opinion and under the scrutiny of the press are, usually, late and not of optimum efficiency. Ideally, all parts of DIFIS that are not strictly accident specific should be either fabricated or designed and ready to be deployed, implying a considerable portion of preparedness (just-in-case) expenses.

8. The DIFIS Consortium

Organization	**Short name**	
Maritime Research Institute Netherlands	MARIN	NL
SENER Ingenieria y Sistemas S.A.	SENER	SP
Institute Français de Recherche pour l' Exploitation de la Mer	IFREMER	F
Commissariat à l' Energie Atomique	CEA	F
Cybernetix S.A.	CYBERNETIX	F
Sirehna	SIREHNA	F
Industrial Systems Institute	ISI	GR
Consultrans S.A.	CONSULTRANS	SP
European Commission Joint Research Centre	JRC [5]	EC

9. Conclusions

The DIFIS system promises some significant advantages over the current state of the art in what regards the prompt intervention on ship-wrecks to prevent marine pollution and eliminate the pollution threat:

- It is very simple: once installed it does not require any valves or other specialised equipment; it has no moving parts and requires no external power; any such operations take place near the surface only at the unloading phase.
- Its installation poses no risk for the structural stability or the wreck; it can be implemented in phases allowing, with the same system / procedure, both the prompt containment of the leaks and the subsequent removal of the remaining hydrocarbons.
- Unloading operations are done near the surface

[4] Inclusive of fabrication, deployment, operation and support activities

[5] Dr. Fivos Andritsos from JRC has had the original DIFIS idea. He is advisor to the project.

through standard industrial equipment.

- The riser tube configuration can be implemented through a modular design, adding operational flexibility and lowering the cost.
- It is entirely passive: the flow of oil is gravity driven; if necessary, it can be enhanced by other means (i.e. through a heat source or by injecting chemicals at the top of the dome).
- Once in place, it does not require regular deep-sea operations or monitoring.
- The presence of a submerged terminal buoy and a high capacity buffer reservoir make the operations tolerant to the rough surface weather conditions.
- DIFIS can be optimised (anchoring parameters, tube and shuttle bell dimensions, riser tube / wire tensioning, depth of the terminal buoy, eventual intermediate buoys etc.
- The concept is highly configurable and can accommodate further improvements.
- It can be deployed in a modular way; the dome could be deployed over the wreck early after the accident so as to contain the leaking fuel while the rest of the tube and the buffer tank can be deployed at a second stage.

However simple the concept might be its realisation presents important technological challenges. The biggest challenge is the realisation and deployment of the long and wide riser tube, having to operate in conditions of important, unpredictable currents sometimes in rapidly changing patterns. Nevertheless, the first detailed calculations and scale mock-up experiments gave very positive indications on its technical feasibility and confirmed to a large extent the initial pre-design.

8. Acknowledgements

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