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Double Inverted Funnel for the Intervention on Ship wrecks

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

J.L..Cozijn [1)], F.Andritsos [2)],
P.A.Konstantinopoulos, K. J. Charatsis, C.Derdas, D.Mazarakos, V.Kostopoulos, [3)]
D.Hoornstra, A.Arnedo Pena, L.Candini, S.Ametler [4)]
A.Fidani, A.Castex, M.Delauze, [5)]
J.F.Drogou, J.P.Lévèque, P.Davies, [6)]
C.Montandon, F.Geffard, [7)]
F.Pecot [8)], V.Estrada [9)]

[1)] MARIN Maritime Research Institute Netherlands
[2)] European Commission – Joint Research Center
[3)] Industrial Systems Institute, Greece
[4)] SENER Ingenieria y Sistemas S.A., Spain
[5)] Cybernetix S.A., France
[6)] Ifremer, France
[7)] CEA, France
[8)] SIREHNA, France
[9)] Consultrans S.A., Spain

Abstract

A method for the prompt and cost-effective intervention and remediation of tanker wrecks dealing with eventual leaks and recovering 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 flow of spilt fuel towards the surface. Instead of channeling the flow directly to the surface, the fuel-water mix is directed 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 channelled, is provided with standard equipment through which shuttle vessels, weather permitting, can recover the fuel rapidly, using standard off-shore 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-CADIZ in 1978, TANIO in 1980, AEGEAN SEA in 1992 etc. In December 1999, the sinking of the tanker ERIKA caused a major pollution of 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, with regards to 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 tankers and other vessels represents to the marine environment there already exist many wrecks lying on the sea bed all over the world, many of them having smaller or larger 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.

In the aftermath of the PRESTIGE disaster, a novel concept for direct intervention at the ship wreck 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.

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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- Project FP6-516360

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° 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 lay in two pieces, at 3.820 and 3.545 m depth, approximately 3,5 km apart. Some 20 leaking points were identified by the NAUTILE, 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 the NAUTILE, albeit in a provisory manner. By mid January 2003, the leakage was reduced to 60-80 t daily and, 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 REPSOL YPF with 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 of opening large holes (Ø 80-90 cm) at each of the tanks, installing valves and bringing 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.

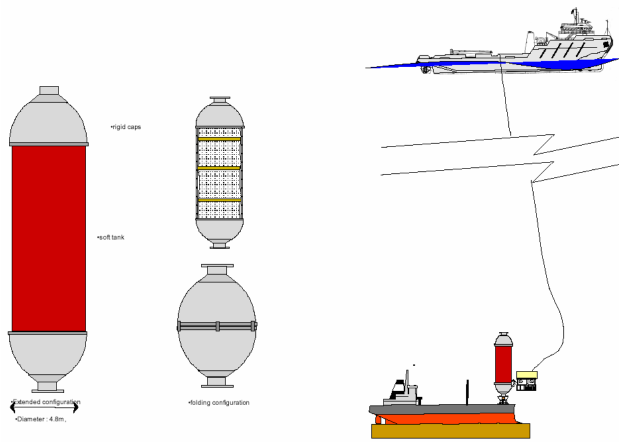

Fig. 1: "Shuttle bag" method foreseen for the PRESTIGE intervention, [Repsol YPF, Proyecto Prestige]

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 were completed in 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 revealed 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 in 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 flow of leaking fuel towards the surface. However, instead of channelling the flow directly to the surface, where the recovery operation would be greatly affected by adverse weather conditions, the flow of fuel-water mix is channelled 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 (depending on the buffer reservoir capacity) and,
- The whole structure is not affected by rough weather (high dynamic loading due to waves).

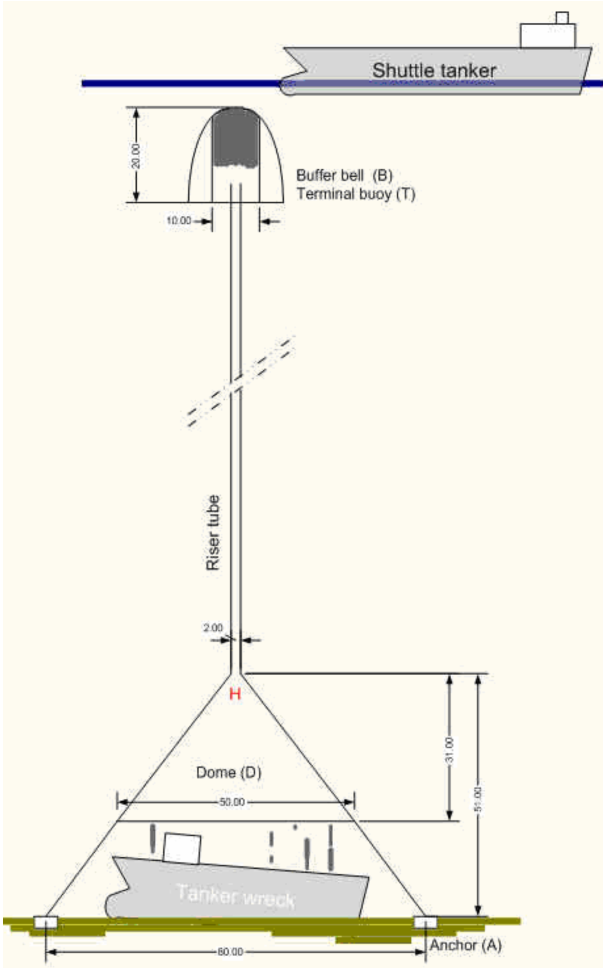

Fig. 2: DIFIS system schematic layout

The system consists of a flexible structure, as light and quickly deployable as possible, according to the depth envisaged, 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 channelled, is provided with standard equipment, so that shuttle vessels, weather permitting, can recover the fuel rapidly, using standard off-shore equipment and procedures.

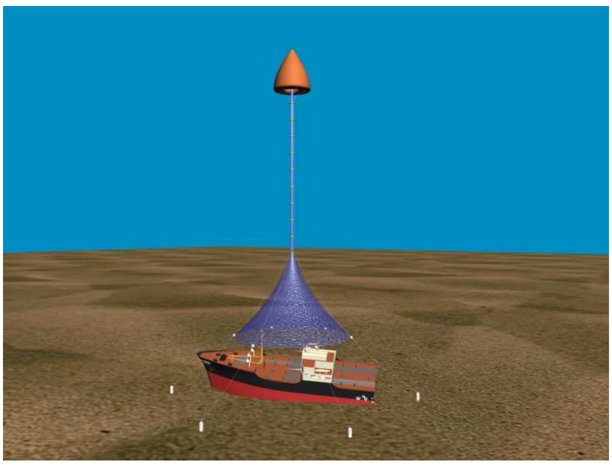

Fig. 3: DIFIS system visualization

The leaking fuel is collected by a kind of inverted funnel, consisting of a fabric dome solidly anchored around the wreck and covering all or the majority of it. 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 to (30-50 m below) 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 allows rapid periodical unloading to a shuttle tanker.

The final outcome from the DIFIS project will be a reference method for the containment and recovery of hydrocarbons or other fluid pollutants lighter than water from ship wrecks, validated by scale model experiments and extensive simulation studies. Design and deployment procedures will be tailored according to reference scenarios, so as to permit, in the 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 with
3. Stiffening lines
4. The Dome Interface
5. The Dome
6. The Anchoring System

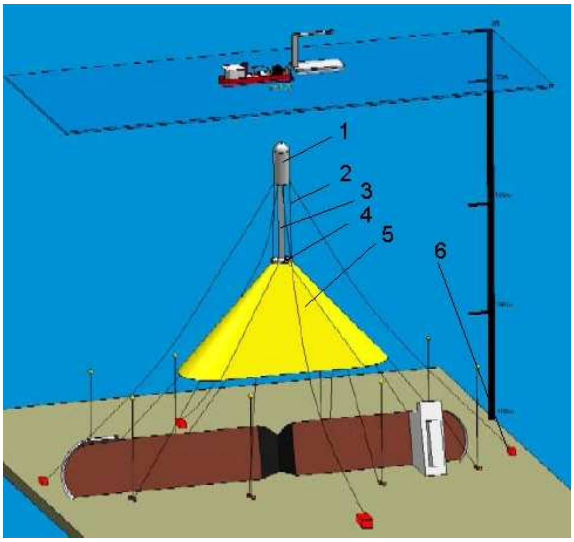

Fig. 4: DIFIS subsystems, [Cybernetix]

3.4 Buffer Bell (BB)

The Buffer Bell (BB) collects the pollutant travelling through the riser tube from the wreck.

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 capacity must be as high as possible. A capacity of 6.250 m^3 seems technically reasonable.

Buoyancy: Is considered from 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 vertical deformation.

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 transported 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 due to the water flow around the buffer bell (low drag coefficient).

Ballast: Since the BB must operate under different conditions and with different contents, a ballast system must be considered which actively adjusts 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 recovered. 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 rate calculation.
- A power source adequate to either :
  - Continuously transmit data revealing the mooring lines condition
  - Plainly support the electronics

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 (RT)

The Riser Tube Column (RT) plays the role of conducting the pollutant towards the Buffer Bell, through gravitational forces, as shown in Figure 5.

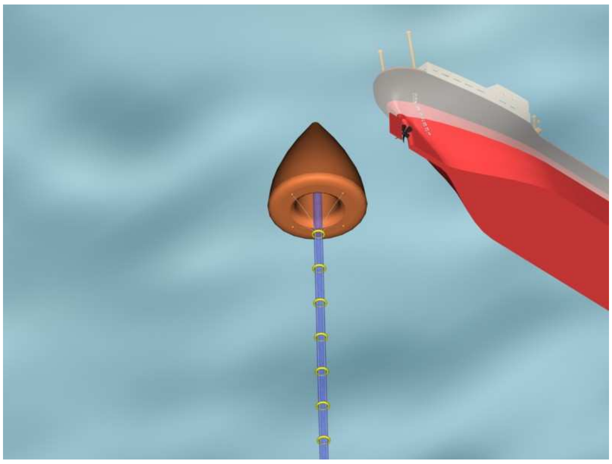

Fig. 5: Riser Tube, Buffer Bell and Shuttle tanker

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 improvement coatings

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

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

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

The diameter of the riser tube must be sufficiently large, in order to achieve conditions similar to core annular flow. Furthermore, a large pipe diameter has the advantage of increased bending stiffness, additionally reducing deformation of the RT and thus minimizing the possibility of clogging.

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. Riser tube stiffening lines will be used to 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 will depend on the existence or not of a BB mooring system.

3.6 Dome Interfacet (DI)

The Dome Interface is a mechanical component placed at the top of the dome.

The main functionalities of the DI are as:

- Docking station for the riser tube
- The major structural reinforcement for the upper part of the dome and the attachment system of this upper part of the dome
- Vertical load transfer from the Riser Tube Stiffing lines to the dome and then to the anchor lines.
- As an option, an emergency docking station for drilling bags such as the ones used on the Prestige wreck

The DI will accompany the total life cycle of the dome, as the latter will be permanently hooked onto it while in operation.

The weight in the water of the DI and the dome should be neutral or of permanent positive buoyancy.

DI is instrumented with electronic measuring devices that transmit data on a real time basis in order to control its descent speed and overall behaviour, this in addition to the constant presence of an ObsROV to monitor the whole operation.

3.7 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 must be sufficient in order to cover as biggest part as possible of a tanker wreck. For the first design, half of a ULCC tanker was the first objective.
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

3.9 Anchoring System

The anchoring system keeps 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, their 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
- Weight as low as possible (synthetic mooring lines)
- Fatigue life equal to or larger than 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. A study of the parameters that are expected to have a 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. A review of the economical and ecological consequences of maritime accidents involving oil spills; the aim was to provide a first indication of the cost envelope for DIFIS.
4. A closer look at the ecological impact of 5 specific tanker disasters.
5. A study of the legislation and regulations 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, fully justify the need for a system such as DIFIS, 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 sea-bed, low temperature, no sea current at the 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 environmental conditions described below

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 adopted as the initial reference target.

In the case of an accident, the DIFIS system should be deployable <u>as soon as reasonably achievable</u>. Short deployment time and simplicity of deployment operations are 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°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°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. DIFIS Preliminary Design results

As a result of the design iterations the Early Design of the DIFIS system concludes as follows:

The elements of the DIFIS system presented below are developed for the deep water scenario.

- A minimal pretension of 1000 Tons is necessary in order to guarantee structural stability of the system. The conceptual design of the elements is based on that pre-tension.
- The conceptual design of the Buffer Bell consists of a steel sphere (Øext: 14 m) and a collecting cylinder made of geo-textile (Length 20 m) reinforced by rigid rings and an adaptor component made of steel, giving a capacity of 2000 m^3 in the conceptual design, which will be increased to 6000 m^3 in the definitive design.

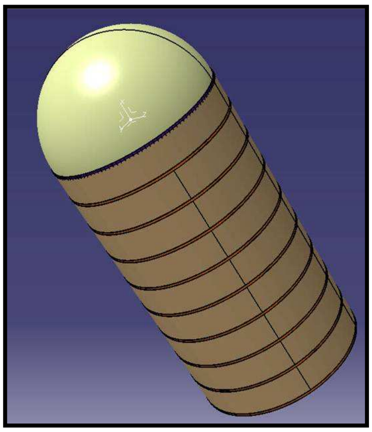

Fig. 6: Buffer Bell

- Six Dyneema stiffening lines (Øext 98 mm) are used to transmit the buoyancy from the Buffer Bell to the dome along the Riser Tube.
- The Riser Tube is composed of a PE-pipe (Øext: 2000 mm; thickness: 77 mm) and 6 stiffening lines made of *Dyneema* (Øext : 98 mm) and steel rings every 50 m, as shown in the figure.

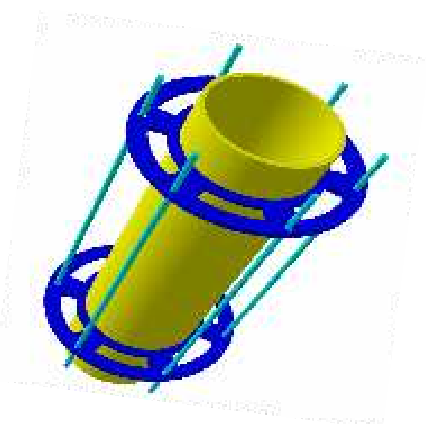

Fig. 7: Riser Tube Column and stiffening lines

- The dome is composed of a conic cover made of pre-tensioned membrane, reinforced with 12 *Vectran/Dyneema* lines (Ǿext: 60 mm). In order to fulfil the functional requirements, the early design has been carried out with a base diameter of the conic cover of 210 m. However, the present state of the art of the technology does not allow manufacturing, folding and deploying of a dome of such dimensions. Realistic dimensions have been limited to a base diameter of the conic cover of 100 m, for a height of 50 m.

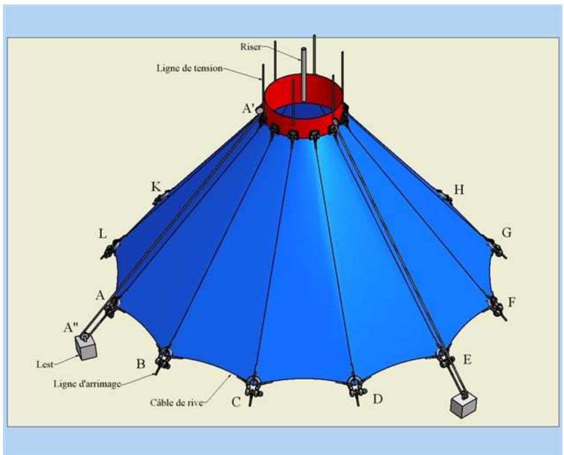

Fig. 8: The Dome with mooring lines

- The anchor alternative (VLA anchor, suction anchor or deadweight anchor) depends largely on the soil conditions and requirements for installation. The preliminary design took into account the concret deadweight alternative. 12 mooring lines of *Dyneema* (Ǿext: 98 mm) are tied to the anchors. Each anchorage point must be able to resist a minimal vertical force of 127 Tons and a transversal force of 123 Tons with a vertical tension of 1000 Tons.
- The study included Concept verification and optimization.

  The first task has concerned multi-phase (oil water mixture) time-domain flow calculations. The evaluation and simulation permitted to validate the DIFIS concept from the point of view of internal flow, both in the Riser Tube and the Dome. The results of these calculations were used to select the conditions for the actual CFD calculations of the internal flow in the DIFIS system.

  A first set of hydrodynamic scale model tests was performed at the MARIN basin to investigate the overall behaviour of the complete DIFIS system in environments of combined current, waves and wind.

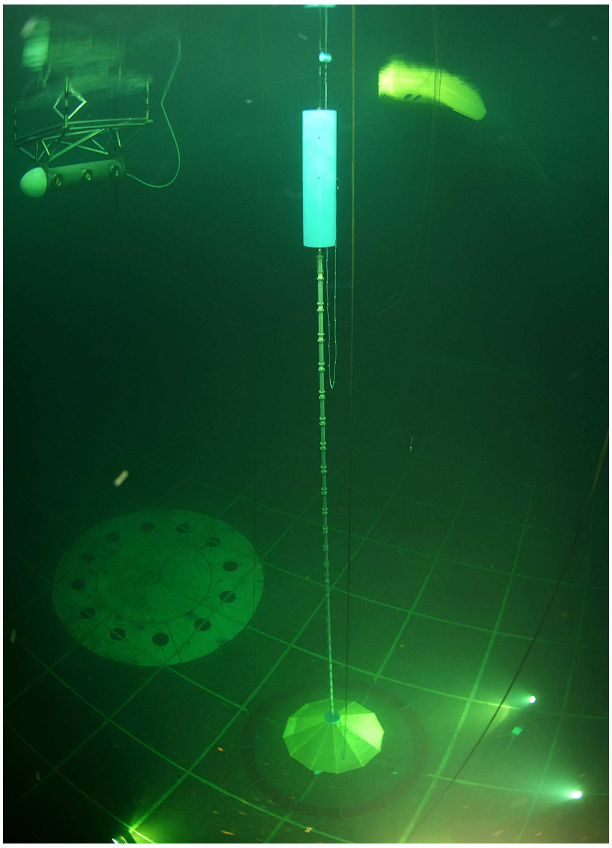

Fig. 9: DIFIS scale model at the MARIN's offshore basin , [MARIN]

A new set of hydrodynamic scale model tests will be performed in 2008. Several aspects of the system operations, such as survival conditions, operational conditions, offloading and deployment will be considered.

- At this stage of the study, the system deployment, with the objectives to be safe and as quick as possible, is the main challenge. Surface vessels needed to perform such an operation could represent a serious drawback in term of cost, as bulkiness, sizes, and complexity rise as depth of operation increases. The basis of the DIFIS preliminary principle is to perform a maximum number of tasks on the installation vessel (Side Derrik level) in order to avoid costly and time consuming operations at depth by ROV, and the need to develop costly ROV tools and interfaces.

The preliminary principle of deployment underlines 12 phases, which have to be specified according to the evolution of the design:

- Phase 1: deployment of the mooring anchorage dead weights
- Phase 2: Surface deployment of the dome and dome housing
- Phase 3: Lowering the Riser tubes along the guidelines
- Phase 4: Surface deployment of the buffer bell.

- Phase 5: Connecting buffer bell to tensionning lines
- Phase 6: Ballasting the Buffer bell
- Phase 7: Clamping the buffer bell onto the guidelines
- Phase 8: Anchoring the dome using mooring lines
- Phase 9: Tightening of the Mooring lines
- Phase 10: Freeing the lifting bags for anchoring tensioning
- Phase 11: Deploying the dome
- Phase 12 : End of deployment and complete survey.

The project will end mid-2008. The remaining tasks include the final design and the definitive deployment procedures, the planning and costing evaluation.

6. The DIFIS Life Cycle

The life cycle of the DIFIS system is presented schematically in Figure 10. Each of these four phases is further analyzed in the following sections.

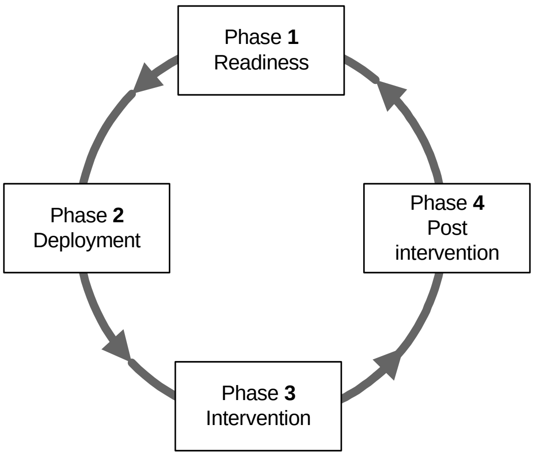

Fig. 10: The DIFIS system Life Cycle

6.1 Readiness

Phase #1 includes all the activities that concern 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 preparedness to intervene, within the DIFIS operational envelope, in:

- A time as short as possible, while
- Tying-down the least 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.

6.2 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 up to the beginning of the pollutant recovery 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 will undertake more than one operation.

6.3 Intervention

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

The most important operation during this phase is the periodic recovery of the pollutant from the BB, 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.

6.4 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 will most probably take place on shore and it is something that is case specific, depending on physical properties of each oil, oil/sea-water percentage mix and evaporation of oil components.

7. 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 include 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 into 3 further categories of operator: the administrative (incl. design, planning etc.), the deployment (in-situ, surface & underwater) and the support (everything else).
- The regulators: the actors concerned 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:

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

Table 3: Main DIFIS classes of actors

8. Cost considerations

Analysis of past intervention costs and impacts from oil spills indicate a range for the total[4] cost of DIFIS from several million € for a relatively "easy" accident up to several tens (possibly > 100) of 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, under normal conditions, is not willing to spend a lot on "just-in-case" equipment. After severe accidents, pressure is exercised on authorities (local, national or EU) to react rapidly without sparing either expenses or resources. However, post – accident interventions performed under the pressure of 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.

9. The DIFIS Consortium

Organization	**Short name**	
Maritime Research Institute Netherlands	MARIN (Coordinator)	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 Center	JRC [5]	EC

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

10. 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:

- The concept is 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 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.

However simple the concept might be its realisation presents important technological challenges. Among the biggest challenges, the study has emphasised:

- The realisation and the deployment of the long and wide riser tube, having to operate in conditions of important, unpredictable currents sometimes in rapidly changing patterns.
- The manufacturing, folding, transport and deployment of a large dome. This point has in a first step limited the wished dimensions, and necessitates further developments.
- The whole system deployment, with the objectives to be safe and as quick as possible, can represent a serious drawback in term of cost as bulkiness, sizes and complexity rise as depth of operation increases. This can lead to consider intermediate water depth ranges (less than 1000 m) where the system could be lighter, with more standard naval means.

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.

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