



HAL
open science

System for high-frequency simultaneous water sampling at several depths during sailing

Pascal Bailly Du Bois, Bertrand Pouderoux, Franck Dumas

► To cite this version:

Pascal Bailly Du Bois, Bertrand Pouderoux, Franck Dumas. System for high-frequency simultaneous water sampling at several depths during sailing. *Ocean Engineering*, 2014, 91, pp.281-289. 10.1016/j.oceaneng.2014.09.022 . hal-02433216

HAL Id: hal-02433216

<https://normandie-univ.hal.science/hal-02433216>

Submitted on 14 Jan 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Highlights

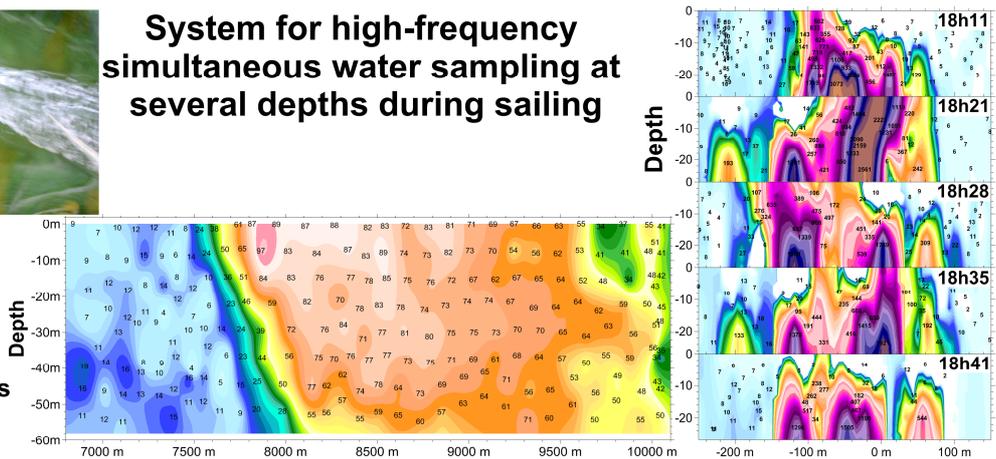
- > System for in-depth high-frequency water sampling at several depths simultaneously
- > Dynalest: a deep-towed depressor with a lift/drag ratio of 80 and a downward lift of 15 000 N at 5 m.s⁻¹
- > Vertical slices of a dispersion plume close to an outfall
- > Tracer measurement for validation of dispersion models > 10 vertical levels sampled each 30 s continuously from surface up to 55 m depth.

Graphical abstract



System for high-frequency simultaneous water sampling at several depths during sailing

Vertical slices in dispersion plumes tritium concentrations (Bq.l⁻¹)



System for high-frequency simultaneous water sampling at several depths during sailing

Pascal Bailly du Bois¹, Bertrand Pouderoux² and Franck Dumas³

¹ IRSN/DEI/SECRE/LRC - Institut de Radioprotection et de Sûreté Nucléaire, Direction de l'Environnement et de l'Intervention, Laboratoire de Radioécologie de Cherbourg - Octeville, rue Max Pol Fouchet, B.P. 10, 50130 Octeville – France.

² Université de Caen, ESIX Normandie, Département GSI, Rue Louis Aragon, B.P. 78 50100 Cherbourg-Octeville, France

³ IFREMER/DYNECO/PHYSED, centre de Brest - Z.I. de la pointe du Diable, B.P. 70, 29280 Plouzané - France

Correspondence:

P. Bailly du Bois Surname: Bailly du Bois First name: Pascal
Laboratoire de Radioécologie de Cherbourg - Octeville (LRC)
IRSN-LRC
rue Max Pol Fouchet
B.P. 10
50130 CHERBOURG-OCTEVILLE France
Tel. direct line: (33) 02 33 01 41 05
Tel. secretary: (33) 02 33 01 41 00
FAX: (33) 02 33 01 41 30
Email: pascal.bailly-du-bois@irsn.fr

Abstract:

A system allowing high-frequency sampling at several depths simultaneously have been developed. It could be used in a strong current area close to the coast with frequent 180° half-turn. It includes three main components: i) a line able to sample at ten depths simultaneously, ii) the Dynalest, a deep-towed depressor that maintains the line submerged at depth with a lift/drag ratio of 80, and iii) an automatic high-frequency sampler with volume and flux control. The system was designed to collect samples for validation of 3D hydrodynamic models in the plume close to a seabed outfall with 4 m.s⁻¹ tidal currents (La Hague Cape). During sampling, the ship was operating normally at speeds of 0.5 - 5 m.s⁻¹ with frequent half-turns. Ten depth levels were sampled simultaneously every 30 s from 0 to 20 or 55 m depth. More than 13 000 samples were collected during a five days campaign. Vertical slices pictures of a dispersion plume were obtained each 5-10 minutes (100 – 200 measurements each one). The different parts of the system may be used separately or together. It can be adapted for varied conditions as greater depths, more vertical levels of simultaneous in-depth sampling or large volumes.

Keywords: **Oceanographic instrumentation, automatic sampler, depth, depressor, modelling, dispersion.**

1 Introduction

During oceanographic cruises, water samples are usually collected at depth using bottles on a manual or automated sampling system, such as bottles mounted on a CTD rosette. These methods require stopping the ship at stations during sampling i.e. downward and upward setup of the sampling system at around 1 m.s^{-1} speed; and bottle closing. It takes overall about 15 - 30 minutes for each station in shallow waters (20 – 50 m). For security reasons, the ship cannot be stopped close to the coast or in areas with strong currents.

In the framework of DISVER project (DISpersion VERTicale) for studying vertical dispersion close to an outfall, we aim to validate three dimensional hydrodynamic models by using *in-situ* radiotracer measurements; this objective requires high-frequency sampling (every 30 s) at ten depth levels simultaneously. This project follows previous studies concerning model validation with high-frequency *in-situ* measurements, but which were based solely on surface sampling (Bailly du Bois et al., 2012).

The waters off the Cap de La Hague represent one of the most difficult areas to investigate for this kind of study, since it combines strong currents (up to 5 m.s^{-1}), proximity of the coast and a complex topography with many rocky shoals and deeps varying from 25 to 90 m over a few kilometres. For operational and security reasons, the ship must remain under way while sampling at speeds from 1 to 5 m.s^{-1} (10 knots). Since we could not find any suitable equipment for such conditions, we developed a system for safe sampling in this context.

The system developed here comprises three main components:

- A sampling line designed to sample ten depths simultaneously;
- A deep towed depressor (known as Dynalest), which maintains the line at depth close to the seabed;
- An automatic high-frequency sampler with volume and flux control.

A review of existing systems for plankton sampling is presented in (Reid et al., 2003) and (Alliance for Coastal Technologies, 2007). The system proposed here could be compared with existing sampling vehicles as Seasor (Hales and Takahashi, 2002). Such systems require long towing cable (1000 m) and allow only one sample at the same time. They are well designed for of shore sampling but they not allow simultaneous sampling at several depths, very high sampling frequency close to the shore and tracer outlet. In such conditions a short cable length is required with high depressor lift/drag efficiency. The system presented here is an alternative to these existing materials with a lower cost.

The different components have been fitted to work together, but they could be used and adapted separately for other purposes. The combined system as configured for this study is adapted for in-depth sampling when at least one of these conditions is required: high frequency sampling; proximity of reefs or coasts, strong currents, several depths simultaneous sampling.

1.1 Materials and methods

1.2 Sampling line

The sampling line allows continuous seawater sampling at ten depths simultaneously during ship operation. It includes ten tubes, each one with its extremity fixed at a given depth; transmission cable and support cable. Three peristaltic pumps at the surface are used to collect the seawater from depth, with up to four pipes connected to one pump.

The characteristics presented here correspond to the particular objective of our project, but the number of sampled levels and their depth, along with the sampling flux and rate, can be adapted for other purposes.

The sampling line must meet the following requirements:

1. It should maintain the tubes at fixed depth to sample the water mass traversed by the ship's track (from 2 to 50 m depth for our purposes).
2. External diameter as small as possible to limit drag.
3. Internal diameter of tubes sufficient to sample the requested volumes at the fixed rate, with adequate separation of the different samples ($50 - 200 \text{ mL.mn}^{-1}$ is required here).
4. It should resist the stresses associated with movements in seawater at more than 5 m.s^{-1} .
5. Support the load of the depressor which maintains the line at depth.
6. Support the sensors recording depth during sampling.

7. Continuous transmission of data measuring the distance between the depressor and the seabed.
8. Easy to set up and recover while ship is under way.

The compromise between points 2 and 3 determines the tube size. An internal diameter of 4 mm allows a flux of $200 \text{ mL} \cdot \text{mn}^{-1}$ with a 100-m-long tube and a pressure drop of 50 000 Pa, (calculated performed with Mecaflux® (Mecaflux) and based on tests), which can be obtained with shipboard peristaltic pumps. The pumps must be maintained as close as possible to sea level to limit the hydrostatic pressure that needs to be counterbalanced by the pumps. Polyurethane tubes with internal and external diameters of 4 x 6 mm, respectively, offer a good compromise between resistance, flexibility, transparency and ease of handling. They could be connected with robust instantaneous connectors. The assemblage of ten tubes, with transmission cable ($\text{Ø} 6 \text{ mm}$) and support cable (stainless steel $\text{Ø} 8 \text{ mm}$), leads to an average external diameter of 20 mm. Tubes were embedded in a thin adhesive tape to fix them together and limit the drag (Fig. 1). Data concerning the calculation of drag forces are available in (Choi et al., 2011; Mark, 2007; Mecaflux; Sun et al., 2011).

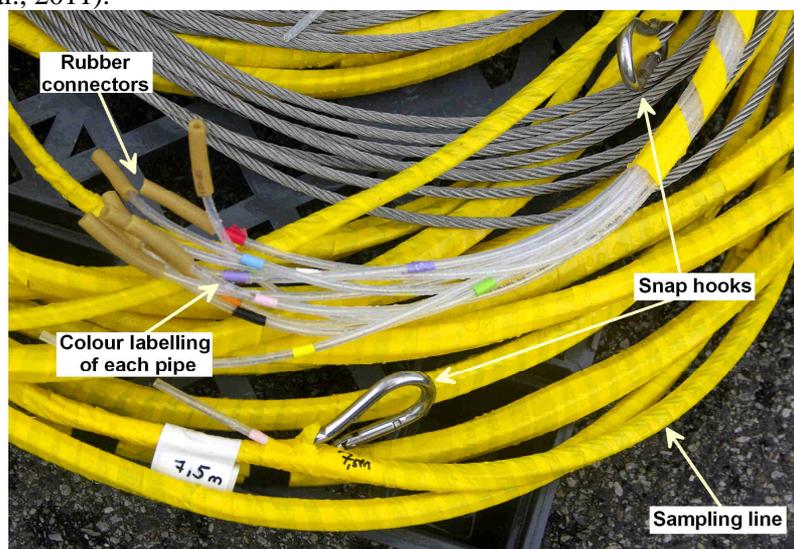


Fig. 1 Sample line protected by yellow adhesive tape, with snap hooks and releasable rubber connections to the sampler.

Tubes could not be directly reeved on the ship winch because they would be crushed during operation as the tensile strength reaches several tons. The solution was to associate the sampling line with a carrying cable. This latter resists the downward tractive force of the depressor and the horizontal drag on the sampling line, which is attached with regularly spaced snap hooks (Fig. 1 and Fig. 2).

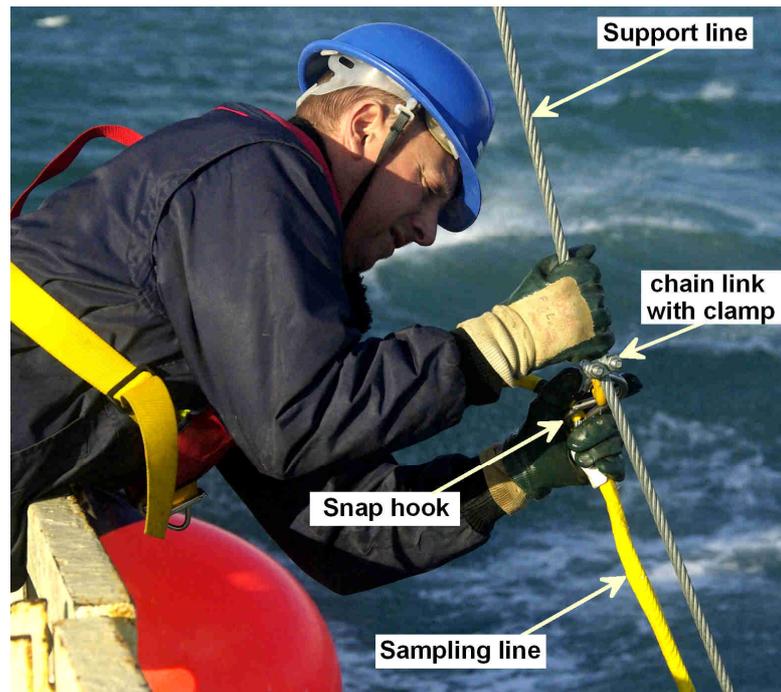


Fig. 2 Fixing the sampling line to the support line with snap hooks.

Pressure sensors are fixed along the line at regular intervals to obtain a continuous record of the real sampling depth (record frequency: 1Hz).

Sampling line characteristics (Fig. 1, Fig. 2):

Supporting cable:

- Ø 14 mm diameter zinc-plated steel, 90 000 N breaking strength.
- Ø 10 mm fixation rings every 2.5 m (sections of chain links), fixed with clamps.

Sampling line:

- Ø 8 mm stainless steel cable, 30 000 N breaking strength.
- 10 x (Ø 4 – 6 mm) polyurethane tubes, with extremities of nos. 1 to 10 fixed at intervals of 2.5 m (30 m line) or 7.5 m (100 m line), fitted with connectors.
- 3 or more regularly spaced autonomous pressure sensors (NKE[®] SP2T100 (NKE)).
- Ø 6 mm depth sensor data cable for the sounder sensor fixed below the wing.
- Ø 10 mm rapid stainless steel snap hooks fixed every 2.5 m, 10 000 N breaking strength. Such robustness is required: an initial test was performed with brass snap hooks having a breaking strength of 3 000 N: once one hook failed at the top, they all broke along the line like a zipper.
- Continuous embedding with a thin 40-mm wide tape, using a minimum overlap of 1 cm. Tape embedding must be carefully performed. The drag force at 5 m.s⁻¹ is so high that it could rapidly destroy the tape protection if it is not well fitted.
- Swivel and shackles.

1.3 The Dynalest deep-towed depressor

A deep-towed depressor, a hydrodynamic "wing" structure providing downward force that drives the end of the sampling line towards the sea floor, is used to maintain the line underwater at the desired depth at a ship speed of 0.5 – 5 m.s⁻¹, under normal operating conditions. The downward force necessary to counterbalance the drag of the sampling line is estimated at 15 000 N for sampling depth interval of 30 – 50 m (calculation performed with Mecaflux[®], (Mecaflux)). The depressor uses the ship speed to create a downward force, which increases with speed in the same way as the drag stress on the sampling line. As a result, the forces exerted correspond to the requirements, and the system can be set up easily by two persons during deployment.

Table 1 reports examples of some existing systems. A key parameter is the efficiency coefficient (lift/drag). Further information concerning deep-towed systems can be found in: (Aiken, 1981; Alliance for Coastal Technologies, 2007; Brown et al., 1996; Dessureault, 1976; Helmond, 2001; Marcelli et al., 2012; Mark, 2007; Mudie and Ivers, 1975; Reid et al., 2003; Sun et al., 2011; Vaz and Patel, 1995).

Provider	Reference	Downward lift at 5 m.s ⁻¹	Weight in air	Efficiency (lift/drag)	Width	Price in k\$ (Alliance for Coastal Technologies, 2007)
YSI	V-FIN 850	11 600 N	195 Kg	5	2,17 m	16
EIVA	ScanFish (Brown et al., 1996)		50 Kg	≈ 10	1,60 m	188
IFREMER	Prototype	10 000 N	200 Kg	4 - 9	1 m	Not for sale
	Batfish (Dessureault, 1976)	11 000 N	85 Kg	3	1.25 m	Unknown
Chelsea Co.	Seasoar (Hales and Takahashi, 2002)	Unknown	150 Kg	Unknown	1.6 m	260
	Dynalest	14 000 N	80 Kg	80	1.6 m	7, self made
Lead profiled	Passive (no depressor)	10 000 N	1100 Kg	500	0,30 m	> 3

Table 1 Main characteristics of existing depressors.

None of the available systems combine a reasonable weight, lift and efficiency in compliance with the objective set here:

- lift greater than 12 000 N at 5 m.s⁻¹;
- handling by only two persons (weight in air less than 100 kg);
- efficiency higher than 50 to minimize the sampling line length;
- high manoeuvrability with ship operating normally with frequent 180° half-turns;
- safety during set up and operation;
- cost lower than 10 k\$;

A new system has been designed to comply with these characteristics: the Dynalest. The main wing was constructed by applying the NACA459 profile, as shown in Fig. 3. The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (Moran, 1984; NACA). The choice of profile was determined using the Xfoil v.6.94 code (XFOIL), by selecting robustness criteria to obtain a maximum efficiency without generating instabilities at operational speeds and tilts. A risk of cavitation appears only at speeds higher than 7 m.s⁻¹. Maximum lift can be changed according to needs (maximum depth, sampling line drag), by modifying the wing surface-area (chord and width dimensions).



Fig. 3 NACA459 profile produced by numerical manufacturing.

The material used must have a density higher than seawater to avoid floating during setting up, but should not be too much higher in order to remain easy to handle. It must be sufficiently rigid to resist lift forces, while being easy to shape, robust and seawater-resistant. Resistance calculations were performed with the software package for material resistance assessment RDM6 (RDM6). Solid aluminium alloy 5083 satisfies the requirements for the lower cost. Profiles were cut by numerical manufacturing. Fig. 4

presents the general plans of the Dynalest depressor, while Table 2 reports its main characteristics. Fig. 5 shows the setup of Dynalest during an oceanographic cruise.

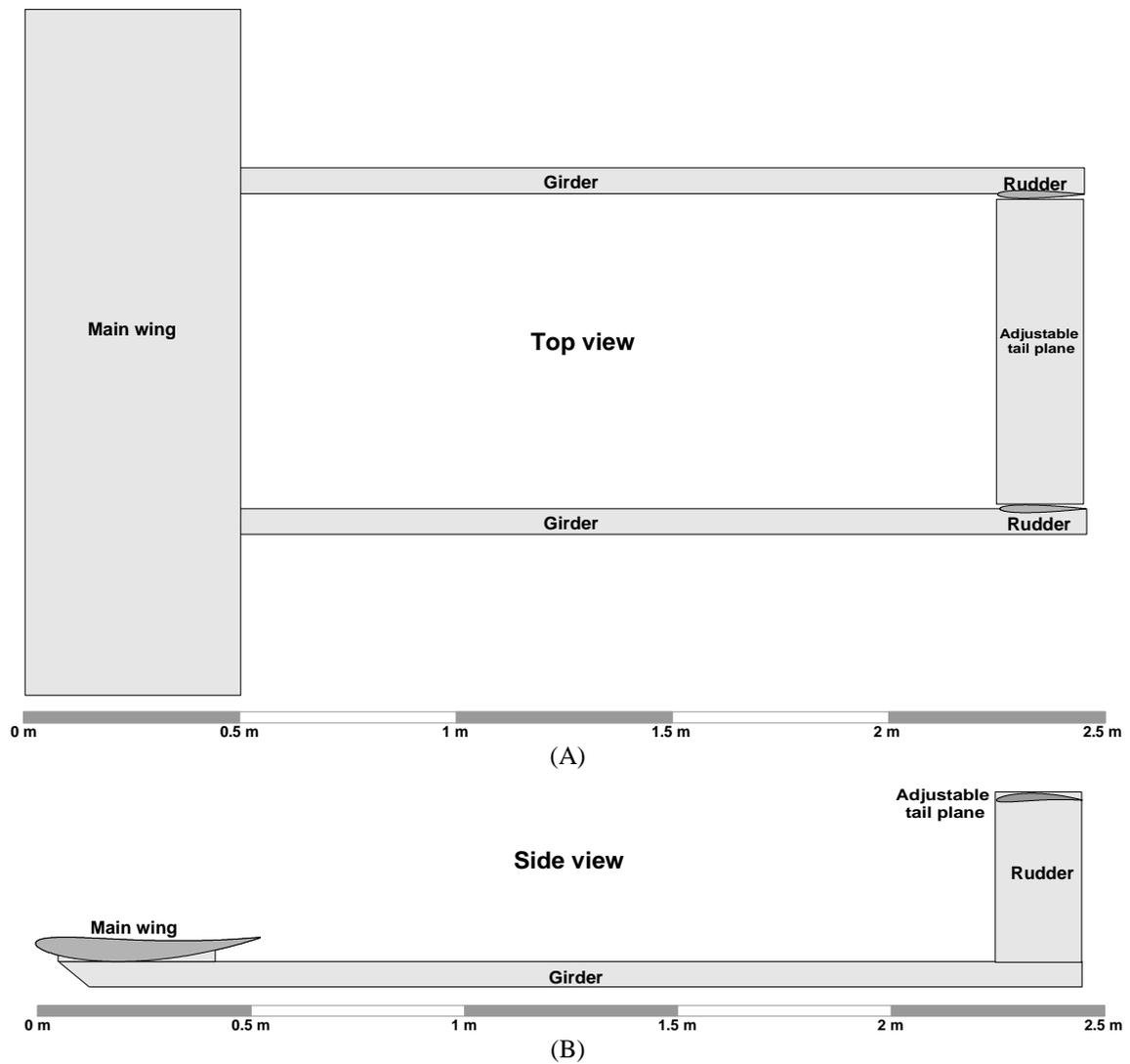


Fig. 4 Dynalest plans - A: top view; B: side view.

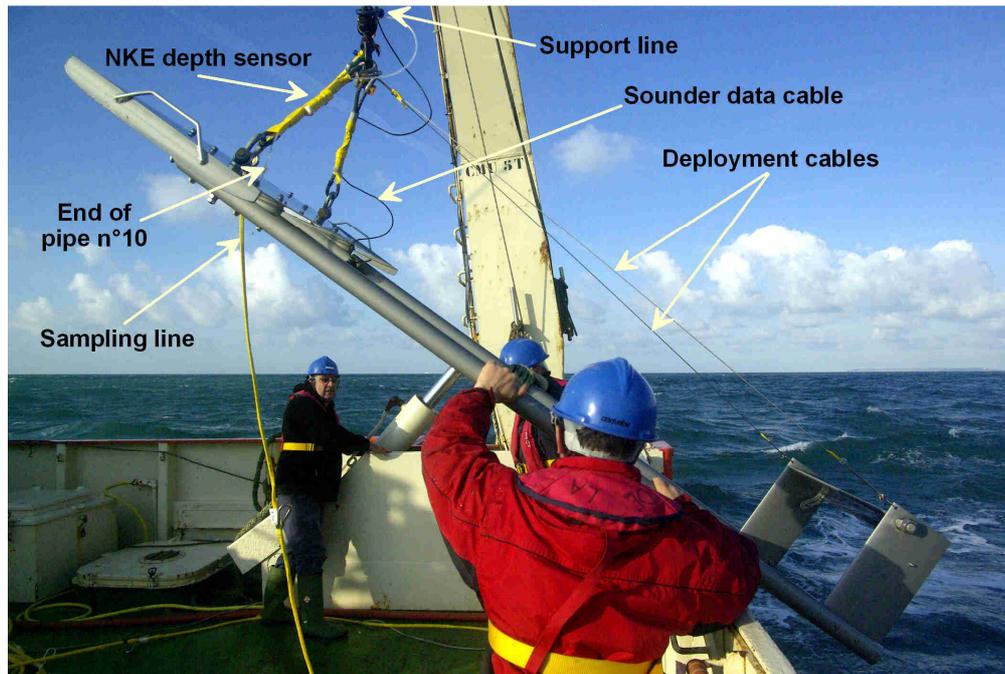


Fig. 5 Setup of the Dynalest.

Depressor profile with stabilizing fin for tilt adjustment	
Material: marine-grade aluminium alloy (type 5083 H11); total weight: 80 kg	
width: 1.6 m; length: 2.4 m; cost: 7000 \$	
Main wing	NACA 459 asymmetric profile (Naca 2012) Length 1.6 m Chord 0.5 m
2 rudders (yaw stability)	NACA 009 symmetric profile Length 0.4 m Chord 0.2 m
Adjustable stabilizing fin (pitch stability)	NACA 459 asymmetric profile Length 0.8 m Chord 0.2 m
Assembly	Two rods, 50 mm diameter. Length 2.35 m Extremities profiled
Calculated efficiency ((Lift/Drag ratio) at 5.1 m.s ⁻¹ with a 7° tilt (Xfoil)	Lift (L): 12 350 N Drag (D): 150 N Efficiency (L/D): 81

Table 2 Characteristics adopted for the Dynalest depressor.

Wing tilt can be adjusted with the adjustable stabilizing fin placed 1.7 m from the wing. A rotating axis allows changing of the upward component of the lift. The simple adjustment system is shown in Fig. 6.



Fig. 6 Adjustment of the stabilizing fin tilt.

1.4 High-frequency automatic sampler

Simultaneous sampling of ten vials every 30 s (1200 samples per hour) cannot not be obtained manually. Such a performance requires an automatic dedicated system.

Fig. 7 illustrates the main components of the sampler. The software written in Pascal-Delphi® controls the displacements of the sampler, as well as the pump rates and valves, and records the time, flux and sampled volume for each sample. The real X, Y and Z positions and time of collection of each sample are calculated after the campaign by taking account of the ship's track, the immersion depth of the extremities of the tubes, as well as the fluxes and volumes in each tube. The ship's track is recorded on-board each 15s with two differential GPS receivers. As the sampling time is recorded each second, the samples positions are interpolated in order to find the exact position at the sampling time.

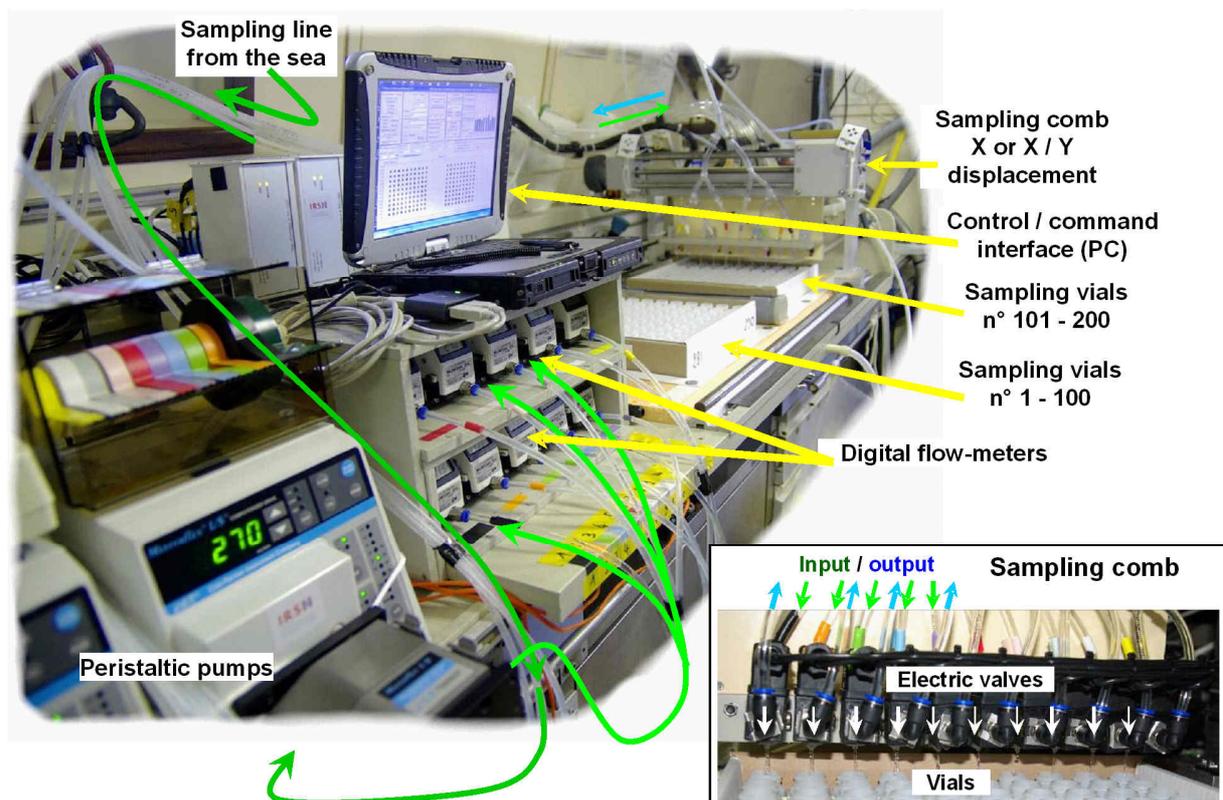


Fig. 7 Automatic sampler on board "Côtes de la Manche" during simultaneous sampling at ten depth levels.

The flow of seawater samples in the ten tubes is ensured by three peristaltic pumps, each one able to handle up to four tubes. The control of sample volumes is carried out by digital flow-meters located upstream of the sampling table (Fig. 7). The main localization error comes from the variation of water transit time in the tubes. This error could be checked after drawing the vertical dispersion plume: they must have the same vertical orientation without systematic bias. Results obtained from all measurements showed that the horizontal position error is lower than 10 m.

In the configuration for sampling at ten depth levels simultaneously every 30 s, the table includes enough space for two boxes of 100 vials. The two boxes allow the changing of one set while the other is being used for sampling. With a 30 s sampling frequency, this leaves a gap of 5 minutes to perform the changeover to the free box. The vials are the same as those used for tritium measurement by liquid scintillation (20 ml plastic vials). After sampling, the table is used to add scintillation liquid so the samples are ready for future measurements by liquid scintillation. A dedicated line and valve are used to fill up each vial automatically with 12 mL of scintillation “cocktail” between sampling periods. Counting times of 50 minutes for each sample are required for quantification of tritium concentration in this area. The method applied is the same as described in (Bailly du Bois et al., 2012) with a detection limit of 7 Bq.l⁻¹.

The most time-consuming work performed in board consists of opening, closing and labelling all samples (14 000 for the six-day campaign in April 2011). In this way, we return from oceanographic cruises with all samples ready for measurement. Pumps are left running continuously in order to renew the water in the tubes during operation. Valves are located as close as possible to the vials (sampling comb in Fig. 7) to minimize the dead-space volume, which represents less than 0.1mL compared with the 8 mL sampled in each vial (1.3 %). Tests were carried out with coloured liquid to ensure that, with samples spaced every 30 s, there is a good separation of the seawater samples collected using a flux of 100 – 200 mL.mn⁻¹. Measurement results confirm these tests (See 2.3 section).

The automatic sampler is a general-purpose tool. It can be used to carry out any kind of liquid sampling, either sequential or in series. The number, spacing and height of the vials may be easily changed. It was used to carry out regular sampling of coastal seawater every 10 minutes during periods of weeks. After modifications, we also use this equipment to control and sample water from atmospheric vapour over several weeks by means of an air dehumidification system (frequency: 30 minutes).

The source code of the software interface, technical specifications of each component or more detailed photos can be provided on request.

1.5 Deployment

Deployment of the system requires the following actions:

1. Install the automatic sampler securely in the ship’s lab with access to the rear deck; test connections, software and prepare the vials (opening of thousands);
2. Mount the support cable on the ship winch;
3. Install the sampling line on deck and connect it to the table with rubber tubes. This kind of connection represents a safety feature in case the cable breaks: the sampler and pumps stay inside the ship without risk of accident.
4. The echo sounder data line is connected to its repeater located on the bridge, in a place continuously visible by the pilot.
5. Fix the sampling line and the support line to the Dynalest, connect the sounder data cable and then deploy the depressor into the water. During this operation, the ship can continue under way. Some thin cables are fixed to the rear of the depressor to maintain it during the setup (Fig. 5). Once the Dynalest is underwater at low speed, it immediately takes up its lift (underway) position and the ship can increase its speed.
6. The support line is deployed with a stop ever 2.5 m to fix the sampling line snap hooks to the support line rings (Fig. 2).
7. When the requested length is deployed, the pilot must regularly check the distance between the depressor and the seabed. Before deployment, it is necessary to obtain a good knowledge of the bathymetry and select an area with limited seabed relief to avoid risks of crashing. In our case, we apply a security distance of 5 m between the bottom and the Dynalest during sampling.
8. The pumps are switched on, and sampling can begin after sufficient time has elapsed to empty dead volumes from the tubes.

9. After sampling, the pumps are stopped. It is preferable to maintain water inside the tubes to facilitate starting up of pumps during subsequent deployments.
10. During recovery of the equipment, the sampling line is decoupled from the support line in the same way as during launching (stop lifting each 2.5 m to unlock each snap hook).

2 Results

2.1 Dynalest tests

Firstly, lift and manoeuvrability tests was performed with a 1/7 scale model. Deployment, stability, lift and drag tests were carried out with the real-scale depressor in the Ifremer-Brest traction canal (Fig. 8), which made it possible to measure and visualize the hydrodynamic behaviour of the Dynalest. Fixation design and tilt tuning were also performed in the canal. Afterwards, the Dynalest was used onboard the research vessel *Côtes de la Manche* (CNRS-INSU) during a test cruise (2008) and four sampling campaigns under real operating conditions.

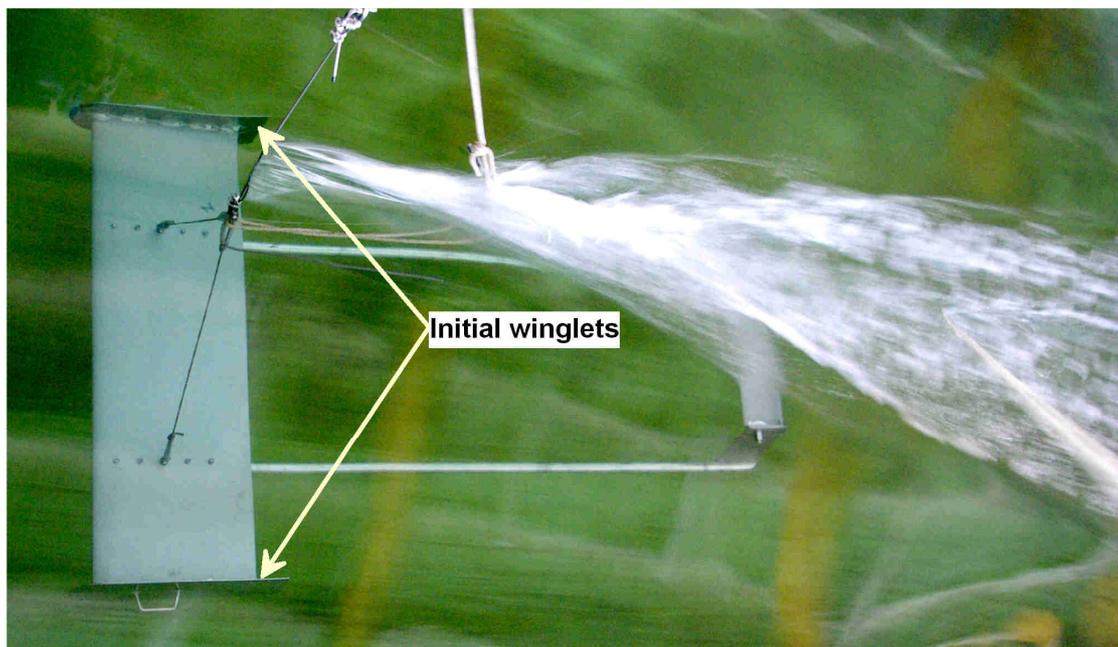


Fig. 8 Test in traction canal at 3 m.s^{-1} .

Dynalest manoeuvrability was tested up to 5 m.s^{-1} . With an immersion of 20 m, the instantaneous stress on the cable shows peaks attaining 100 % of the mean lift. With an immersion of 50 m, the maximum stress variations are lower (65%).

Fig. 9 shows a comparison between the lift values calculated with different tilt and the lift measured in the traction canal as well as in the open sea. The effective measured lift lies in the higher range of the calculated values, corresponding to a calculated wing tilt of $7^\circ - 8^\circ$. The average measured lift allows application to sampling depths greater than 50 m with the designed sampling line. Higher wing tilt angles lead to instabilities of the lift and unhooking of the wing during a rapid half-turn at 4 m.s^{-1} (ship rudder tilt of 40° : Dynalest reaches the surface).

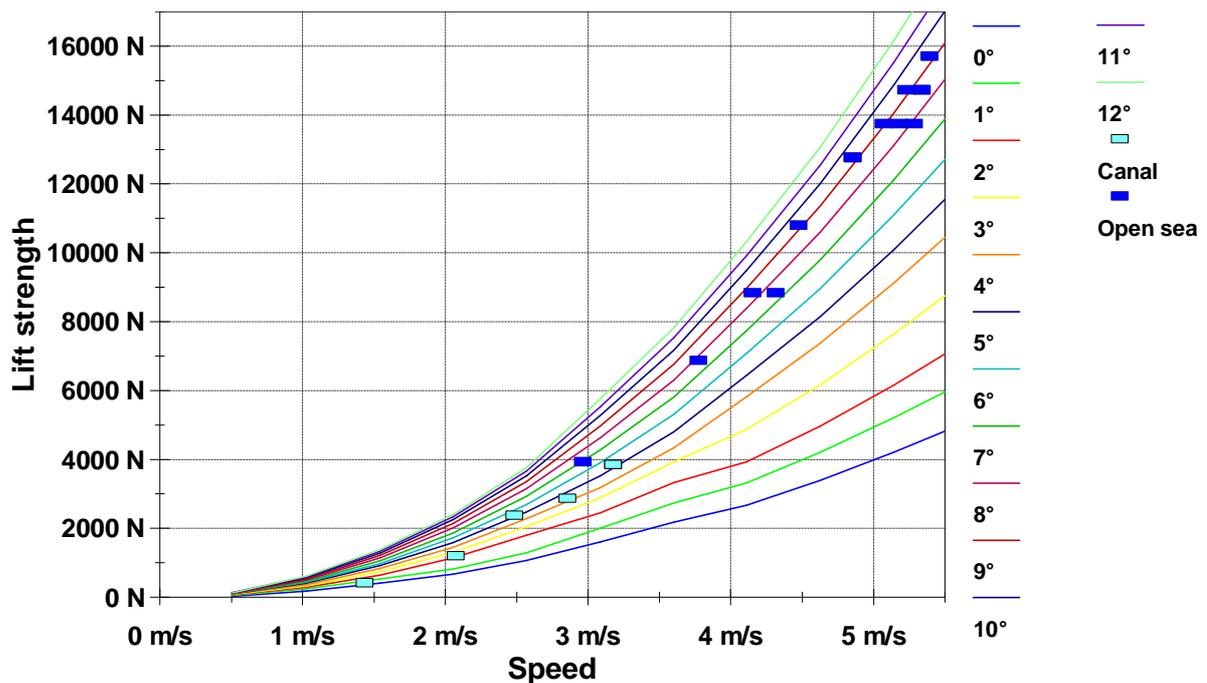


Fig. 9 Lines: calculated lift for different tilts (Xfoil); squares: measurements in traction canal (light blue); in open sea (dark blue).

2.2 Operational tests

The sampling system has been implemented in an operational way since 2009 during three oceanographic campaigns; the ship was able to operate in the Cape de La Hague area without taking account of the towed line. Overall, more than 35,000 samples were collected at different depths. The system was used with a 30-m and a 65-m line, which made it possible to sample at ten levels down to 25 m and 50 m water depth, respectively.

2.2.1 Initial excessive longitudinal stability

The main problem encountered during the first test campaign was the too high directional stability of the system. Initially, winglets were positioned at the extremities of the main wing to obtain a good lateral stability. Results obtained in the traction canal show that this objective is reached, since the depressor appears to be driven as on rails (Fig. 8). Tests performed during the first campaign at sea in 2008 confirm all the calculations and assumptions, and we decided to monitor a real release of radionuclides followed by *in-situ* sampling. During this operation, the ship performed a rapid half-turn at a speed of 4 m.s⁻¹. During this unexpected manoeuvre, the depressor followed its own trajectory and had no time to follow the ship's track. The lift force reached the 30 000 N breaking strength of the support line used at that time, with the result that it suddenly broke and the first depressor was lost.

Consequently, we decided to rebuild the same system but without lateral winglets (Fig. 8). The middle position of the attachment of the two cables on the wing was lowered. The cross-section of the support cable was increased (14 mm diameter instead of 8 mm), with an ultimate breaking strength of 90 000 N.

With this new depressor, the excessive directional stability disappears: the ship can now sail without taking account of the towed depressor, carrying out rapid turns at high speed. This represents an essential security feature in our deployment area (strong currents, rocky shoals and proximity of the coast).

During the first tests, a slight adjustment of the depressor fixation was necessary to obtain a deployed position of the line exactly parallel to the ship's axis. We simply inserted a 2-mm thick ring in one of the shackles axes to correct the position, no other corrections were made. After several deployments, we can ignore the presence of the line and the depressor during sampling. Except for checking the distance to the seabed, the pilot can navigate the ship as if there were nothing being towed.

The depressor acts in a passive manner, which is an advantage since it is very robust and does not need particular attention before and during deployment. During operation, sensors fixed to the line yield a record showing variations of several metres in immersion depth. These variations are mainly associated with frequent half-turns (every 5 – 10 minutes) at high speed, during which the depressor needs 15 - 30 seconds to recover its underway position. Such depth variations are less significant with longer transects.

Repeated high operational speeds require careful attention to ensure protection of the sampling line. Check and punctual repair of the protection tape appears necessary after about fifteen hours at sea, depending mainly on the quality of the tape used.

We do not observe problems with tube clogging during cruises. This could occur in more turbid waters such as rivers. Fibre filters could be added at the ends of the tubes to prevent clogging.

The depressor can carry additional autonomous sensors, as an example, we fitted a SBE 19 Seacat profiler during one campaign (0.13 m diameter, 0.7 m length).

After the first deployment, the crew had no particular difficulties to deploy the depressor and the line. As two persons must work close to the edge of the rear deck to lock and unlock the snap hooks, they must be attached to prevent falling. During this operation, the ship crane must position the cable close to the ship edge to facilitate coupling and decoupling of the sampling line.

The cost of the system is 7000 \$ for the Dynalest, 1200 \$ for the lines and 2500 \$ for the automated sampler. It takes three hours for two persons to mount a 25 m line with ten tubes and tape protection.

2.3 3D measurements of tritium dispersion

Fig. 10 and Fig. 11 shows examples of results obtained with dissolved tritium measurements (HTO) near the outfall of the AREVA-NC nuclear reprocessing plant. Positioning of the ship during sampling was assisted by model simulation in order to cross the plume during a known release (Bailly du Bois et al. 2012). For example, 13 400 samples were collected during five days at sea in 2011. As each sample request one hour of counting time for tritium measurement, it represents nearly two years for measurement by liquid scintillation counting.

In Fig. 10, the transects presented here represents transverse “slices” across the axis of plume propagation, at a distance of 850 m from the outfall. Approximately 100 to 200 samples were collected from 2 to 22 meters depth during each transects, which are spaced at intervals of 5 to 10 minutes.

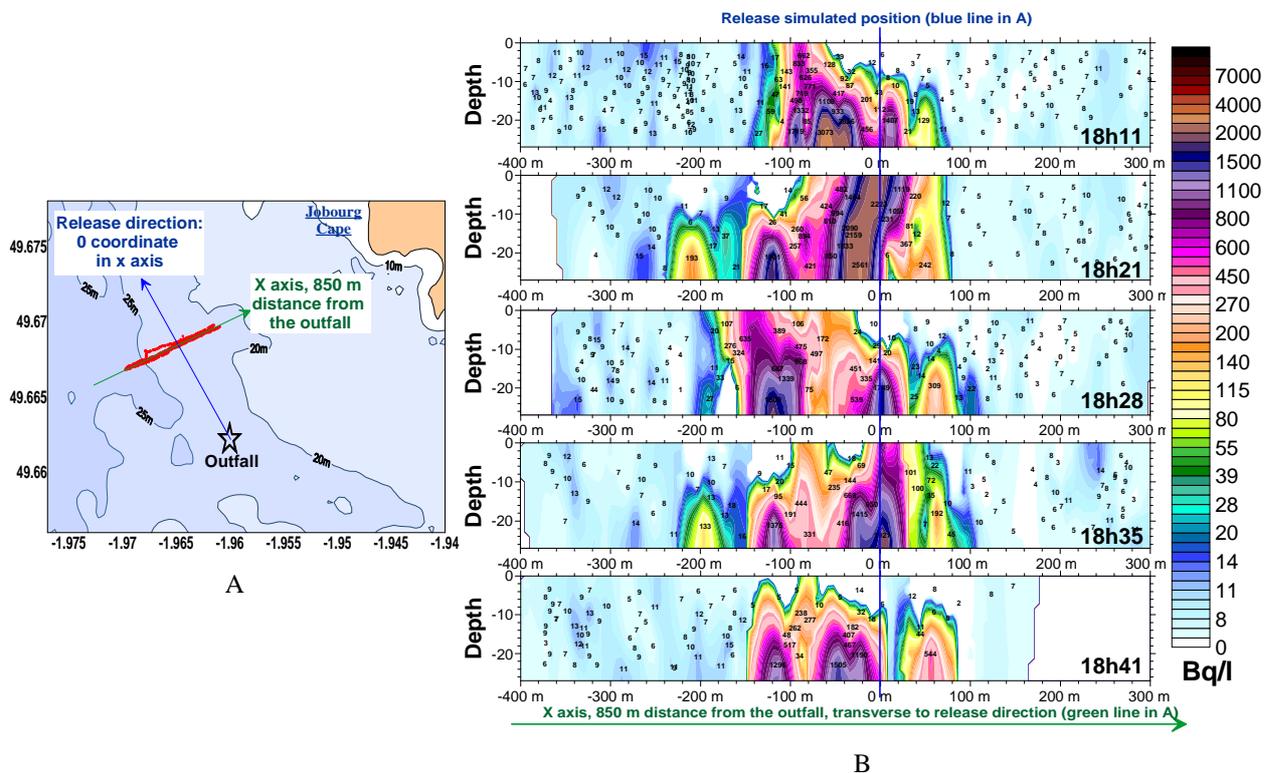


Fig. 10 A: "Côtes de la Manche" sampling points (red dots) and B: tritium concentrations measured during 2010 campaign with vertical slice obtained from four transects. Numbers: measured concentrations in $Bq.l^{-1}$.

The left-hand part of the figure shows the ship's track during sampling, with many 180° half-turns. The seawater current during operation was about $3 - 4 m.s^{-1}$, and the ship's speed was at least $1 m.s^{-1}$ faster.

The right-hand part of the figure shows that the objective was reached, with an accurate representation of the plume in space and time. The strong variations of concentrations at the same depth confirm the good separation of samples in the tubes. The homogeneity of the measured plumes from one transect to

another shows that post-cruise calculations of the exact location and time of sampling are correct: there is no bias resulting from the ship's orientation. Furthermore, the results obtained reveal unexpected highly complex and variable structures that are interesting to investigate.

In Fig. 11, approximately 250 samples were collected from 0 to 55 meters depth during each transects, which are spaced of 45 minutes, four hours after a release. In this area the tritium plume crossed the La Hague Deep with depths ranging from 80 to 100 meters. The right-hand part of the figure shows a more homogeneous plume than in Fig. 10 with identification of surface to 50 meters labelling in the first transect (top of the figure), followed by mostly deep labelling in the second transect (bottom of the figure). These observations result from current variation between surface and deep waters. This means that the labelling is firstly transported in surface waters where the currents are higher, in the top of the figure. In the bottom figure clean waters have replaced labelled ones close to the surface meanwhile slower bottom currents transport waters still labelled.

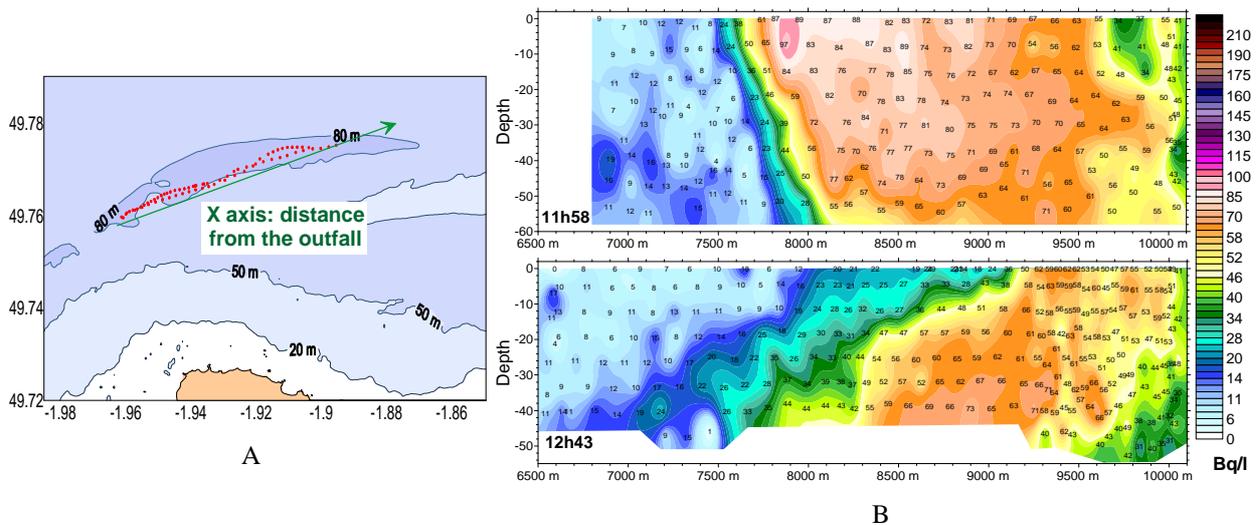


Fig. 11 A: "Côtes de la Manche" sampling points north of La Hague Cape (red dots) and B: tritium concentrations measured during 2011 campaign with vertical slice obtained from four transects at up to 55 m depth. Numbers: measured concentrations in Bq.l⁻¹.

Such pictures would be inaccessible without deployment of the sampling system described here. The overall results obtained will be discussed in future studies.

3 Discussion

The system is designated for the difficult sampling conditions associated by validation of short-term hydrodynamic models by in-situ measurements that require simultaneous sampling at several depths. The only way to reach this objective is to build different sampling lines adapted to the different ranges of depth investigated, 0 – 25 m and 0 – 55 m here. This also requires a separate line containing the tubes for sampling and another supporting cable. In real conditions the coupling of these two lines does not represent a significant problem. The main concern is the variability of the bathymetry which could require rapid pick up of the line to prevent crash of the seafloor. This question could be anticipated by a good knowledge of the bathymetry.

For different depth ranges / number of levels / sampling volumes; all characteristics of the system could be adapted, giving in mind that the overall drag of the sampling line governs the size of the depressor. Its efficiency is proportional to the surface of the main wing: roughly, a double surface of the wing gives possibility to double the sampling depth or the number of vertical levels.

If oceanographic surveys generally not require such particular sampling conditions, the system developed could nevertheless be useful in coastal areas as it is easy to deploy and monitor and allow close-to-the-shore investigations. The high efficiency (lift/drag ratio) of the Dynalest minimizes the length of the line, dead volumes and gives more manoeuvrability to the ship. In our cases the ratio between the moored line and the sampling depth was 1.2. The values obtained with undulating systems are in the range 1.5 -3 (Aiken, 1985; CTG; Dessureault, 1976; Hales and Takahashi, 2002).

Number of samples is not limited and volume depends of the tube size. As the whole line consist of polyethylene and rubber tubes for the peristaltic pump, the system allow sampling of seawater for chemical or trace metals analysis. The automatic connections exist in Polyvinyl chloride (PVC). The only metallic part is the stainless steel electric valve on the automatic sampler. They could be changed in specific valves for trace metal analysis.

The system could be applied for suspended matter sampling, a pumping system used in stations have proven the possibility of continuous analysis of particulate matter with bottom sampling (Lafite et al., 2000). To give orders of magnitude, the flux obtained with 4x6 mm tubes is around 200 ml.mn^{-1} for a 100 m line, a pressure drop of 50 000 Pa and an average speed of 0.3 m.s^{-1} . It is sufficient to avoid sedimentation of suspended particulate matter of diameter lower than 0.3 mm. If we use only two tubes (two sampling depths) with a similar drag and pressure drop, it gives 8x10 mm of diameter. The flux obtained is around 1.3 l.mn^{-1} with an average speed in the tube of 0.4 m.s^{-1} .

If only one depth level is required, a faired tow cable could be used as described in (Hales and Takahashi, 2002). It requires a specific specialized winch but allow higher sampling depths.

4 Conclusions

The DISVER project aims to use *in situ* measurements to validate three-dimensional models for simulating the dispersion of dissolved substances at sea. This validation requires the simultaneous high frequency sampling at different water depths while the ship is under way.

A specific system was developed for this purpose, it comprises:

- Two sampling lines composed of a support cable, a transmission cable and ten tubes for sampling ten depths continuously from 0 to 25 m and from 0 to 55 m respectively.
- Dynalest, a deep-towed depressor that maintains the sampling line in-depth, with the ship sailing from 1 to 5 m.s^{-1} .
- An automatic high-frequency sampler allowing the collection of 10 samples every 30 s (1200 samples per hour), as well as their preparation for measurement.

This equipment was tested at sea under operational conditions. More than 35,000 samples were collected in this way. Picture slices of the vertical dispersion of the dissolved tritium close to an outfall were obtained every ten minutes.

The sampling system can be used in situations that require sampling at high frequency and/or variable depth in aquatic environments while preserving the ship's manoeuvrability at sailing speeds.

Although this system was designed for particularly difficult sampling conditions, it is general-purpose and can be adapted to circumstances where repetitive or continuous sampling needs to be carried out at different depths in coastal areas, rivers or lakes. The operational depth tested with the described equipment are 20 m and 55 m. Greater depths or more detailed vertical sampling could be reached by enlarging the size of the ballast depressor. The system could be applied for chemical or suspended matter sampling and measurements without changes on the vessel equipment or navigation rules.

5 Acknowledgements

We wish to thank particularly the following persons and teams involved in the development of the system:

Crews of the CNRS/INSU vessel "Côtes de la Manche", the teams of the IRSN/LRC and IFREMER, as well as Emmanuel Poizot and students of CNAM/INTECHMER in Cherbourg, who participated in the Dynalest tests.

Luc Solier from IRSN-LRC for tritium measurements.

AREVA NC personnel for the round-the-clock data communication concerning the release fluxes.

Mr. Hervieu from NAUDIN Company for his help in providing supplies and mounting of the Dynalest.

The Ifremer-Brest ERT/HO test canal team Xavier Bompais and Emmanuel Mansuy

We are also grateful to Dr M.S.N. Carpenter for post-editing the English style.

6 References

Aiken, J., 1981. The undulating oceanographic recorder mark 2. *Journal of Plankton Research* 3 (4), 551-560.

Aiken, J., 1985. The Undulating Oceanographic Recorder Mark 2, Mapping Strategies in Chemical Oceanography. American Chemical Society, pp. 315-332.

- Alliance for Coastal Technologies, 2007. Towed vehicles: undulating platforms as tools for mapping coastal processes and water quality assessment, in: (ACT), A.f.C.T. (Ed.), Seaside, California, pp. 1-32.
- Bailly du Bois, P., Dumas, F., Solier, L., Voiseux, C., 2012. In-situ database toolbox for short-term dispersion model validation in macro-tidal seas, application for 2D-model. *Continental Shelf Research* 26, 63-82.
- Brown, J., Brander, K.M., Fernand, L., Hill, A.E., 1996. Scafish: A high performance towed undulator. A new PC controlled towed undulator is aid to understanding coupling between physical and biological processes. *Sea Technology*, 37(39): 23-27.
- Choi, J., Shiraishi, T., Tanaka, T., Kondo, H., 2011. Safe operation of an autonomous underwater towed vehicle: Towed force monitoring and control. *Automation in Construction*, Volume 20, Issues 28, Pages 1012-1019.
- CTG. SeaSoar ocean towed data acquisition vehicle, Chelsea Technologies Group Ltd. Accessed: 09/09/2014; Available from: <http://www.chelsea.co.uk/marine/towed-vehicles/towed-vehicle-overview>.
- Dessureault, J.G., 1976. "Batfish" a depth controllable towed body for collecting oceanographic data. *Ocean Engineering* 3 (2), 99-100,IN105-IN106,101-111.
- Hales, B., Takahashi, T., 2002. The pumping seasoar: A high-resolution seawater sampling platform. *Journal of Atmospheric and Oceanic Technology* 19 (7), 1096-1104.
- Helmond, I., 2001. Towed Vehicles. *Encyclopedia of Ocean Sciences*, Academic Press, Oxford, Volume 13, Issues 13-14, Pages 2994-3003.
- Lafite, R., Shimwell, S., Grochowski, N., Dupont, J.P., Nash, L., Salomon, J.P., Cabioch, L., Collins, M., Gao, S., 2000. Suspended particulate matter fluxes through the Straits of Dover, English Channel: observations and modelling. *Oceanologica Acta*, Volume 23, Issue 26, 21 November 2000, Pages 2687-2700.
- Marcelli, M., Pannocchi, A., Piermattei, V., Mainardi, U., 2012. New Technological Developments for Oceanographic Observations, in: Marcelli, M. (Ed.), *Oceanography*. InTech, Chapters published March 23, 2012 under CC BY 3.0 license, pp. 41-77.
- Mark, A.G., 2007. Transient behavior of towed cable systems during ship turning maneuvers. *Ocean Engineering*, Volume 34, Issues 11&12, Pages 1532-1542.
- Mecaflux. Toolbox and help for fluid calculations. Accessed: 01/10/2012; Available from: <http://www.mecaflux.com/>.
- Moran, J., 1984. *An Introduction to Theoretical and Computational Aerodynamics*. New York, Wiley, c1984, New York.
- Mudie, J.D., Ivers, W.D., 1975. Simulation studies of the response of deeply towed vehicle to various towing ship maneuvers. *Ocean Engineering*, Volume 3, Issues 1, Pages 37-46.
- NACA. NACA airfoil. Accessed: 09/09/2014; Available from: http://en.wikipedia.org/wiki/NACA_airfoil.
- NKE. NKE instrumentation. Accessed: 10/09/2014; Available from: <http://www.nke-instrumentation.com/>.
- RDM6. Resistance of Materials, structures calculation by finite element method. Accessed: 09/09/2014; Available from: http://iut.univ-lemans.fr/ydlogi/rdm_version_6.html.
- Reid, P.C., Colebrook, J.M., Matthews, J.B.L., Aiken, J., 2003. The Continuous Plankton Recorder: concepts and history, from Plankton Indicator to undulating recorders. *Progress In Oceanography* 58 (2-4), 117-173.
- Sun, F., Zhu, Z., LaRosa, M., 2011. Dynamic modeling of cable towed body using nodal position finite element method. *Ocean Engineering*, Volume 38, Issues 34, Pages 529-540.
- Vaz, M., Patel, M., 1995. Transient behaviour of towed marine cables in two dimensions. *Applied Ocean Research*, Volume 17, Issues 13, Pages 143-153.
- XFOIL. XFOIL interactive program for the design and analysis of subsonic isolated airfoils. Accessed: 09/09/2014; Available from: <http://web.mit.edu/drela/Public/web/xfoil/>.