

**Real-time and continuous remote radiological monitoring System in the Strait of Gibraltar: (REMUS project)  
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**ABSTRACT**

REMUS project involves new technologic developments that allow real-time and continuous remote monitoring of sea areas using autonomous probes in anchored buoys, powered with solar panels and equipped with low consumption sensors and one onboard PC that communicates via GSM with a central laboratory in land. Sensors incorporate a very sensitive (few Bq m<sup>-3</sup>) NaI detector for gamma-emitting radionuclides, oceanographic instruments (current meters, CTDs), and chemical sensors (pH, chlorophyll,...). This technology allows the remote environmental monitoring of the upper sea (although some additional sensors can be equally deployed in depth) combining the interest in the early detection of environmental risks (releases of many hazardous materials) and the fundamental research in marine systems, as challenge in the preservation of natural resources and the human health through the knowledge. Thus, the development of predictive models is also one objective of this project. We selected the Gibraltar Strait as an excellent scenario where implement a project based on this new technology. The Strait of Gibraltar is of enormous environmental significance, as it represents the communication pathway between the Mediterranean and the Atlantic seas, and it may be playing a capital role in the global climate change (through the outgoing Mediterranean salty flow). It is also a sensitive place for accidental releases of hazardous materials, because the intensive ship-traffic, including nuclear cargo and nuclear propulsion ships, the complex longitudinal and transversal trade routes, and the particular weather and oceanographic conditions (strong winds and currents). The REMUS project started its implementation through the International Atomic Energy Agency (IAEA) Technical cooperation package and follows for continuation through the Morocco-Belgium and Morocco-Spain Co-operation Programmes. Moroccan partners are: CNESTEN, Marine Royale, Port Tanger MED (TMSA) and Ministry of the Environment.

**1. INTRODUCTION**

Interest in the need of environmental monitoring in the GIBRALTAR STRAIT, in which a wide range of oceanic processes and interactions of global interest occur, has recently increased in order to ensure proper surveillance and control of marine pollution and consequently to complying with international recommendations and binding agreements pertaining to the protection of marine environment. The effects of the English submarine incident (end 2000) in the Gibraltar strait and the radiological incident of Algeciras, Spain (melting of a Cs-137 source at a steel manufactory ACENIROX) suggest an adequate national and regional technical capabilities and expertise for long-term environmental monitoring as a key to control the area and to develop emergency model in the case of any future accident in the zone.

The continuous and remote environmental monitoring of the sea is a long-time pursuit objective of the international scientific community. It is absolutely essential for an accurate forecast of the state of the sea, for the early detection of environmental risks (accidental spillage of hazardous materials) and for the understanding of some long-term processes as those related with climate change. This represents a new challenge in the preservation of natural resources and the human health through the knowledge.

Recent technological developments make now possible to use autonomous probes in anchored buoys, powered with solar panels and equipped with low consumption sensors and one onboard PC that communicates via GSM with a central laboratory in land. These systems are particularly interesting for the monitoring of coastal sea areas, where anthropogenic impacts can be of major relevance for the environmental and human health. In open seas the GSM can be replaced by satellite based communication systems.

**KEYWORDS:** *GIBRALTAR STRAIT, NaI detector for gamma-emitting radionuclides, marine environment, REMUS*

Radionuclides released into the aquatic environment are usually accompanied by gamma-emitters. Therefore, a gamma-monitoring system would provide an excellent solution for the monitoring of radionuclides in the aquatic environment. Gamma-ray spectrometers operating underwater can be effectively used for short term as well as long term monitoring of marine radioactivity. They, in specific cases, replace sporadic sampling campaigns and laborious analytical measurements in the laboratory. Gamma-ray monitors can operate either in a stationary mode or be towed (e.g. for sea-bed mapping of gamma-emitters). Stationary monitoring systems have several advantages when compared to traditional sampling systems e.g. (a) real-time reporting of data, (b) investigation of temporal changes, (c) development of time series. On the other hand, towed monitors can cover large surfaces of sea-bed which require large-scale sampling and analysis of many samples in the laboratory.

A flexible design of the probe (and particularly of the associated software) allows its re-adaptation to incorporate new sensors or to replace the existing ones. By this way, it will be possible to select specific sensors depending on the potential risks in the study area, or to implement new experimental designs.

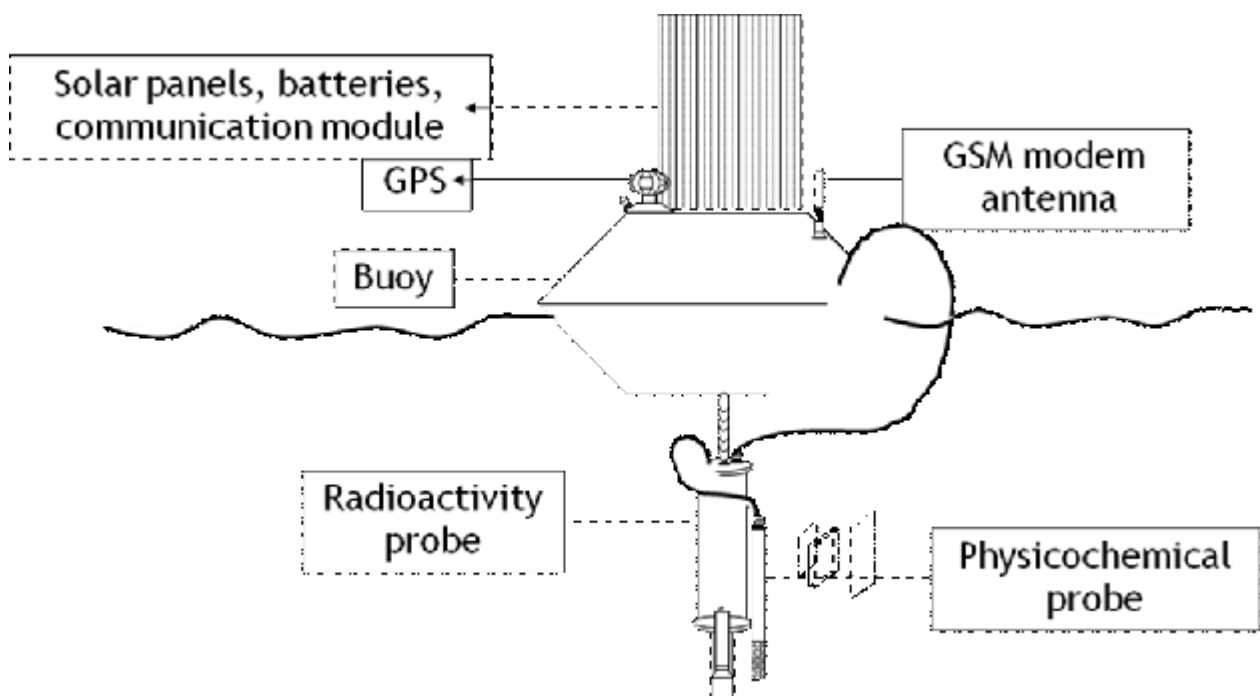


Fig. 1: Description of the System

## 2. PROJECT DESCRIPTION

The Strait of Gibraltar has been selected as an excellent scenario where to implement a research project based on this new technology. It is relevant due to the intense shipping activities in the Strait, which include the transport of radioactive material from/to the nuclear fuel reprocessing plants of Sellafield and Cap de la Hague (in UK and France respectively), the transit of nuclear submarines (Tireless incident in 2000) and nuclear powered ships in general. Shipping routes are complex, with intersections of longitudinal routes with some 2000 annual transverse rotations Algeciras-Ceuta and Algeciras-Tanger. The area of the Strait of Gibraltar has a high ecological and economical (tourism, fishing activities) value, and there are also some important towns. A release of radioactivity into the Strait as a consequence of an accident can lead to a relevant dose to the local population and serious economical impacts. A monitoring programme of the Strait would provide real-time data of activity levels and, in the case of an incident, would provide input data to models used for decision-making purposes.

Therefore, the project consists of the following stages:

1. Laboratory testing of the probe.
2. Validation of the probe in an estuarine system (Kenitra) in Morocco (real environmental conditions).
3. Selection of the most suitable sites to place the probes in the Strait, which will be done by numerical modelling.
4. Final operation of the probes in the Strait. Long-term recording of oceanographic and water-quality parameters.

### 3. LABORATORY TESTING OF THE PROBE

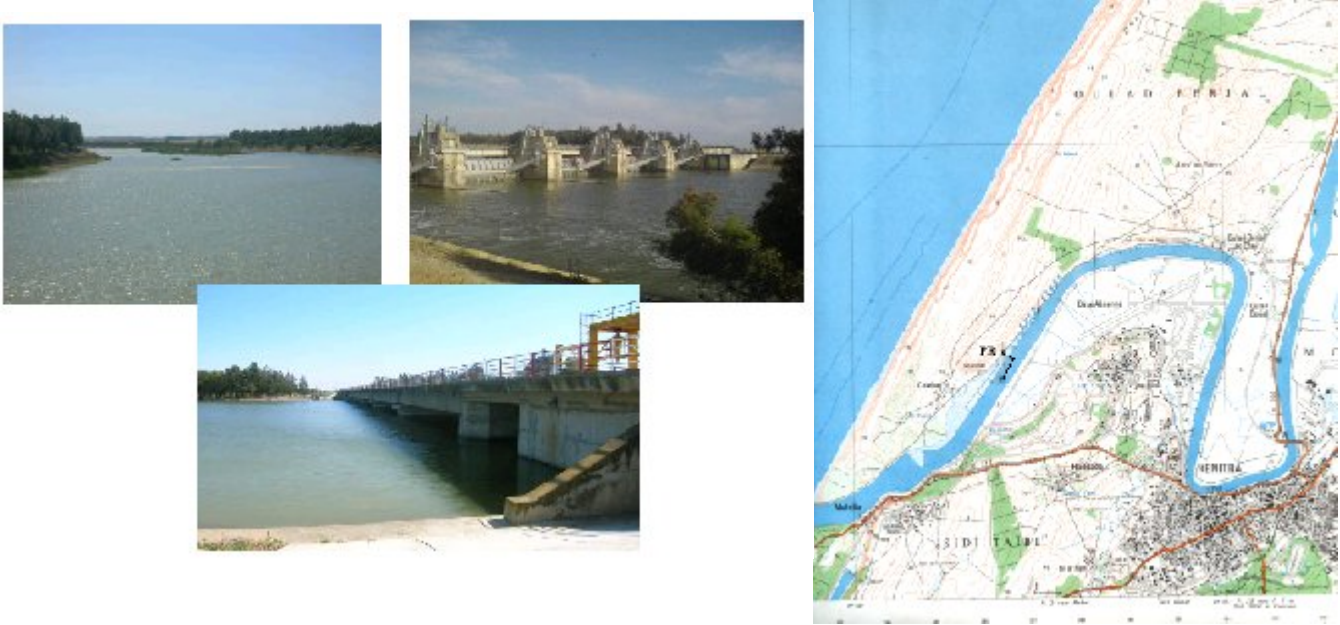
The detection system efficiency has been pre-evaluated in a 20m<sup>3</sup> tank (250 cm diameter, 300 cm height). Dimensions of the tank allow assimilating it to an infinite medium for gamma energies up to 2.4 MeV, without applying any correction factor. The tank was filled with low-level natural radioactivity water (226Ra and 40K). 133Ba (2 kBq/m<sup>3</sup>) and 137Cs (1 kBq/m<sup>3</sup>) standards with their respective carriers were added to the water. The achieved sensitivities (few Bq/m<sup>3</sup>) have been compared to the sensitivities achieved in low-level gamma spectroscopy laboratories. For example, the count time required to reach a sensitivity of 5-10 Bq/m<sup>3</sup> in sea water with a 25% relative efficiency HPGe detector enclosed in a lead shielding is more than 5 times longer for the 2.5 litre Marinelli geometry. Better sensitivities can be achieved at laboratory if larger sample volumes are collected and then concentrated, but at the price of delayed measurement results.



Fig. 2: 20 m<sup>3</sup> tank

### 4. VALIDATION OF THE PROBE IN AN ESTUARINE SYSTEM IN THE ESTUARY OF KENITRA;

The estuary of Kenitra is of major environmental relevance for several reasons: the important population living in the surroundings, the harbour and the wildlife reservoirs for migratory birds. Upstream several industries release their wastes, enhancing the concentrations of heavy metals in the water and the particulate matter. The entrance of the estuary is protected by a defence dock to prevent the intrusion of sand in the harbour, a serious problem in most of the Atlantic ports from Morocco. The low activity liquid wastes from the nuclear reactor operated by the CNESTEN will be released in this estuary in the near future (PR, see map). The scientific programme is designed in such a way that it will be possible to test the radiometric sensors and the protocol for a simulated alarm situation.



**Fig. 3:** PR: Future low activity liquid wastes discharge from the nuclear reactor operated by the CNESTEN

A training period with the probe placed in a secure marine environment, easily accessible for maintenance and testing has started. The reservoir of Kenitra (Barrage de Garde: SEBOU river) has been selected for this purpose. The results are :

(a) real-time reporting of data, (b) investigation of temporal changes, (c) development of time series, d) Validation of the probe in real environmental conditions.



**Fig. 4:** Probe installed in Sebou river (Barrage de Garde)

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Name of the region	<b>I131</b>	<b>Cs137</b>	<b>Co60</b>	<b>K40</b>	<b>Pb214</b>	<b>Bi214</b>	<b>Taux_Glob</b>	<b>PIC150</b>
Energy isotope (KeV) :	364,5	661,6	1332,5	1460,6	352	609	0	150
Inferior Limit :	325	600	1250	1380	295	560	100	100
Superior Limit :	415	720	1410	1540	405	660	2000	200
Alarm Level 1:	100000	100000	1000000	1000000	100000	1,00E+07	1000000	100000
Alarm Level 2:	2000000	2000000	2000000	2000000	200000	2,00E+07	2000000	200000
Detection Efficiency :	9,76E-05	6,19E-05	3,52E-05	3,22E-05	0,000101	6,51E-05	0	1
Efficiency uncertainty [%] :	10	10	10	10	10	1	1	5
Emission [%] :	81,2	85,2	100	10,6	37,6	46,1	0	100

Tab. 1: Gamma Regions configuration

It is expected to find tidal variations in salinity in this estuary. Atlantic tides are noticeable (above 2 m amplitude) and the river flow is also important, at least during the wet season.  $^{40}\text{K}$  is a naturally occurring gamma emitter that can be found in salt water at relatively high concentrations (typically  $10 \text{ kBq/m}^3$ ). Thus, the radiometric sensor register a variable  $^{40}\text{K}$  signal, which has to follow the salinity signal recorded by the oceanographic sensors (EC plus temperature). For this purpose the gamma spectrum has been processed every 20 minutes interval (the minimum time interval required to study a tidal variation). In normal operation and during an alarm situation it is very important to identify the maximum in the signal (related with the position of the centre of the radioactive patch) in order to make reliable predictions about the future path of the patch (using the simultaneous recording of current speed and direction). Thus, this exercise has a double goal: to test the proper functioning of the radiometric and the oceanographic sensors, and to test the capability of the global system for treating varying signals with high temporal resolution. This exercise required several days/weeks of operation and the support of field sampling and laboratory measurements.

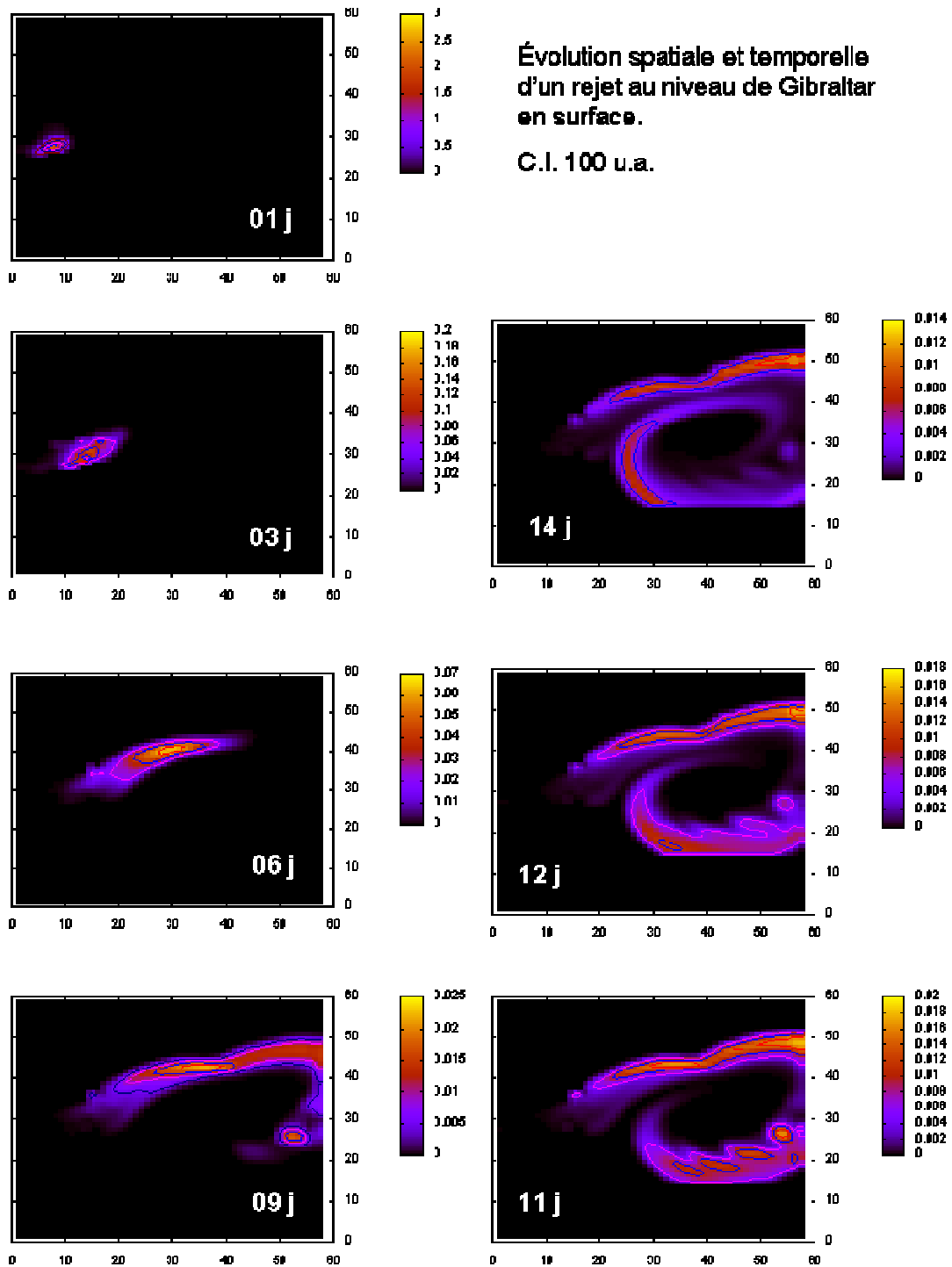
### 3.3 Selection of the most suitable sites to place the probes in the Strait

One of the most critical aspects of the project is the selection of the sites where the probes are to be placed. These sites have to be relatively shallow and protected from the strong currents existing in the area, which ultimately can lead to losing the probes. As a consequence, they will have to be placed close to both coasts of the Strait. However, selected sites must be the most sensitive ones to any release of radioactivity that eventually occurs in the Strait.

This task has been carried out by means of numerical modelling of the Strait. A 2D two-layer model was selected for this purpose since it is an acceptable approach for studying the flow dynamics of the Strait. The model solves the hydrodynamic equations with appropriate boundary conditions to obtain the instantaneous tidal currents over the Strait as well as the residual flow. Computed currents have been treated by standard tidal analysis to obtain tidal constants (amplitude and phase of each current component for each tidal constituent included in the model). These tidal constants have been stored in files that will be read by the dispersion model. The computation of currents from the tidal constants is computationally much more efficient than solving the hydrodynamic equations “on-line” with dispersion. A particle-tracking approach has been used to simulate the dispersion of radionuclides since this technique does not present the classical problems of numerical diffusion that are characteristic of the finite difference solution of the advective terms in the dispersion equation. The modelling work thus consisted of the following stages:

- Definition of the model domain and discretization: computational grid development.
- Development of the hydrodynamic sub-model: calibration and validation through comparisons of observed and computed currents.
- Development and calibration of the lagrangian dispersion sub-model including interactions of radionuclides with sediments.
- Simulations of accidents along navigation routes: numerical experiments to determine the most suitable places to locate the probes.

These modelling tools have supported the final decision about emplacements. Nevertheless, special attention will be paid to explore the suitability of the Algeciras and Ceuta areas, in the eastern boundary of the Strait. The dispersion on any accidental release of hazardous materials in the inner Strait will tentatively displace eastern in the upper layers following the Atlantic inflow. Thus it is expected that the probability of detection will be higher in the eastern part of the Strait. The final decision was to install one probe on buoy at the entrance of the Tanger MED port and the second one was to fix it on the boat of the Marine Authority in order to have data in several points of the Gibraltar Strait (mobile probe) and at different deeps (Fig. 7).



**Fig. 5:** Spatial and temporal evolution of arbitrary radioactive discharge at surface in the Gibraltar Strait after 11 days.

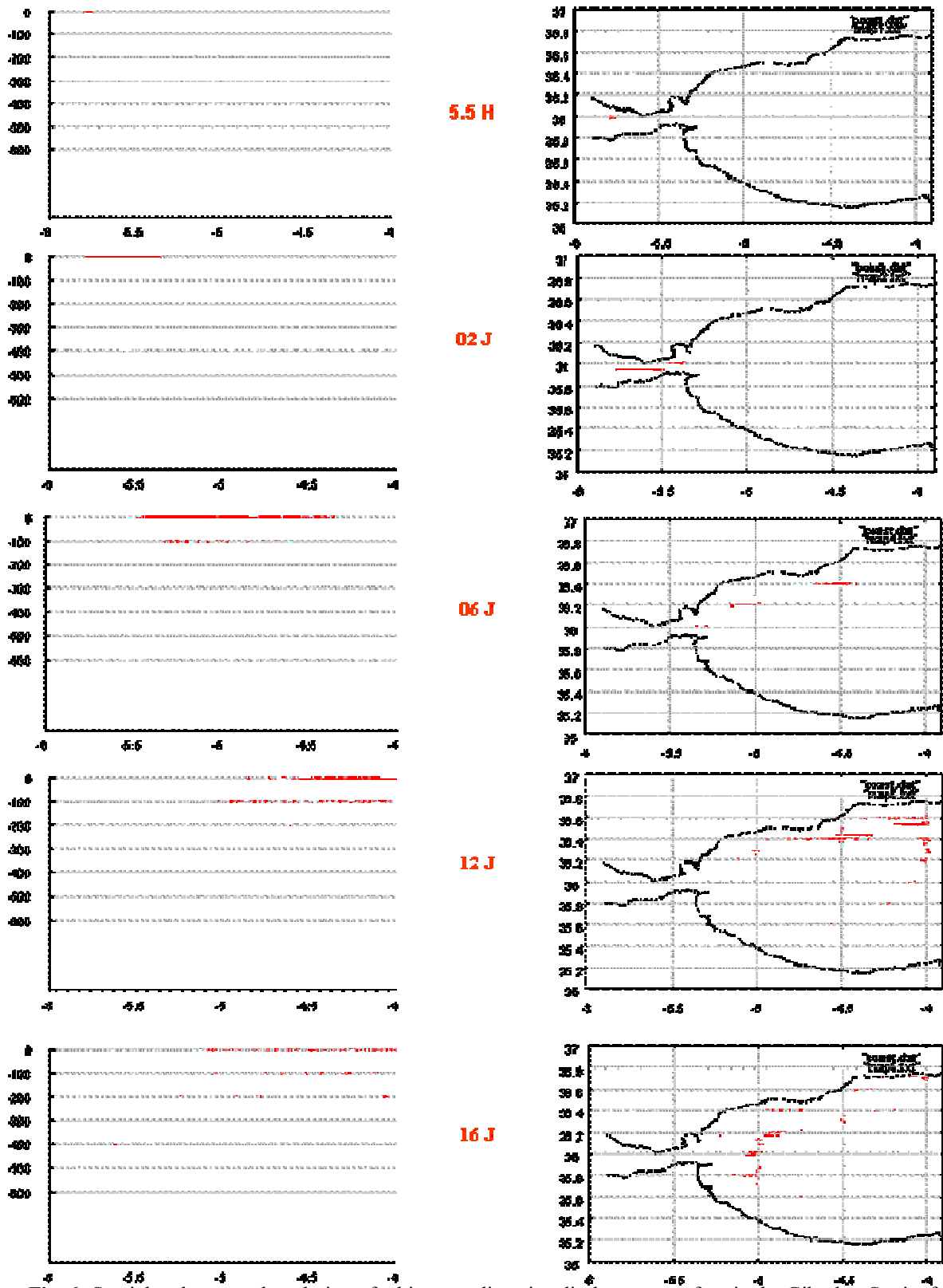


Fig. 6: Spatial and temporal evolution of arbitrary radioactive discharge at surface in the Gibraltar Strait after 16 days.



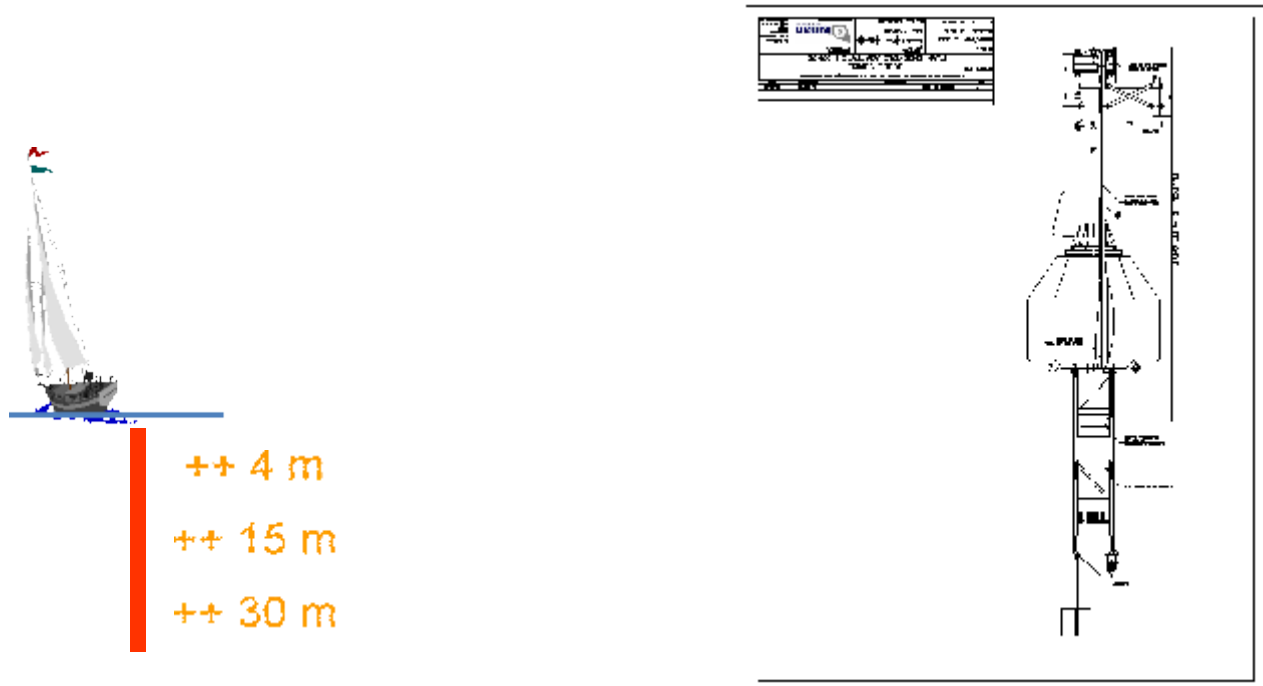


Fig. 7: Schematic construction of the Mobil and fixed probes

### 3.4 Operation of the probes in the Strait

The last step in the project is the operation of the probes in the Strait. They all have been managed on a network philosophy basis.

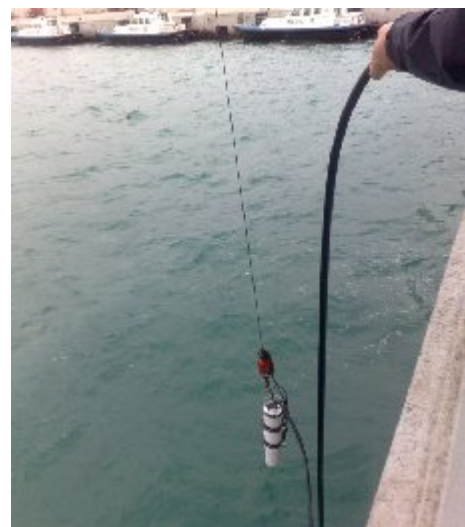
Two probes have been tentatively operated on the Strait. The whole system is in operation and provides not only information on possible radioactivity releases in the Strait, but also valuable scientific information about other physical and chemical parameters that will contribute to a better knowledge of the Strait of Gibraltar system. All the data acquired by the 2 probes will be transferred to all partners of the REMUS project.

The operation has to be continued in time to allow long records of oceanographic and water-quality parameters. Operation for maintenance has been programmed at least once a year. During the first year the maintenance is more frequent in order to ensure the proper functioning of the probe in these environmental conditions.





**Fig. 8:** Operation of the final installation of the fixed probe on buoy at the entrance of the Tanger MED port



**Fig. 9:** Operation of the final installation of the mobile probe on boat of the Maine Authority

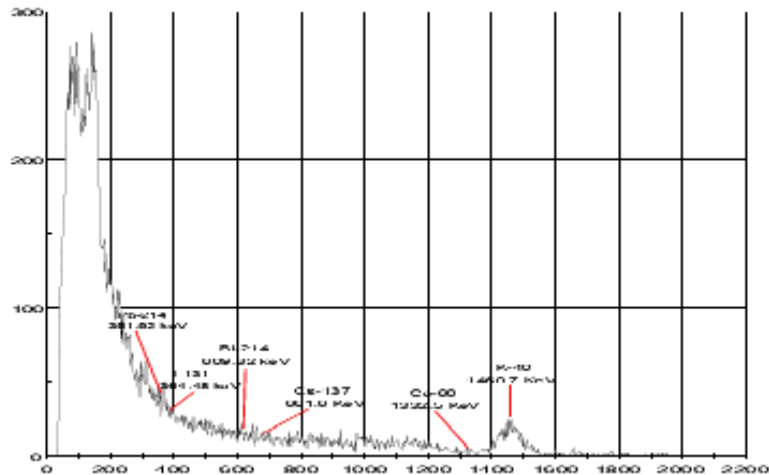


Fig. 10: Gamma-spectra recorded in water, integrated over 2 hours

### 5. Sustainability of the Project

The CNESTEN has given a high priority to this multi-regional project of the Gibraltar Strait monitoring. Morocco is amply supplied with supports which are interested by this project implementation and which are financial partners in this project, namely the Ministry of Environment, the TMSA (Tanger MED Special Authority), Marine Royale and the CNESTEN.

In relation to the use of data:

- The model will be first developed from existing data sets (bathymetry, tidal charts, studied on wind and surface currents and existing models). During the operation, the 2 probes provides a valuable data set on water currents that can be used, in combination with meteorological data (supplied by the governmental institution) for a better calibration and refinement of the model.
- Long-term records of water currents, salinity, temperature and chlorophyll data at three different locations supports studies on seasonal and long-term variability in combination with numerical modelling.
- Early detection of environmental risks.
- Support to the decision-making.
- Long term study on gamma spectrometry looking for seasonal trends in connection with oceanographic data.
- Creation of a home page on internet from which the IAEA and the scientific community can follow the development of the project.

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