Buried Waste in the Seabed – Acoustic Imaging and Bio-toxicity

Results from the European SITAR Project

Philippe Blondel and Andrea Caiti

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Foreword

Forty per cent of the world's population live within 100 km of the coastline and hundreds of millions of people are dependent on the oceans for their livelihood. This is true for Europe, where our seas and coastal zones are of strategic importance to all Europeans. They are home to a large percentage of our citizens, a major source of food and raw materials, a vital link for transport and trade, the location of some of our most valuable habitats, and the favoured destination for our leisure time. Yet Europe's seas are facing serious problems of habitat destruction, loss of biodiversity, contamination of water resources and resource depletion. In addition, the consequences of global climate change (e.g., sea level rise and increase in the frequency and intensity of storms) are likely to be increasingly felt in the future.

Despite these pressures, for many the seafloor may seem safe from the human disturbances that threaten other environments. Yet most natural and artificial wastes – such as sewage sludge, dredged spoils from harbours and estuaries, dangerous synthetic organic compounds and packaged goods – make their way to the seafloor over time.

The dumping of waste at sea, or "ocean dumping", is generally banned worldwide and is regulated by two conventions: the London Dumping Convention (1975) and the MARPOL[1] Convention (1978). The motivation for banning ocean dumping gained momentum when, for example, contaminated wastes from sewage-derived microorganisms were discovered at public beaches, and shellfish beds were contaminated with toxic metals. As a consequence, significant progress has been made in the prevention of ocean dumping.

However, less has been done to eliminate the effects of past dumping practice. A particular difficulty arises from the fact that the information on toxic dumpsites is not easily available, since, not surprisingly, many dumping operations involving

[1] MARPOL is short for MARine POLution.

hazardous material – of an industrial or military nature – have been carried out covertly. In areas where information is available, however, the problem is becoming of increasing concern.

One such area is the Baltic Sea, where existing documentation indicates that at least 65 000 tons of toxic chemical munitions have been dumped in these waters in the post-World War II years. The Helsinki Commission has investigated the status of Baltic Sea dumping, and it has recommended further *in situ* research on the toxicity and bioaccumulation effects on water, sediment and biota.

Starting from the above background, the SITAR project entitled "Seafloor Imaging and Toxicity: Assessment of Risk Caused by Buried Waste" (EC contract no. EVK3-CT-2001-00047) was established to make available instrumentation and systems to meet these requirements. The project started on 1 January 2002, had a duration of 3 years and brought together 10 partners from 6 European countries.

To meet its objectives the project required the merging of multidisciplinary scientific and technological expertise including: marine acoustics propagation and signal processing; biological and chemical toxicological analysis applied to marine biota; design, development and marketing of innovative marine instrumentation; image processing, geo-referenced data management and decision support systems; and environmental risk assessment and waste management. Such a diverse and complementary range of expertise could only be gathered together by combining competences that can be found in separate Europe-wide organizations. The SITAR project therefore provides a good example of how the "European added value" of the RTD[2] projects funded by the European Community can best be used to successfully address complex research problems.

The availability of the technology and scientific methodologies developed in SITAR will enable the implementation of risk prevention and monitoring measures prescribed by the European regional seas conventions, with potentially common procedures and approaches in all the European seas.

In the true spirit of the European Union's RTD Framework Programmes, the partners of the SITAR project through the publication of this book are disseminating their results to the widest possible community. The hope is that the potential users of these results (researchers, practitioners, local, regional and national authorities, to mention just a few) will test the validity of the methods and the tools that are presented and contribute constructively to their possible improvements for the benefit of the entire society.

In concluding, I would like to take this opportunity to thank all SITAR partners for their commitment, hard work and open collaborative spirit throughout the duration of the project.

Alan Edwards,
EC Scientific Officer for the SITAR Project
Brussels, December 2005

[2] RTD is short for Research and Technology Development.

Figures

Colour figures sit between pages 112/113

Tables

Abbreviations and acronyms

AChE	AcetylCholinEsterase
ACTC	ACetylThioCholine iodide
ARMINES	Association pour la recherche et le développement des processus inductriels
AUV	Autonomous Underwater Vehicle
B&K	Brüel & Kjaer
B[a]P	Benzo[a]Pyrene
BATH	University of Bath
BIE	Boundary Integral Equation
CHEMU	see HELCOM CHEMU
DBMS	Data Base Management System
DDT	DichloroDiphenylTrichloroethane
DE	Differential Evolution
DGPS	Differential Global Positioning System (Differential GPS)
DMF	DiMethylFormamide
DPC	Displaced Phase Centre
DSS	Decision Support System
DTNB	DiThiobisNitroBenzoate
dw	dry weight
ECAT	Environmental Centre for Administration and Technology
ECOD	Ethoxycoumarin-*O*-deethylase
EN	Ecole Navale
EROD	Ethoxyresorufin-*O*-deethylase
ESRI	Environmental Systems Research Institute
FARIM	Frequency Analysis-based Roughness and Impedance estimation Method
FM	Frequency Modulation
FOI	Swedish Defense Research Establishment

G	Gaussian probability density function (or Gaussian distribution)
G-G-R	Gaussian–Gaussian–Rayleigh
GA	Genetic Algorithm
GESMA	Groupe d'Études Sous-Marines de l'Atlantique
GIS	Geographical Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HELCOM	Helsinki Commission
HELCOM CHEMU	ad hoc working group on dumped chemical munitions of the Helsinki Commission
HF	High Frequency
HPLC	High-Performance Liquid Chromatography
ICS	Inertial Coordinate System
IEC	International Electrotechnical Commission
ISACS	Integrated System for Analysis and Characterization of the Seafloor
ISME	Interuniversity Centre of Integrated Systems for the Marine Environment
ISO	International Organization for Standardization
IT	Inertial Tensor
KDA	Kongsberg Defense and Aerospace
KTH	Royal Institute of Technology, Stockholm
LBL	Long BaseLine
LF	Low Frequency
LSM	Least Squares Method
LU	Lower triangular times Upper triangular
MARPOL	MARitime POLution convention
MAS	Multiple-Aspect Scattering
MI	Mean Intensity
ML	Maximum Likelihood
MLE	Maximum Likelihood Estimator
MOM	Method Of Moments
MRF	Markov Random Field
MRU	Motion Reference Unit
NaCl	Sodium chloride
NADPH	Nicotinamide Adenine Dinucleotide PHosphate
NETCDF	NETwork Common Data Format
NTNU	Norwegian University of Science and Technology
OCS	Object Coordinate System
PAH	Polycyclic Aromatic Hydrocarbon (ΣPAH: sum of PAH)
PBB	PolyBrominated Biphenyl
PCB	PolyChlorinated Biphenyl (ΣPCB: sum of PCB)
PDF	Probability Density Function
Plums	*Pl*atform for *u*nderwater *m*easurement *s*ystems

P-SAS	Planar Synthetic Aperture Sonar
PSSS	Parametric Side-Scan Sonar
R	Rayleigh probability density function (or Rayleigh distribution)
RK	Ray–Kirchhoff
RMS	Root Mean Square
ROV	Remotely Operated Vehicle
RT90	Rikets Nät 1990 (Swedish: Swedish grid). Coordinated system used for government maps in Sweden
Rx	Receiver
SAS	Synthetic Aperture Sonar
SD	Standard Deviation
SEPA	Swedish Environmental Protection Agency
SGU	Swedish Geological Survey
SU	Stockholm University
TL	Transmission Loss
TNT	TriNitroToluene
TOC	Total Organic Carbon
TOPAS	Parametric sub-bottom profiler (Kongsberg)
TVG	Time-Varying Gain
Tx	Transmitter
UV	UltraViolet
VIS	VISual
VRML	Virtual Reality Modeling Language
W	Weibull probability density function (or Weibull distribution)
WGS84	World Geoïdal Surface 1984
WP	Work Package
ww	wet weight

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SITAR project partners

This book reports activities and results that have taken place within the SITAR project (funded by the European Union). Scientific activities were divided among the partners according to the specific expertise of each. In the book the scientific teams from each project partner are collectively indicated through the partner acronym. The acronyms used, together with the scientific coordinator and main point of contact (p.o.c.) for each partner, are listed in alphabetical order:

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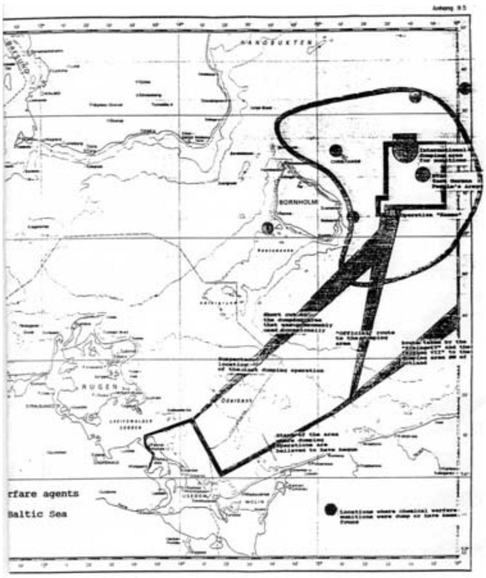
Part I

The SITAR Project: background, goals, project structure



1

The SITAR Project: background, goals, project structure

A. Caiti

1.1 BACKGROUND: DUMPING AT SEA, EUROPEAN LEGISLATIONS AND ASSESSMENT OF BURIED WASTE

Dumping at sea is defined and regulated by two global conventions: the London Dumping Convention (1975), dealing with direct disposal of dumping at sea, and the MARPOL Convention (1973, modified 1978), dealing with ship-borne operations. At European level, the directives of the global conventions are included in several regional conventions which deal with marine pollution at a regional or individual sea basis (e.g., the Barcelona Convention for the Mediterranean Sea, 1975; the Helsinki Convention for the Baltic Sea, revised 1992; the Paris Convention for the North East Atlantic, 1992). In all these conventions, the signing countries have agreed "to prevent and eliminate" pollution at sea from various sources, including dumping; moreover, the conventions apply the precautionary principle – that is, "the enforcement of preventive measures when there is reason to assume that substances or energy introduced into the marine environment may create hazards to human health, harm living resources and marine ecosystems even when there is no conclusive evidence of a causal relationship between inputs and their alleged effects."

As far as dumping at sea is concerned, the above conventions have allowed significant results to be obtained in terms of prevention and regulation of current dumping practice; however, much less has been done to eliminate or at least to monitor the effects of past dumping practice, in particular of toxic material. There have been several reasons for this lack of action. Among them, the fact that the information on toxic dumpsites is not easily available: not surprisingly, many dumping operations involving hazardous material, of industrial or military nature, have been done covertly, even before the signing of the London and MARPOL Conventions. In areas where information is available, however, the problem is becoming of increasing concern. One such area is the Baltic Sea, where existing documentation indicates that at least 65,000 tons of toxic chemical munitions have been dumped in the post-World War II years, with toxic agents including mustard and viscous mustard gas, adamsite, clark, lewisite and tabun. Another European area where similar dumpings have occurred is the North Sea (Rapsch, 2000); the Adriatic Sea is also suspected to be a recipient of toxic waste, although in this case there is a consistent lack of precise information. The Helsinki Commission – HELCOM – has conducted a specific study on the status of Baltic Sea dumping (HELCOM CHEMU, 1994), showing that the preservation status of the chemical containers range from well preserved to totally corroded; moreover, among the contaminants, mustard gas remains in stable form on the seabed, while the other contaminants react in water, producing arsenic compounds that also rest at the seabed. While ruling out the possibility of environmental damage on a large scale, the HELCOM working group has recommended further investigations, in particular on the following topics:

(1) further search for location of chemical waste, and in particular determination of the amount of toxic waste buried within the sediment, and determination of the state of corrosion of the containers;
(2) *in situ* investigation of the toxicity and bioaccumulation effects on water, sediment and biota due to leakage of toxic material.

Implementation of the above recommendations have been so far frustrated: for the first topic, because of the lack of adequate instrumentation for imaging of buried objects of the expected dimensions; for the second topic, due to the lack of appropriate analytical methods able to evaluate the *in situ* toxic impact on marine biota of a contaminated sediment, including bioaccumulation effects.

In particular, standard site surveys over a dumpsite (or a shipwreck site) are nowadays performed by first exploring the site with a side-scan sonar instrument, to collect a map of location of objects over the area of interest, and subsequently by inspection of each object with video-cameras operated from an ROV (Remotely Operated Vehicle). In this way it is possible to gather information on the nature of the objects, dimensions, orientation, state of preservation, etc. All this information is necessary in order to precisely evaluate means, costs and efforts required for future actions at the site (like, for instance, clean-up or recovery operations). While current instrumentation is effective for inspection of objects exposed on the seabed, neither state-of-the-art side-scan sonar systems nor, clearly, video-cameras are able to gather the same information as for objects buried within the seabed sediment. Standard sub-bottom profilers are often used to collect information on the subsurface structure, but these instruments operate at relatively low frequency, in order to ensure bottom penetration, and hence they do not possess the resolution needed to image buried objects of small dimensions (throughout the book by "small dimension" we mean a cylinder-like object of 1-m length and 0.1-m diameter).

As for environmental risk at a toxic dumpsite, a crucial role is played by the nature of the toxic contaminant. Previous studies have been conducted only for a few components found in known dumping areas, such as those of the Baltic Sea. These studies (Federal/Länder, 1993; HELCOM CHEMU, 1994 and references therein) have focused entirely on acute toxicity. This is of concern, since some compounds (such as organic hydrophobic structures) do not have direct acute toxic effects. Instead, they express their effects at a time long after exposure or during a prolonged exposure period. Stable organic pollutants also show the ability to bioaccumulate both by bioconcentration directly from the water phase, and by biomagnification via the food web. In many cases, the parent compounds are not toxic, while the ultimate toxic substances are formed during the metabolism of these compounds. Hence, acute toxicity investigations may provide only a limited and partial picture of the environmental status of a given area.

1.2 THE SITAR PROJECT: GOALS AND PARTNERSHIP

Starting from the above background, a team of ten laboratories and institutions Europe-wide (see p. xxiii) submitted in 2001 a project proposal to the European Union, in accordance with the rules and priorities established by the 5th Framework Programme for Research and Development, on the investigation of novel technologies and scientific methodologies for risk assessment of dumpsites in presence of buried waste containers. One of the most crucial aspects in any proposal preparation is the choice of project title, in order to produce an effective (and easy to spell) project acronym; after several tests, Philippe Blondel from the University of Bath proposed "Seafloor Imaging and Toxicity: Assessment of Risk caused by buried waste – SITAR." Once the project got approval from the European Union, Peter Dobbins, also from the University of Bath, designed the project logo.

SITAR was established with the goal of investigating scientific methodologies and techniques to make instrumentation and systems available, as first priority, to meet the requirements of the HELCOM recommendations, identified as the more detailed specifications of actions to assess the threat posed by toxic dumpsites. The project started on January 1, 2002, and had a duration of 3 years. The specific goals of the project were detailed as follows:

- developing acoustic methods and instrumentation for imaging of waste barrels/containers of small dimension buried in unconsolidated sea sediments;
- developing biological testing methods to determine the relative *in-situ* bioaccumulated toxicity at a contaminated site;
- integrating and making accessible the acoustical imaging data and the biotoxicological information to end-users and decision makers.

The research consortium (see p. xxiii) assembled to meet the goals included the necessary merging of multidisciplinary scientific and technological expertise: underwater acoustics, signal processing, marine biotoxicity, geo-referenced data management, decision support systems, environmental risk assessment and waste management. Such a diverse and complementary range of expertise could be gathered together only by combining competences found in separate organizations Europe-wide; cooperation at European level has allowed the critical mass to be established, in terms of