Chemical munition dump sites in coastal environments

Edited by

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Federal Office for Scientific, Technical and Cultural Affairs (OSTC)
Federal Ministry of Social Affairs, Public Health and the Environment
Brussels 2002

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D/2003/1191/7

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Preface

In September 2001 the Belgian Federal OSTC Project "Evaluation of the Paardenmarkt site" neared its conclusion. The problem of the "Paardenmarkt", an old hazardous munition waste site off the coast of Knokke-Heist, is not unique. Large quantities of warfare, both chemical and conventional, were dumped after WW1 and WW2 in the (often shallow) European seas, thereby forming a potential threat to the marine environment and the densely populated European coasts. At this moment we do not have a ready-made methodology to solve the complex problem of sea-dumped toxic warfare. Tackling the problem calls for international co-operation and mutual exchange of information, methodologies and results.

During recent years increasing research has been carried out on marine dump sites in different European countries, including Russia. Attention has been paid to the tracking and location of dumping grounds, to monitoring strategies, to corrosion and pollutant release, to risk assessment and ecotoxicology. In order to assess the latest state-of-the-art in marine dump site research and to allow the exchange of international experience and expertise in this border-transgressing issue, an international workshop on "Chemical munition dump sites in coastal environments" was organised in July 2001 in Gent, Belgium, by the Renard Centre of Marine Geology (University of Gent).

The results of the workshop are presented in this volume. After a short introduction, which sketches the historical background and sets the stage for the following chapters, the papers in this volume have been loosely grouped into three main sections. A first section deals with status assessment, focusing on different detection methods and monitoring techniques. The following section stresses aspects of risk assessment, for instance related to corrosion release, ecotoxicology and the washing ashore of munition. Finally the papers in the third and last section focus on the national policy in a number of European countries and the legal implications involved.

The workshop was organised in the framework of the Paardenmarkt evaluation project (OSTC project MN/02/88). The project team involved the following partners: Renard Centre of Marine Geology - Gent University; Magelas; G-Tec; TNO Prins Maurits Laboratory (The Netherlands); Université Aix-Marseille III (France); Marine Biology - Gent University; Civil Engineering - Gent University; Institute for Nature Conservation. The participation of foreign partners supported an early international approach for a border-transgressing problem.

The organisers gratefully acknowledge the support of the Federal Office for Scientific, Technical and Cultural Affairs (OSTC) and the Federal Environment Administration of the Federal Ministry of Social Affairs, Public Health and the Environment.

Chemical munition dump sites in coastal environments : a border-transgressing problem

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Introduction

The problem posed by sea-dumped chemical weapons deserves considerable international attention: the amount of these weapons dumped in the North European seas since the end of World War I runs into hundreds of thousand of tons at least. The toxic warfare, often dumped in relatively shallow waters and areas of active fishing, not only represents a serious threat to the marine environment but also to the often densely populated European coasts. Because many dumping operations were carried out secretly, it is not always clear who can be held responsible. Some dump sites are located in international waters (and thus beyond any particular nation's responsibility), although more often dumping operations were carried out in territorial waters near the borders of neighbouring states.

Highly toxic material has time and again showed up, for instance when retrieved in fishing nets or washed ashore on beaches, attracting local media coverage only. Nevertheless, this issue has not always been given adequate and comprehensive scientific attention. In fact, the problem has been neglected for a long time at the international level, and some countries which conducted dumping operations have only recently made official data available.

There were a number of reasons for the decades of delay in addressing this problem. For one thing the issue is politically sensitive because it raises the problem of accountability, and the government bodies of both the states that carried out the operations and those bordering the dumping areas were reluctant to tackle this sensitive problem (especially during the Cold War). These political obstacles have mostly been removed now. Another factor is the complexity of this matter, which requires comprehensive and profound expertise and therefore involves a huge commitment of financial and technological resources.

In recent years, however, sea-dumped chemical weapons have been the subject of growing concern in a number of international fora and workshops. Although the full extent of the dumping operations still remains unclear (due a lack of documentation and loss or destruction of records), a large number of dump sites have been documented.

Historical background

Chemical weapons (CW) were first used on a large scale in the battle of Ypres in April 1915. During the entire First World War a wide range of toxic warfare agents was produced (at least 40 different compounds) and employed on the battlefields. An estimated 1.45 billion shells were fired during the war; about 66 million of these contained toxic agents.

Outrage at the effects of chemical warfare led to the signing in 1925 of the Geneva Protocol for the Prohibition of the Use of Asphyxiating, Poisonous or Other Gases, and Bacteriological Methods of Warfare. Strangely enough the treaty did not forbid the development, production and possession of these weapons. A large number of nations signed the treaty, but also expressed that they should maintain the right to retaliate any chemical attack on their territory with the same means, as well as the right to use chemical weapons against non-signatories of the protocol.

The invention of organophosphor compounds (a.o. Sarin, Tabun and Soman) in the 1930's and 1940's gave a new dimension to chemical warfare. During World War II no chemical weapons were employed, although large stocks were produced by Germany, the US, Japan, the Soviet Union and the UK. In 1945 the allied countries installed an inspection committee charged with the detection, dismantling and recovery of the - mainly German - CW stocks. At that time dumping at sea was considered the best and most practical solution to get rid of these old CW stocks, thereby completely ignoring the consequences for the environment.

Also after World War II the production of CW continued, and on several occasions chemical weapons were deployed at war (a.o. in Vietnam, Yemen, Kurdistan, Iraq, Iran). For decades dumping at sea remained a widely used method to reduce old or obsolete stocks. With the growing environmental protest in the 1970's the number of dumping operations at sea gradually declined, and in many countries it is nowadays forbidden.

A first important step in dealing with the problem of unconventional weapons was made in 1972 with the opening for signature of the "Biological and Toxic Weapons Convention" (BTWC). The treaty forbids the development, production and storage of bacteriological, biological and toxin weapons. The BTWC entered into force in 1975.

During the 1980's further steps were taken towards a convention banning chemical weapons. Many years of hard effort finally led to the signing of the "Chemical Weapons Convention" (CWC) in 1993. The CWC prohibits the development, production, stockpiling and use of chemical war material for military purposes and calls for the destruction of the present stocks. The parties to the CWC need to clarify the status of sea-dumped chemical munitions under the convention. The CWC, however, provides no incentives to recover chemical weapons that were sea-dumped before 1985. If CW are recovered their status under the CWC may be uncertain as declarations of such recovery are voluntary and the treaty contains no explicit destruction requirements for such recovered munitions.

As a result of the growing environmental awareness the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (Oslo Convention) was signed in 1972. It entered into force in 1974. In that same year the Convention for the Prevention of Marine Pollution from Land-Based Sources (Paris Convention) was signed, entering into force in 1978. In 1992 both conventions merged into the new Oslo-Paris Convention for the Protection of the Marine Environment of the Northeast Atlantic (OSPAR Convention), which entered into force in 1998.

In 1974 the first Convention for the Protection of the Marine Environment of the Baltic was signed (Helsinki Convention). In 1992, a new Convention was signed by all the countries bordering on the Baltic Sea and by the European Economic Community. The new 1992 Convention entered into force in January 2000. The governing body of the Convention is the Helsinki Commission or HELCOM.

It is generally accepted that CW cannot be openly dumped at sea today. The CWC explicitly forbids the dumping of CW in any body of water for its state parties (Verification Annex, Part IV(A), § 13). The OSPAR and HELCOM Conventions forbid the dumping of toxic waste at sea; however in these treaties no explicit reference is made to war material. Still, there is no other way than considering a chemical warfare agent as a toxic substance: this characteristic is at the heart of the definition of chemical weapons.

Major CW dump sites

Although sea-dumping of CW started already after World War I, the first intensive dumping efforts came right after World War II. Between 1945 and 1948 some 300,000 tons (gross weight) of CW were recovered on German territory (HELCOM CHEMU 1994; Anon. 1993). By far the largest part of these weapons (according to Stock (1996) as much as 85%) were dumped in the Baltic Sea and Skagerrak Strait on the orders of the British, Russian and American occupation authorities. Up to now over 80 conventional and chemical munition dump sites have been identified in the North Sea and Northeast Atlantic, excluding the Baltic Sea (OSPAR 2002). However this list is probably not complete - according to Paetzel (this volume) at least 5 known Norwegian dump sites, located in the Skagerrak and in fjords, are not included.

At least 170,000 tons of CW were dumped in the Skagerrak (HELCOM CHEMU 1994; Anon. 1993; Stock 1996, Duursma 1999; Laurin 1997). The main dump site is located in the Norwegian Trench, south of Arendal, where 9 ships (containing roughly 30,000 tons of CW) were sunk by the American authorities (operation "Davey Jones Locker"), and more than 30 ships (containing over 125,000 tons of CW) were sunk by the British authorities (Stock 1996; Laurin 1997; Frondorf 1996; Fonnum 1993). At least 9 ships (some estimations mention 16 ships) were scuttled by the British authorities off the Swedish coast, 25 miles west of Måseskär (Laurin 1997; Granbom 1996). The total content of CW is unknown, but at least 2 ships loaded with 20,000 tons of CW were sunk here (Granbom 1996).

In the Baltic Sea at least 50,000 tons of CW were dumped by the Russian, British and German authorities. Most of the munition was thrown over the side of the ship, in some cases entire ships were sunk. The largest dump site is located off Bornholm, where over 40,000 tons of CW were dumped. Other dump sites include the Little Belt, where 2 ships loaded with 69,000 Tabun shells and 5000 tons of CW were dumped, and the Gotland Basin, 70 miles west of Liepaja, where 2000-5000 tons of CW were dumped (HELCOM CHEMU 1994; Anon. 1993; Duursma 1999; Laurin 1997). There are also indications that the munition was partially thrown over board during transport to the Baltic dump sites, but the exact amount is not known (Laurin 1997; Andrulewicz 1996).

Large quantities of CW were also dumped in the North Sea after World War II. Off the Norwegian west coast the United States dumped two vessels containing 4500 tons of CW (Laurin 1997; Frondorf 1996). Several ships were also scuttled near the island of Helgoland. Off the German coast ammunition (mainly conventional) was dumped on a large scale by the German authorities. The total amount of dumped warfare is estimated between 0.75 - 1.5 million tons. At least 8 dump sites are known along the Lower Saxonian coast, from the Wadden Sea to the Frisian islands (Rapsch & Fisher 2000). Many of these dump sites are located in very shallow water, in some cases even surfacing at low tide. At least 12 ships loaded with CW were sunk near the Doggerbank (Rapsch & Fisher 2000).

Shortly after World War II the UK conducted extensive dumping operations in the Atlantic Ocean to dispose of its WW2 stockpile of CW. During the operation codenamed "Sandcastle" huge quantities of CW (including 120,000 tons of mustard gas munition and 17,000 tons of Tabun munition) were dumped in deep water off the Hebrides, Land's End and NW Ireland (Anon. 2001). In Beaufort's Dyke, a 200-300 m deep and 3.5 km wide trench between Scotland and Northern Ireland, over 1 million tons (according to some sources up to 2 million tons) of chemical and conventional war material has been dumped since 1945, possibly from as early as 1920; the last dumping operation probably took place in 1976 (Anon. 2001; SOAEFD 1996).

Since World War II large amounts of CW have been dumped by the Soviet authorities in the arctic seas. On this subject there is hardly any official information. According to an American study (MEDEA 1997) a maximum of approximately 115,000 tons of mustard gas and Lewisite were dumped into the White Sea, the Barents Sea and Kara Sea. In addition, a maximum of 32,000 tons of Tabun and Sarin was estimated to have been dumped in these seas. In total 5 potential dump sites have been identified in the area (MEDEA 1997).

No official data are available about possible CW dump sites off the French coast. Unofficial sources report the clearing of stocks of WW1 ammunition, a.o. at the mouth of the Somme river, where the war material was dumped in big pits at low tide and brought to explode at high tide. According to Laurin (1997) at least 3 vessels loaded with CW were sunk in the Bay of Biscay after World War II by the Allies. For many years large amounts of chemical (and nuclear) material have been dumped in the bay by different countries. In 1960, Tabun shells recovered from the Little Belt were cast in concrete and dumped in the Bay of Biscay (Anon. 1993; Glasby 1997).

Dump sites outside Europe

Between 1945 and 1968 the US authorities dumped at least 100,000 tons of CW off the American east and west coast (a.o. California, New Jersey, West Virginia & South Carolina, Gulf of Mexico) (MEDEA 1997). Between 1968 and 1970 a number of large dumping operations were carried out on the continental shelf off the coast of New York and Florida (operation " CHASE - Cut Holes And Sink 'Em ") (MEDEA 1997).

Immediately after World War II thousands of tons of mustard gas were dumped off Nova Scotia by the Canadian Navy; in some cases the entire vessel was scuttled. Between 1959 and 1962 surplus American munitions were dumped along Canada's east coast by the US Navy (Myles *et al.* 2001). At present four munition dump sites are under lease to oil and gas exploration companies (Myles *et al.* 2002).

Off the coast of Japan large amounts of CW were dumped by the US occupation forces right after World War II. It is believed that prior to the end of the war, the Japanese Imperial Army also dumped CW on a regular basis. Many of the dump sites are situated close to the shore. Nothing is known about the quantity of the dumped war material or exactly when these dumping operations were carried out (MEDEA 1997).

At the end of World War II a total of almost 15,000 tons of CW (mainly filled with mustard gas) was dumped off the Australian coast on at least three different locations. During the 1960's and 1970's a number of smaller dumping operations were carried out in Australian waters (Plunkett 1998).

Accidents

Over the last 50 years a large number of accidents related to sea-dumped CW have been reported in the Baltic, the North Sea, the Adriatic Sea and the Sea of Japan. Most accidents involved fishing crews; in some cases complete lumps of Yperite (mustard gas) were fished up, often resulting in serious burning wounds. Numerous incidents have also been reported related to the washing ashore of shells.

The largest number of accidents were reported by Danish fishermen in the Baltic Sea - as much as 450 accidents since 1976 (Theobald, this volume). The latter is most likely related to the policy in Denmark - fishermen are compensated for each shell that is recovered and brought onshore (HELCOM CHEMU 1994; Laurin 1997). In Sweden, where no such policy exists, the number of reported accidents is surprisingly low. This seems to indicate that most likely many accidents are not reported, and probably the shells are thrown back into the sea.

Local fishermen in the Irish Sea also regularly bring up munition in their nets. At least one fisherman was injured by explosives. In the 1990's thousands of small chemical and toxic explosives devices were washed up on the beaches of Northern Ireland and Scotland's west coast (a.o. Mull, Oban, Arran). The munition had most likely become dislodged as a result of pipe laying activities close to the Beaufort dump site; some people were badly injured when bombs they picked up on the beach ignited (Anon. 2001). A detailed survey was undertaken in the mid-90's; the results showed that large quantities of CW were dumped outside the charted dump site (SOAEFD 1996).

International policy

One of the first organisations to deal with the problem of sea-dumped CW in Europe was the Baltic Marine Environment Protection Commission (HELCOM). In 1992 the CHEMU (Chemical Munitions) *ad hoc* Working Group was established with the main purpose of reporting the information related to CW in the Baltic; Denmark acted in this as lead country. The general conclusions and recommendations of the CHEMU working group are discussed in this volume (Theobald).

HELCOM collaborates closely with the OSPAR Commission on the subject of sea-dumped CW. The OSPAR "Standing Advisory Committee for Scientific Advice" (SACSA) gathers all information in relation to munition dump sites and the possible recovery methods. Recently an *ad hoc* working group has been established which deals a.o. with (1) reporting, recording and assessment of encounters with marine dumped chemical weapons and munitions, (2) guidelines for fishermen and other users of the sea, and (3) surveillance and management practices; lead country is Ireland.

Also in Europe the Conversion For the Environment Foundation (CFE) has dealt with the problem of sea-dumped CW. The foundation is an international, non-governmental organisation with headquarters in the Netherlands and Russia. It focuses on acute environmental problems related to the defence industry, with specific attention for marine CW dump sites. In collaboration with NATO two workshops were organised on "Sea-dumped Chemical Munitions" in 1995 and 1996. The results of the first workshop were published in the book "Sea-dumped chemical weapons : aspects, problems and solutions" (Kaffka 1995).

The Chemical and Biological Warfare (CBW) Project of the Stockholm International Peace Research Institute (SIPRI) has carried out an extensive study of the CW problem, bringing together scientists from different European countries. The results of these studies have been published in 1997 in the book "The challenge of old chemical munitions and toxic armament wastes" (Stock & Lohs 1997).

In the beginning of the 1990's expert groups in Denmark, Sweden and Germany prepared several national reports on dumped chemical munitions in the Baltic Sea (HELCOM CHEMU 1994; Anon. 1993; HELCOM CHEMU 1993). Since the mid-90's an increasing number of studies have been carried out in Europe and Russia (e.g. Rapsch & Fisher 2000; SOAEFD 1996; van Ham *et al.* 2000; Missiaen *et al.* 2001; Muribi 1997; Emelyanov *et al.* 2000). Caused by a deep concern about Russian dumping operations in the arctic seas during the cold war, the United States recently carried out a detailed study of these CW dump sites (MEDEA 1997).

A number of scientists and international organisations believe it is best to leave the dump sites undisturbed, especially if they are in deep water. In 1994, HELCOM recommended that CW dumped in the Baltic Sea be left undisturbed and concluded that they pose no immediate danger to the marine environment (HELCOM CHEMU 1994). The large number of accidents reported in this area however seems to contradict this. Moreover, there are too many uncertainties to draw any firm conclusions. For instance, the rate of deterioration of the munitions is unclear, not all the dump sites are known, and the behaviour of the leaking warfare is not fully understood.

In most countries the "do not touch" policy still applies, and no actual measures have been taken against possible future environmental catastrophes. Up to now only two recovery operations were carried out in Europe - in the Little Belt in 1960, where two shipwrecks filled with Tabun shells were recovered, and in the German Wadden Sea in the 1950's, where due to increased demands for scrap dumped ammunition was recovered to be used in steel production. Although it is nowadays believed that recovery of dumped munition may in some cases be technically feasible, there are serious concerns about the high risks involved both for salvage crews and for the marine environment.

The Gent workshop

In the past, most field research has been focused on (1) tracing and documenting dump areas, often using conventional acoustic and magnetic techniques, and (2) screening of seabed sediments and water samples. In many cases the sampling sites were more or less picked at random, and screening was done for merely one or two chemical warfare agents, thereby often overlooking the fact that conventional weapons may as well contain highly toxic substances.

Laboratory studies have up to now mainly paid attention to the stability of toxic warfare agents. Still, the marine ecosystem is not comparable with the laboratory environment, and little is known about the dynamic behaviour of pollutants under actual marine conditions, their environmental impact and possible bio-accumulation in fauna and flora (even after long periods of time some agents remain extremely hazardous).

During recent years, however, an increasing number of detailed investigations have been carried out in different countries (e.g. on corrosion research, pollutant release, ecotoxicity, geophysical monitoring, risk evaluation). In order to assess the latest state-of-the-art in marine dump site research and to allow the exchange of international experience and expertise in this complex matter, an international workshop was held in July 2001 in Gent (Belgium) on *"Chemical munition dump sites in coastal environments"*. The workshop was organised in the framework of the Belgian federal OSTC project "Evaluation of the Paardenmarkt site", an old hazardous military waste site off the Belgian coast.

The workshop was divided in 3 different sessions : status assessment, risk assessment, and policy. Each session was rounded off by a debate, which allowed to make maximal use of the present expertise and to confront advice and opinions.

Status assessment

Liebezeit focuses on munition dumped in the German Wadden Sea. Most of the dump sites (16 in total) are located in extremely shallow water. Estimates are that between 0.75 and 1.5 million tons were dumped here. Apparently there seems to be no clear danger but due to a lack of information this may be misleading - up to now no detailed sampling was carried out on the sites. On one dump site munition shells have surfaced and may form a possible threat.

Paka & Spiridonov present an overview of Russian surveys of dumped CW in the Baltic Sea and Skagerrak from 1997-2000. Near-bottom dynamics were studied as well as the chemical properties of the sea water. Dump sites were investigated using a.o. water and sediment samplers, side-scan sonar, magnetometer, and ROV's for inspection of sunken vessels. Numerous observations of leakage were made. However it is not known what proportion of dumped CW is leaking or how far the corrosion process has advanced.

Research into the transport routes to the Bornholm dump site is discussed by **Schultz-Ohlberg *et al.*** In order to save time large quantities of munition were dumped in the Baltic before the actual dump site was reached. Between 1994 and 1997 a total of 8 side-scan sonar and magnetometry surveys were carried out. About 100 objects were located; of these, 4 turned out to be munition on the sea floor, all the others were buried. A number of objects still remain unidentified.

Gorodnitski & Filin focus on Russian magnetometric investigations in the Baltic Sea and Skagerrak. The technique of precision magnetic gradiometry, used here in combination with side-scan sonar investigations, has allowed the exact localisation of 3 submerged vessels in the Bornholm Deep and 8 vessels in the Skagerrak Strait. This will finally allow better monitoring of these dump sites, and clearly illustrates the efficiency of gradient magnetic measurements for the investigations of munition dump sites.

The evaluation of an old WW1 munition dump site off the Belgian coast is presented by **Missiaen *et al.*** An estimated 35,000 tons of warfare was dumped here, of which presumably one third contain chemical warfare agents. The munition is nowadays largely covered under accumulating fine-grained sediments, and most likely not too heavily corroded. At this moment there are no strong indications for acute danger but regular monitoring is needed.

The different presentations in this session make it clear that status assessment will highly depend on the site itself. Each site is unique - deep sites will differ a lot from shallow sites, and also the dumping methods will vary (e.g. loose munition vs. whole ships). A first step in each site assessment should therefore include detailed bathymetry and hydrographic investigations. The possibility to use new Navy technologies must be investigated, such as electro-optical lasers for geochemical detection.

It is worth pointing out that up to now all corrosion studies have focused on (sea) water, but we still don't know what happens in the sediment. As long as there is not more information available on these processes the only option is to sample regularly in order to check the migration of the toxic compounds. Still, a worst-case "sudden release" scenario does not seem very realistic.

The possibility to use mussels for biological monitoring should not be ignored, not only with respect to the search for chemical warfare agents but also for conventional explosives such as TNT and amatol, which are equally very toxic. It is stressed that upon degradation TNT will bind itself closely to the sediment. The question is also raised if techniques used for land sites, such as vapour analysis, can be applied at sea.

Risk assessment

Van Ham focuses on research carried out on conventional munition dump sites off the Dutch coast and in the Oosterschelde. Today it is recognised that there are a large number of toxic compounds present in conventional munitions. Depending on the site characteristics, location, type and quantity of munition, specific actions may be necessary. If no immediate action seems necessary at the moment, frequent monitoring will be mandatory to assure the safety of the environment and the public.

A study of the risks related to dumped CW in the Baltic is presented by **Theobald**. The chances for dumped munition washing ashore in the Baltic is estimated to be very low. There is a risk in the Bornholm Basin that chemical munition shells or lumps of viscous mustard gas can be caught in bottom trawl nets, hauled on board and thus cause contamination of the fishermen. All known cases of contamination to date were caused by viscous mustard gas. Risks to consumers from contaminated fish seem unlikely and have so far not been shown to exist.

Martin introduces the results of modelling studies of drifting objects (e.g. mines) at the sea surface and on the sea floor. This eventually allows to map the areas where munition is likely to reach the shores and beaches. Studies have shown that moving an object on the sea floor involves high current velocities. Different models are possible, such as scouring and burying. These models can help to evaluate what happens upon impact of the munition with the sea floor.

Waleij, Ahlberg *et al.* present an overview of the Swedish policy and discuss recent studies in Sweden on acute toxic effects of mustard gas and Clark. The results indicate that the acute toxicological danger of mustard gas is less than that of Clark. The minimum EC50-value is independent of temperature; the important factor is the exposure time. Sediment experiments indicated that Clark absorbs easily to sediment. Tests on *Nitocra spinipes* showed that the sediments were toxic even though the chemical analysis could not detect any of the substances.

As was the case for status assessment, the main question in risk assessment also seems to be whether the approach should differ from site to site or whether one general approach is possible. Is a different approach needed for dispersed sites and concentrated sites and should such approach also depend on the environment, or is some standardisation possible. In solving this question we may learn from former recovery actions.

A comparison with land studies could also help here. CW risk assessment for land contamination is done according to the source-pathway-receptor model (a hazard only becomes a risk if a pathway and sensitive receptor are present). This involves different steps : (1) Is there CW present : what, how much; (2) What is the public access to the site; (3) What is the public access to CW (possibly the last step can be applied to fishermen). Each step in the process is given a certain rating.

The need for some sort of risk modelling is stressed by many. In order to perform such complex modelling a detailed input data base is needed (hydrographic, sedimentology, chemical, …). Furthermore it is necessary to specify exactly the risks that need to be modelled : risks to the public - risks to the environment - risks to the sediments. Starting with a first, simple model, this can be extended along the way, thereby slowly moving towards a more detailed and accurate model.

Policy

The present policy in Norway on sea-dumped CW is discussed by **Paetzel**. In 1989 research was done on one dump site; only 5 (out of 38) shipwrecks were investigated; 13 water samples were taken. On the basis of these results it was concluded that there is no danger involved, and since then nothing has been done. Recent media attention raised the need again for further investigations. Nevertheless new working groups still keep referring to the incomplete (and therefore most likely unreliable) 1989 report.

The legal implications of sea-dumped CW and treaties involved are presented by **Zanders**. The Chemical Weapons Convention (CWC), which entered into force in 1997 aims at the world-wide destruction of all CW. However, it does not specifically encourage to remedy sites with CW dumped in bodies of water. Different classes of CW have their respective declaration and destruction obligations.

Reynders finally presents a discussion on the involvement of NATO in solving the problem of sea-dumped CW. In October 2000 a workshop was organised in Riga by the Eastland Coastal Maritime Operations programme on "Environmental and safety implications of the recovery and disposal of dumped ordnance in coastal waters". NATO is willing to participate in the coordination of future projects involving the inventory of dump sites and risk assessment standardisation.

During the discussion following this session the fact is stressed that no time should be lost and immediate actions must be undertaken very soon. The most important things to be done are to (1) set up an inventory of dump sites, (2) create an openness through public information and improved communication, (3) start up different monitoring programmes, and (4) take the first steps towards a risk assessment model.

It is clear that our present knowledge is not sufficient. More research is needed to assess the correct status of each site. However there is no general strategy for doing this, and each site will demand its proper strategy. New techniques must be investigated, and as long as not all the facts are known regular sampling must be carried out. Continuing fundamental research may ideally be done through international cooperation, including Russia (this will also help to increase the credibility). The resulting knowledge and information will also allow to further refine or tune the monitoring programmes.

Open flow of information is equally important. This will not only allow to increase the international public awareness, but it may also form a powerful argument in the political debate that is recently going on in several European nations. A first step should be to set up an inventory of CW dump sites. This will ideally necessitate the organisation of a network of NATO and PFP (Partnership For Peace) countries involved in this matter.

Conclusions

The main conclusions and recommendations of the workshop can be summarised as follows:

- Although many dump sites do not seem to pose an immediate risk, the lack of data and incomplete investigations often give rise to conflicting messages.
- More research (using novel techniques) is needed in order to (re-)assess the correct status of each dump site. As long as not all the facts are known regular monitoring and sampling must be carried out.
- Information on the exact amount and location of dumped CW often varies from one source to another. An inventory of European marine CW dump sites should be set up as soon as possible; support from the military (NATO) is essential in this.
- There is still very little information on the environmental risks. The state of corrosion, for example, may differ widely from one site to another. The possible hazards of each site need to be determined accurately.
- Steps must be taken for the development of a risk assessment model for marine munition dump sites; to this end the experience from land risk assessment models should be used.
- Sea-dumped CW are a border-transgressing problem; exchange of information and international cooperation are therefore crucial. The European Commission, for one, should provide financial support.

- Creating more openness and public awareness is of vital importance. Not only will this help to take away the incertitude and doubts on the subject, but it will also avoid over-concerned reactions.

Last but not least, it is clear that no strategic reflection can outstrip the ethical motives and common sense involved. This problem deserves the best of our capacities, both today and in times to come. This we owe to society and the future generations.

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Dumping and re-occurrence of ammunition on the German North Sea coast

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Abstract - After World War II a total of 750,000 to 1.5 million tons of ammunition were dumped along the German North Sea coast. The material originated not only from German sources but also from allied ones. Although some accidents with chemical ammunition occurred in the 1950's there is no positive evidence for large-scale dumping of chemical warfare in the coastal North, except for one report mentioning some 90 tons of gas grenades dumped near Helgoland. In the inner German Bight 16 dumping areas are known. Eight of these are located along the Lower Saxonian coast (comprising about 75 % of the total amount of dumped warfare) and four each in the vicinity of the islands of Sylt and Helgoland. The areal extension of the dump sites ranges from roughly 40 km² to roughly 1 km². Due to increased demands for scrap metal about 2/3 of the dumped ammunition was recovered from 1948 to 1958. Dredges, magnets and special grabs were used for this purpose. Estimates based on magnetic studies suggest that today a minimum of 10,000 tons of ammunition is still to be found in Lower Saxonian waters. On the other hand, during one single fishing season more than 3000 kg of ammunition were fished. This indicates that a) the uncertainty in the data is still very large and b) large parts of the dumped ammunition are still present at the sediment surface. Recent findings (a.o. in Jade Bay) also suggest that the dumped ammunition is not permanently buried. On the Hooksieler Plate, one of the major dumping grounds, grenades were found on the tidal flat surface despite the fact that this area was covered with about 8 m of sand when the Jade Bay shipping channel was deepened. Ammunition is also regularly recovered during maintenance dredging. Especially after winter storms, ignition devices which had been detached from the ammunition before dumping are found along the beaches of the inner part of the bay.

Introduction

A total of 16 dumping grounds have been identified in the German North Sea. Eight of the dumping grounds are located in Lower Saxonian coastal waters (Fig. 1). Four each can be found near the islands of Sylt and Helgoland.

The areal extent of the dumping grounds varies from about 41 km² (area 7 - Fig. 1) to about 1.4 km² (area 4 - Fig. 1). In Lower Saxonian waters a total dump area of 88 km² was used while the Helgoland ground covered about 2.7 km² and the Sylt ones a total of 33 km².

According to British sources a total of 750,000 to 1.5 million tons of war material was dumped in the North Sea after the war. However, in these chaotic days no exact records were kept and information on both amount and locations are to a large part based on more or less reliable eyewitness accounts. Therefore these figures remain highly uncertain.

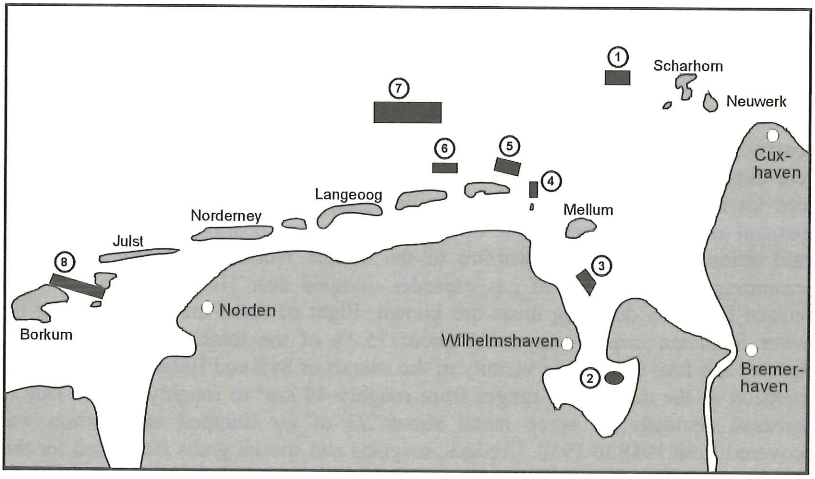

Fig. 1. *Map of the ammunition dumping areas along the Lower Saxonian coast.*

The dumped material was almost exclusively conventional ammunition of all calibres, ranging in size from rifle cartridges over grenades to bombs. Near Helgoland 90 tons of Tabun were also dumped in 1949 (at 54° 8' N, 7° 53' E). Large-scale dumping of chemical ammunition also occurred in the Skagerrak, where numerous ships a.o. loaded with mustard gas were dumped (see also Paetzel, this volume).

Furthermore, a considerable tonnage of chemical weapons was transported to the German North Sea ports to be dumped at sea and of which the exact dumping locations are not known.

Not only German war material was dumped at sea but also surplus ammunition from allied sources. Dumping started right after the war and was supposed to be finished in December 1946. Although this was largely achieved minor dumping actions took place until 1949.

From the port of Wilhelmshaven about 250,000 tons of ammunition were shipped, making this port the most important one for these operations.

Conventional ammunition consists - besides the explosive material - almost completely of metals. Especially copper, tungsten, brass, tin, lead, aluminium and zinc were valuable for the commencing post-war industrial production. Thus dismantling became a commercially viable alternative to dumping. This advantage was first recognised by the

Americans who stopped dumping at sea in autumn 1946 while the British continued dumping.

Various devices were used to recover ammunition in coastal waters. Besides dredges also electromagnets (from 1955) and special grabs were employed (Fig. 2). During the first years torpedo nets were also used. Magnets allowed to recover ammunition that was already covered by sand (up to 1.5 m). The latter partly holds for grabs also.

Ammunition fishing was a lucrative business initially but gradually lost its importance until in 1957 only two ships were left to work in the Jade Bay.

The recovered ammunition was worked up from early 1952 until April 1958 in Wilhelmshaven (Fig. 3).

The plant suffered from a heavy explosion on March 26, 1953. Although no fatalities were recorded certain types of ammunition (i.e. long ranging ones) were no longer accepted after the accident, which might also have contributed to the decline in this type of "fishery". The non-accepted ammunition was dumped back into Jade Bay.

From July 1952 to December 1954 the plant worked up around 50,000 tons of ammunition and provided a total of 2500 tons of non-iron metals (W, Cu, brass, Sn, Pb, Al, Zn), 38,000 tons of scrap metal and over 900 tons of TNT to the industry.

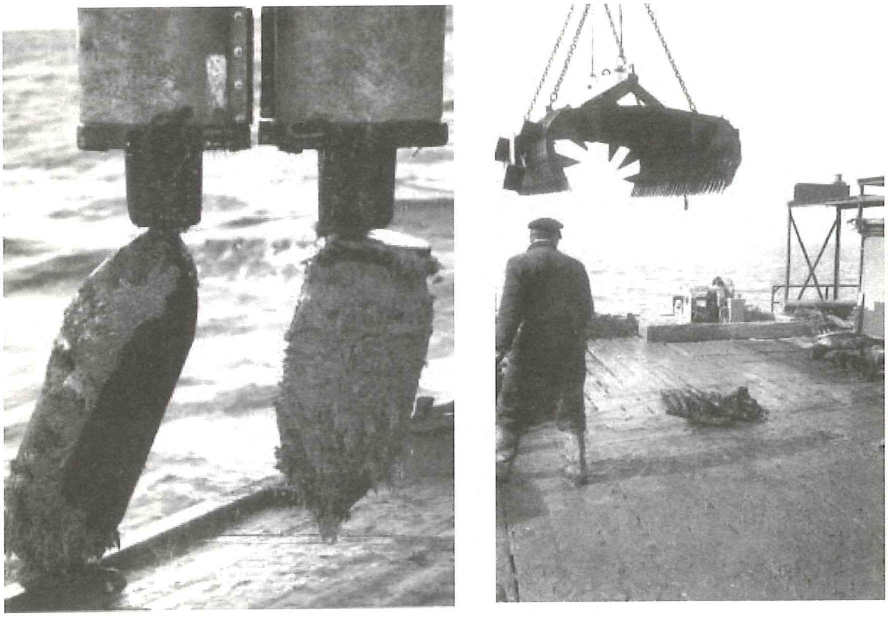

Fig. 2. *Devices for ammunition recovery. Left: electromagnet, right: grab (Source: Rapsch & Fischer, 2000).*

Fig. 3. Recovered ammunition at the Wilhelmshaven plant, 1952 (Source: Rapsch & Fischer, 2000).

Potential environmental impact

The dumped ammunition experienced severe erosion quite rapidly after disposal (Fig. 4). It is also evident that the material contained within the hull has been removed. Whether this is due to simple dissolution, chemical reactions or bacterial degradation is unclear.

Fig. 4. Example of short-term corrosion of dumped ammunition (photograph taken in 1953) (Source: Rapsch & Fischer, 2000).

On the other hand, encrustation also occurred (Figs. 5 and 6).

Although a large amount of literature exists on the effects of explosives' residues in soils, groundwater and other terrestrial systems, virtually nothing is known on the effects of leached material (i.e. explosives) on marine systems.

Fig. 5. *In-situ photograph of a dumped bomb (Source: Rapsch & Fischer, 2000).*

Fig. 6. *Examples of grenades recovered in 1995 (Source: Rapsch & Fischer, 2000).*

Assessment of the present status

In Lower Saxony systematic investigations of land areas suspected of being contaminated with explosives and other residues started in 1988; marine dumping areas were included in 1990.

Two systems were used here: one was a side-scan sonar to detect the presence of material on the sea floor, the second a magnetometer capable of detecting metallic objects below the sea floor.

While in the investigated areas the first system did not always provide evidence for ammunition lying on the sea floor, the second was able to detect a series of anomalies (Fig. 7).

The results indicate that in area 1 the ammunition is presently covered by 0.5 to 2 m of sediment. The latter was further confirmed by the analysis of sediment cores which showed elevated trace metal levels in the upper layers indicating an anthropogenic input after about 1960. This suggests that any metal objects (some of those recorded by magnetometry are thought to be ship wrecks) still present on this dumping site might not re-surface again due to the thick sediment cover.

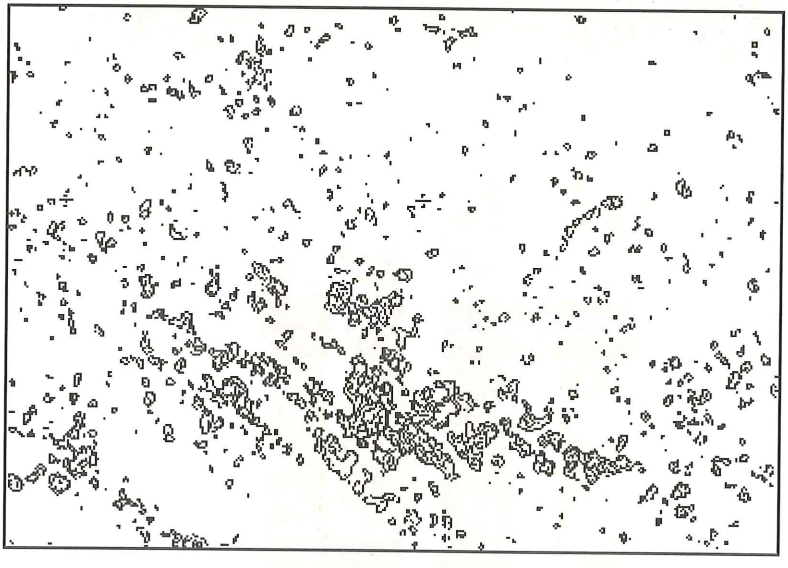

Fig. 7. Magnetic anomalies in dumping area 7 (for location see Fig. 1) (Source: Rapsch & Fischer, 2000).

On the other hand, similar operations in area 7 showed that ammunition was widely distributed over the area and only partly covered by sediment. There were also indications of fishing activities (net residues on the ammunition) as, according to local fishermen, these areas are rich fishing grounds. This is presumably due to the fact that epibenthic growth on the ammunition provides good nutrition for demersal fishes (Fig. 5).

Besides this, smaller concretions (Fig. 8) are regularly found on the tidal flats of the Lower Saxonian Wadden Sea, especially the Jade Bay, and the island beaches (Fig. 1). These usually contain iron cores around which concretions have been formed. Some of these are derived from exploded ammunition, some still contain intact rifle shells (Fig. 9).

Furthermore, larger shells and mines are drifted ashore more or less regularly, particularly after winter storms. As in most cases the ignition devices had been removed prior to dumping, so there is no actual danger from shells etc. washed ashore. The shells are also to be found on top of tidal flat sediments (Fig. 10). Mostly they are heavily encrusted and show only little surface corrosion when the crusts are removed.

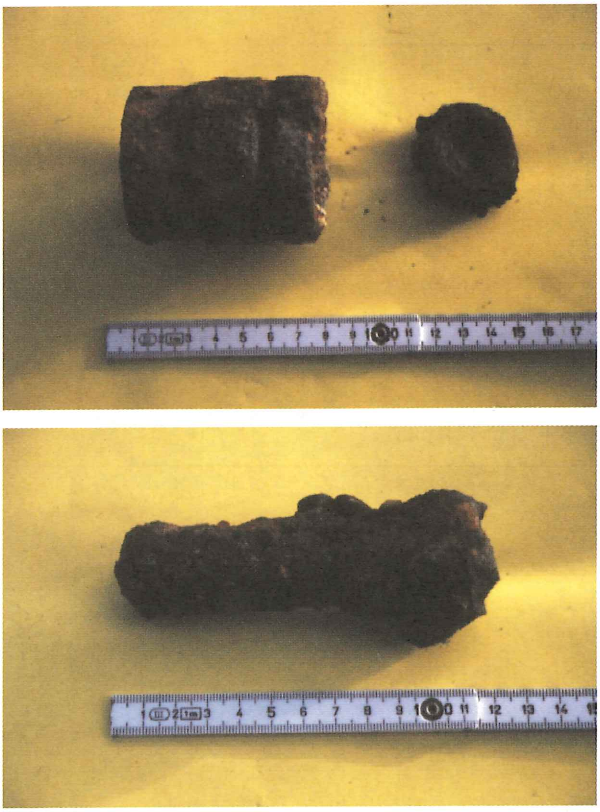

Fig. 8. Examples of concretions found in 2000 on tidal flat surfaces of Jade Bay.

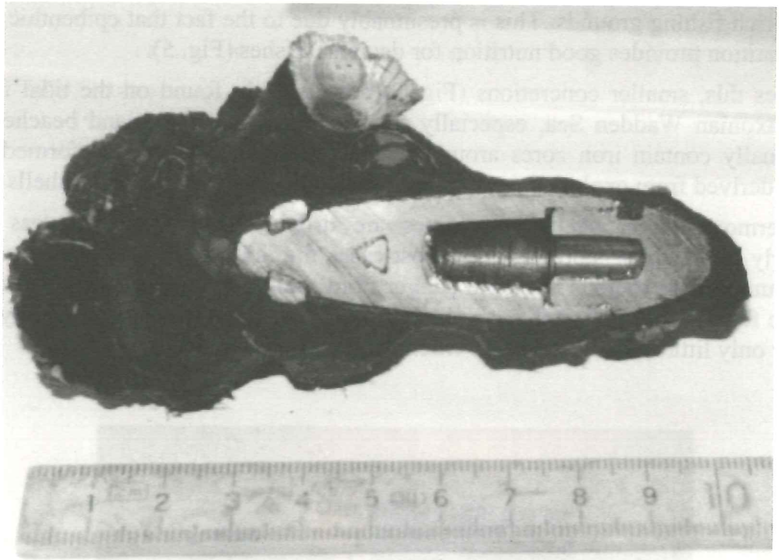

Fig. 9. Example of rifle shell in concretion matrix.

***Fig. 10.** Grenades found on the Hooksieler Plate, one of the major dumping areas in Jade Bay, in 1999.*

It is interesting to note that the grenades shown in Fig. 10 are from an area which according to official sources was considered to be "safe" after burial of dumped ammunition by about 8 m of dredged sediment when the Jade Bay shipping channel was deepened.

The regular occurrence of ammunition during maintenance dredging works indicates that even 8 m of sediment might not be enough to render World War II ammunition inaccessible. Thus, in the highly dynamic environments of tidal flats the re-occurrence of this material appears to be very likely.

Ignition devices apparently also have been dumped and are found regularly on the beaches of Jade Bay (Fig. 11). These ignition devices can be considered to be dangerous to the unsuspecting finder especially when mechanical action is exerted upon these devices.

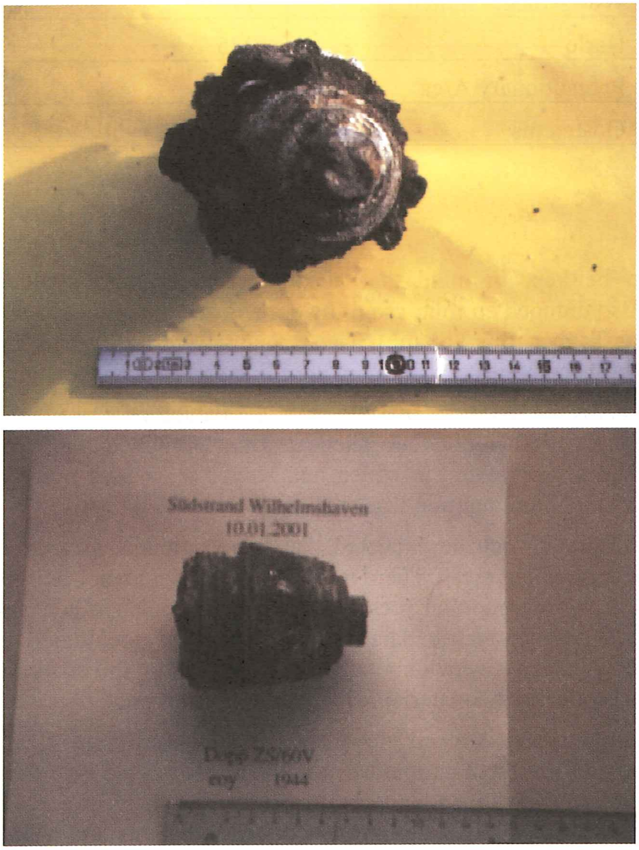

Fig. 11. *Ignition device found in 2001 on the "Südstrand" beach of Wilhelmshaven.*

Based on diver-investigated magnetic anomalies the estimated amounts of ammunition still present in the Lower Saxonian dumping grounds are summarised in Table 3.

Table 3. *Ammunition still present on Lower Saxonian dumping grounds.*

area	ammunition [tons]
1 Scharhörn Riff	> 5
2 Jade Bay	not investigated
3 Hooksieler Plate	not investigated
4 Minsener Oog	> 1
5 Wangerooger Plate	~ 17
6 Harle	~ 225
7 Precautionary Area	~ 8557
8 Oosterems	~ 440

It should also be kept in mind that according to common practice of the time ammunition was also dumped en route from the ports to the dumping grounds (cfr. Schulz-Ohlberg, Lemke & Tauber, this volume). These routes were only partly investigated and also showed magnetic anomalies especially in the SE approaches to the dumping grounds.

Experimental recovery operations in 1995 with one fishing boat resulted in >3000 kg of fished ammunition (>1000 individual shells). This prompted the Lower Saxonian authorities to initiate a programme in which ten, later five, fishing boats participated. In 1999 a total of 4669 kg of ammunition was recovered.

Despite these efforts, it can be expected that large amounts of ammunition are still present in the former dumping areas. There is an apparent discrepancy between the estimate of about 10,000 tons of ammunition present in Lower Saxonian waters, as based on the side-scan sonar and magnetometric data and diver surveys mentioned above, and the estimate of about 500,000 tons which could be present based on the difference between the possible maximum input and the material recovered in the 40's and 50's.

Although the ammunition dumped into the German coastal North Sea some 50 years ago apparently does not represent an important threat to the marine ecosystem at present, it cannot be ruled out that after more complete corrosion of the shells or containers explosives and other (toxic) compounds might be introduced into sediments and near-bottom waters. This may provoke negative responses of the benthic fauna and possibly also along the food chain.

Instead of conclusions a citation:

North Sea Quality Status Report 2000

Chapter 6.10.2 Dumped ammunition

"From time to time munitions such as incendiary devices and smoke bombs are washed up on the beaches along the east coast of Ireland, the Isle of Man and the west coast of Scotland. This presents a hazard to the public. OSPAR is considering a course of action for dealing with dumped munitions."

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All information given above has been taken from the following reports or publications unless otherwise indicated:

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Annex - Explosive compounds

In 1992 a total of 4336 munition-related areas on land, possibly up to 6000, with an estimated total area of >2000 km² was recorded in Germany (Haas and Kopecz, 1996). These include ammunition plants, testing grounds and sites used to explode ammunition after World War II.

Table 4 gives an idea about the amounts of explosives produced in Germany during World War II. Figure 12 provides the structural information. Not only brisance explosives were used in ammunition but also compounds to provide the initial ignition and propellants (Table 5).

Powders contain plasticisers (di-n-butylphthalate, diphenylamine), and stabilisers (diphenylurea compounds) to capture released nitro compounds.

Brisance explosives are persistent in the environment. Nitro compounds exhibit blood damaging effects. They are potentially carcinogenic and mutagenic. Water solubilities are around 100 mg/L (fresh water).

Table 4. *German production of brisance explosives in 1945.*

TNT	20,600 (tons/month)
hexogen	7000 (tons/month)
2,3-DNB	3300 (tons/month)
nitropenta	1390 (tons/month)
picric acid	700 (tons/month)
of minor importance	tetryl, hexanitrodiphenylamine, nitronaphthalin

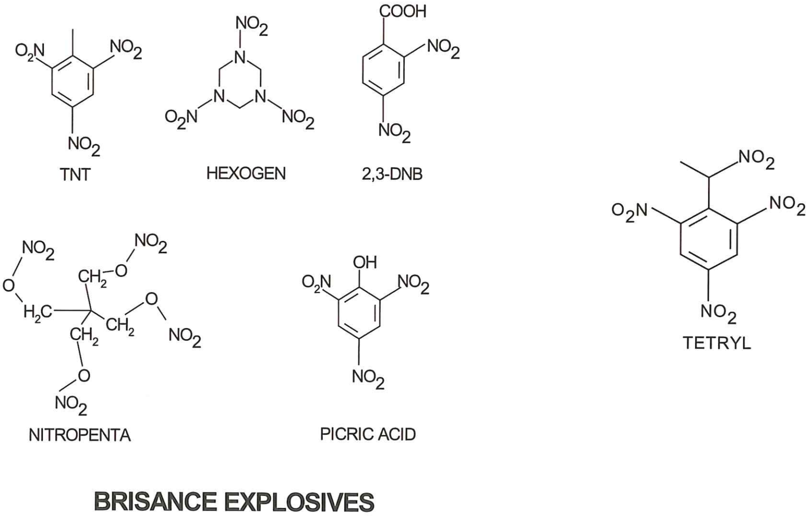
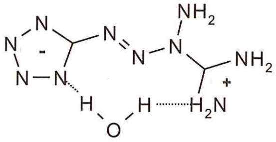


Fig. 12. *Structure of common explosives.*

Table 5. *German production of propellants and powders during World War II.*

propellants

PbN_3	1944:	144 tons
Pb trinitroresorcinate	1944:	56 tons
tetracene	1944:	9.7 tons

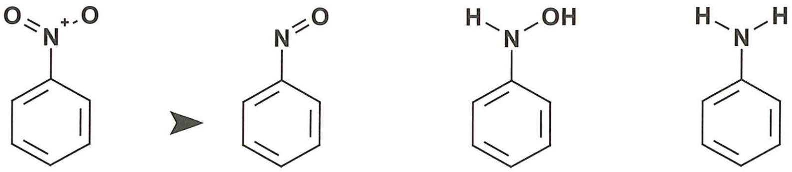


TETRACENE

powders used as propellants

one to three basic: nitrocellulose	1939-'45:	153,000 tons
solvent free: nitrocellulose/nitroglycerin	1939-'45:	740,000 tons

Degradation proceeds via reduction to amines :



Nitric acid esters are hydrolysed to give hydroxy compounds and nitrate.

Nitroamines are reduced to nitramines via nitroso and hydroxylamine compounds :

Research of dumped chemical weapons made by R/V "Professor Shtokman" in the Gotland, Bornholm & Skagerrak dump sites

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Abstract - A review is given of Russian research on dumped chemical weapons in the Baltic Sea and Skagerrak made by the R/V "Professor Shtokman" during six cruises from 1997-2000. The investigations were carried out by the Karpinski All-Russia Geological Institute (St. Petersburg) and the Shirshov Institute of Oceanology (Kaliningrad), in the framework of the Russian Federal Programme "World Oceans". The aim of the project is oceanographic and geo-environmental monitoring of CW dump sites, in order to predict possible ecological consequences for the marine environment. Instrumentation used during the cruises included water and sediment samplers, side-scan sonar, magnetometer, current meters, current profiler, and microstructure probe. ROV's were also used for inspection of sunken vessels. The monitoring studies were preceded by hydrologic measurements to understand possible spreading of toxic agents by water currents at the dump sites. Numerous observations of leakage were made. The magnitudes of anomalies of *pH*, *As* and *P* in the Skagerrak and Bornholm dump sites were similar. At the Gotland dump site the only signs of leakage were specific changes of micro-biota. However it is still not known what proportion of dumped CW is leaking or how much of the primary amount of warfare poison-gases has already decayed. To this end samples of CW should be obtained from the interior of sunken vessels.

Introduction

As evidenced by reports of the HELCOM *ad hoc* Working Group on Dumped Chemical Munition (HELCOM CHEMU) in 1993-1994, World War II left about 300,000 tons of German chemical weapons (CW), containing approximately 65,000 tons of warfare poison-gases (WPG) such as mustard gas, arsenic and phosphorous compounds (Alexandrov & Emelianov 1993; Anon. 1993; HELCOM CHEMU 1993a; HELCOM CHEMU 1994; HELCOM CHEMU 1993b). These CW were captured by the Allies (USA, Great Britain, France, USSR) after the end of World War II. A large fraction of these weapons was loaded onto ships that were subsequently sunk in 2 sites of the Skagerrak, near Måseskär and Arendal. Over 40,000 tons of CW were dumped over the sides of vessels in the Bornholm, Gotland and Little Belt dump sites. According to a report by the German Federal Maritime and Hydrography Agency several vessels (containing 23,000 tons of CW) were also scuttled in the areas to the SW and to the E of Bornholm Island (Anon. 1993).

In the succeeding period of time after publication of the HELCOM CHEMU reports, the dump site issues were studied by experts who worked on behalf of governmental (MEDEA 1997; Theobald, this volume) and non-governmental organisations (Borisov 1997; Garrett 1999; Heintze 1997; Laurin 1997; Surikov & Duursma 1999). As a result, however, neither the volume of basic data nor the original conclusions have been essentially changed. Still, specialists and the public have become increasingly aware of the details of this problem and the environmental effects of WPG. For example, American experts developed a general approach for the evaluation of damage to the environment and proposed WPG release scenarios for cases of a more or less spatially uniform distribution of munitions (MEDEA 1997). Russian experts stressed the case of "volley" release of WPG as a result of the simultaneous destruction of corroded shells stacked in the holds of sunken vessels (Borisov 1997; HELCOM CHEMU 1993a).

Unfortunately, despite the conclusions from experts that investigations should be continued, no wide-scale and coordinated actions have been undertaken. Nevertheless, some Russian institutes pursued their investigations in this field. The Karpinski All-Russia Geological Institute (VSEGEI), in St. Petersburg, and the Shirshov Institute of Oceanology - Atlantic Branch (SIO AB) in Kaliningrad, started collaborating in 1997, and, since 2000, performed a joint project supported by the Russian Federal Programme "World Oceans". The aim of the project is oceanographic and geo-environmental monitoring of CW dump sites, with a goal to study conditions essential for the forecast of consequences related to marine dumping. Traditional marine science instruments and research methods have been used in this programme and are described below.

This report gives a review of Russian research on dumped chemical weapons using the R/V "Professor Shtokman" during six cruises (Table 1).

Instrumentation

The set of instruments used on the research cruises included:

- standard water and sediment samplers (Fig.1, *8-10*)
- a towed undulating profiler constructed on the basis of an IDRONAUT 316 Ocean multi-parameter probe consisting of a CTD, pH, and oxygen sensors (Fig.1, *3*)
- a side-scan sonar and differential proton magnetometer developed at the SIO AB (Fig.1, *4-5*)
- moored self-recording current meters (Fig.1, *1*)
- a towed RDI acoustical Doppler current profiler (Fig. 1, *6*)
- a moored microstructure probe for measuring near-bottom turbulence developed at the SIO AB (Fig.1, *2*).

The shipborne X-ray "Spectro-Scan" analyser provided efficient detection of As, Pb, Zn, Cu, Co, Ni, Fe, Mn, Cr in the bottom sediments. In addition, standard chemical and physio-chemical facilities were used for detection of O_2, forms of phosphorus, pH, and Eh in the water. Necessary amounts of the samples were prepared for further analysis on shore. ROV's were rented for the inspection of sunken vessels. No mustard gas or other WPG special analysers were used. A Sarin detector, designed for gas defence troops, was deployed only on the last cruise. This deployment was successful, and similar techniques for detecting other warfare agents (mustard, Soman, CS- and V-gases) should be used in the future.

The results of the magnetometry studies are discussed elsewhere in this volume (Gorodnitski & Filin).

Table 1. *R/V "Professor Shtokman" cruises.*

Cruise No.	Dates	Main Instruments *	Areas**
PSh34	12.08.97 - 06.09.97	NB, IDR, MCM, NiB, NBC, G, ChA, XR, MiBio	AB, BB, SK, SF, GB, GdB
PSh39	05.06.98 - 03.07.98	IDR, MCM, NiB, NBC, G, ChA, XR, DM, SS, Bio, MiBio	GB, SF, BB, AB, SK, GdB
PSh43	07.09.99 - 03.10.99	IDR, MCM, ADCP, DM, NiB, NBC, G, ChA, XR, MiBio	BB, SF, GB, GdB
PSh44	24.12.99 - 13.01.00	IDR, MCM, ADCP, NiB, NBC, G, ChA, XR, Bio, MiBio	BB, SF, GdB
PSh46	01-10.08.00 22.08.00 - 02.09.00	IDR, MCM, ADCP, NiB, NBC, G, ChA, DM, SS, MiBio, ROV, MBT	GB, SF, BB, SK, GdB
PSh48	13-30.06.01	IDR, MCM, NiB, NBC, G, ChA, XR, DM, SS, ROV, MBT	BB, GdB

* NB = Towed Niel Brown CTD, IDR = Towed IDRONAUT 316 Probe, MCM = moored current meters, ADCP = acoustical Doppler current profiler, NiB = Niskin bottles, NBC = Niemistö bottom corer, G = grab, SS = side-scan Sonar, DM = differential magnetometer, ChA = hydro- and geochemical analyzers, XR = X-ray analyzer, Bio = general purpose biological sensors, MiBio = microbiological sensors, ROV= remotely operated vehicle, Tu = moored bottom turbulence meter.

** AB = Arkona Basin, BB = Bornholm Basin, GB = Gotland Basin, GdB = Gdansk Basin, SF = Slupsk (Stolpe) Furrow, SK = Skagerrak (Måseskär).

An overview of the location of the sites mentioned here can be found in Gorodtnitski & Filin, this volume (Fig. 2).

Hydrologic measurements

To understand spreading from sources of dissolved and particulate substances in water with currents, we must understand lateral and vertical water exchange, especially in the near-bottom layer. To help gain this understanding, hydrologic measurements were made in regions with currents, in the thermohaline structure, and in regions containing turbulence. These measurements began with general studies of meso- and micro-scale dynamics of the Baltic Basins. They were started much earlier than the CW dumping monitoring studies.

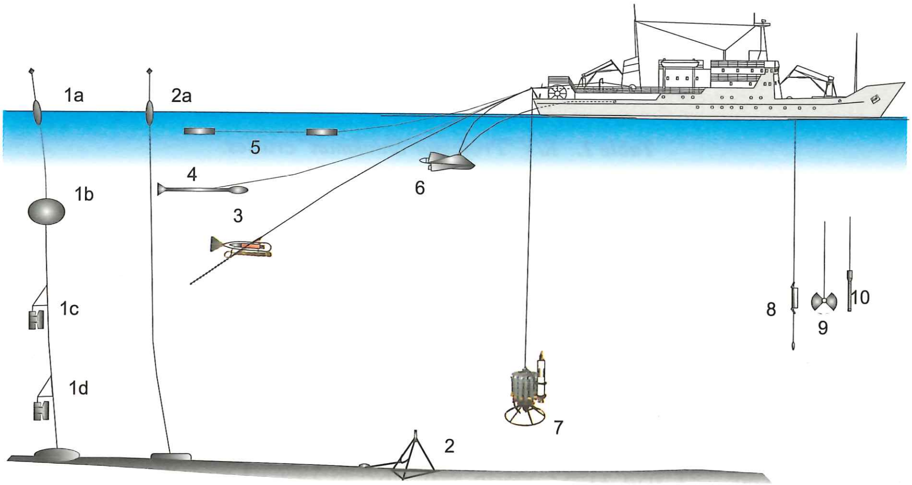

Fig. 1. Instrumentation of the R/V "Professor Shtokman". 1 - moored system consisting of a marker buoy (1a), a submerged float (1b), and current meters (1c, 1d), 2 - moored turbulence measuring probe with marker buoy (2a), 3 - towed undulating multi-parameter profiler, 4 - side-scan Sonar, 5 - differential proton magnetometer, 6 - towed ADCP, 7 - small volume water sampler, 8 - Niskin bottle, 9 - grab, 10 - Niemistö bottom corer.

Based on these hydrological measurements, it became clear that some experts underestimate the hydrodynamical activity within the Baltic dump sites (Anon. 1993). Because of the importance of physical conditions in calculating the exchange processes, hydrological measurements were planned near each dump site and it was tried to understand the Baltic ecosystem at whole. Fortunately, all three dump sites were located in areas of importance in understanding the long-term living conditions in deep Baltic basins. The Skagerrak is the first link of that chain, as it is the origin of the dense salt water in the Baltic. The Bornholm Deep is the important buffer and accumulation link of that chain and the first deep basin where stagnation effects become apparent. The Gotland Deep is the final basin on the route of the dense salt water inflow for long stagnation periods (we exclude basins north of the Gotland Deep for simplification).

The water exchange in the Baltic is characterised by the following : 1) the chain works only during major inflows, which are themselves rare; therefore the flux of pollutants from the Skagerrak into the Baltic is mostly dependent on the major inflows; 2) the dense salt Bornholm waters penetrate into the Gotland Deep permanently, although this process is strongly intermittent due to seasonal and synoptic changes of the sea-atmosphere interaction; 3) renewal of the dense salt Bornholm waters comes from waters conditioned in the Danish straits (Kattegat and Sounds) and in the Arkona Basin; 4) even the moderately-dense salt water inflow into the Bornholm Basin, which by itself is incapable of replacing the near-bottom waters, provides a slow withdrawal of any substances accumulated in the near-bottom layer due to turbulent diffusion; and 5) the same is true for the renewal of the East Gotland Deep dense salt water.

This slow withdrawal idea is plausible for the Gotland (Liepaja) dump site at a depth interval of 70 - 105 m, which is close to the depth of the permanent halocline and coincides with the depth of internal wave activity and the interaction of the internal waves with slopes. But this withdrawal is not evident for the central part of the Bornholm Deep, so the efforts of the R/V "Professor Shtokman" were focused on this area.

In many cruises data were obtained using a CTD which was raised and lowered while the boat was moving forward. From these measurements, one can determine water parameters in a horizontal-vertical plane, and construct contours of the parameters. The easiest way to show changes in water properties over long times, then, is to compare some successive transects in roughly the same area.

As evidenced by the transects shown in Figs. 2a and 2c, taken in September 1999, the deepest Bornholm water had a temperature of 7 °C and a salinity of 14 - 16 ‰. In contrast, in December 1999 (Figs. 2b and 2d) all the deep Bornholm water had been replaced by warmer and more saline water. In Fig. 2d, water of 15 ‰ salinity is seen overflowing the Stolpe Sill, while 3 months ago this water washed the Bornholm dump site. Figures 2b and 2d demonstrate also the important property of basin-scale dynamics in the Bornholm Deep responsible for overflow of dense water at the sill – that is, the seiche-like motion, which provides elevation of dense waters higher than their average level. Examination of the T and S distribution within the Stolpe and Gdansk Basins shows proper changes caused by old Bornholm near-bottom water.

Another important question is the level of mixing activity that should be expected close to the Baltic sea bed. Some authors guess that the Bornholm deep layers are usually inactive during long periods of absence of major inflows. The current meter data does not confirm that conclusion. Frequent and long absence of oxygen in the near-bottom layer does not mean that water exchange stops absolutely at that time.

Advective and mixing activity in the centre of the Bornholm Deep does not depend only on major inflows. Measurements of turbulence at a mooring in June, 2001 have shown that intermittent turbulence was measured, and this turbulence was probably related to currents induced by inertial waves (Figs. 3 and 4), while these waves were related to eddy motions originating in the vicinity of the Bornholmgat Strait (a transect which demonstrates these typical eddy patterns is not shown).

The monitoring results indicated that the periphery of the Bornholm Deep is an area of permanent generation of eddies, dynamic disturbances which propagate to the vicinity of the dump site. The Bornholm dense salt water layer is thin (20-30 m), this explains why disturbances within such a layer reach large amplitudes. Part of this energy is consumed to support turbulence, which was discovered by both direct measurements of velocity fluctuations (Fig. 4) and indirect signs, including frequent homogenisation of thermohaline structure close to the sea bed.

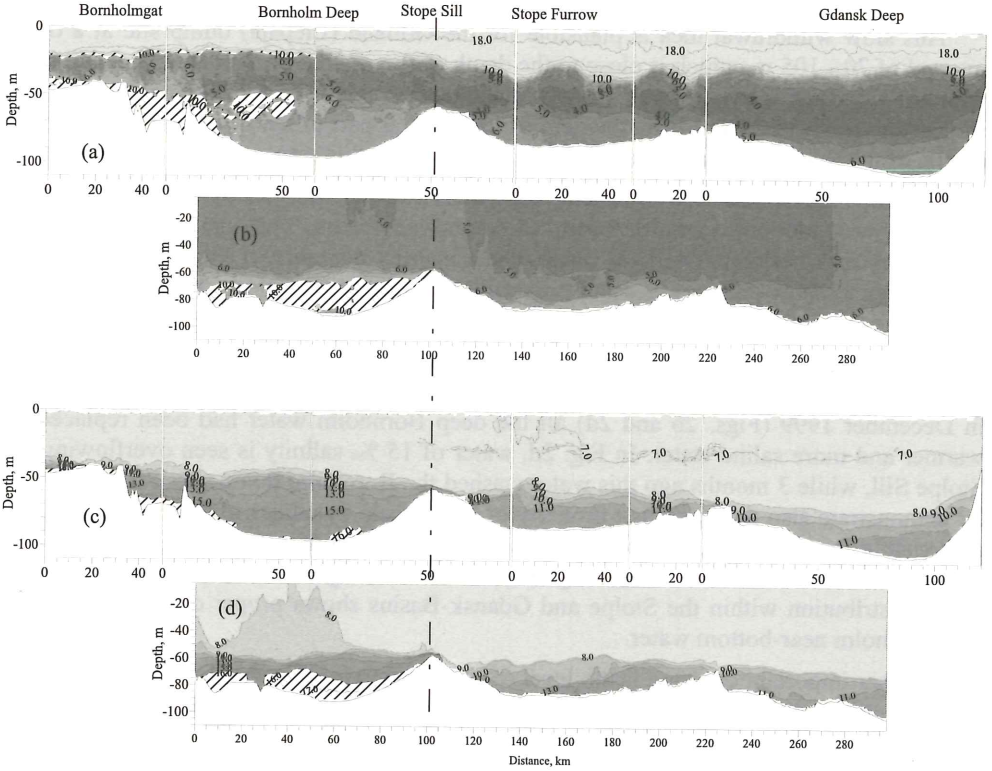

Fig. 2. Distributions of temperature (a, b) and salinity (c, d) in the Southern Baltic from the Arkona Basin to the Gdansk Deep in September (a, c) and December (b, d) 1999. Positions of narrows, deeps and sills are marked by their names. Intervals of temperature 9 < T < 10 °C and salinity S > 16‰ are marked out by hatching.

Movement of particles over the sea bed, observed using a video camera on the ROV, and considerable turbidity of the near-bottom water provided other evidence of the presence of the near-bottom currents contributing to erosion of bottom deposits.

In contrast to the Bornholm dump site, we may expect released products at the Skagerrak (Måseskär) and Gotland dump sites to be spread in much greater volumes of water and in lower concentrations due to the absence of strong limitations for both lateral and vertical fluxes of pollutants.

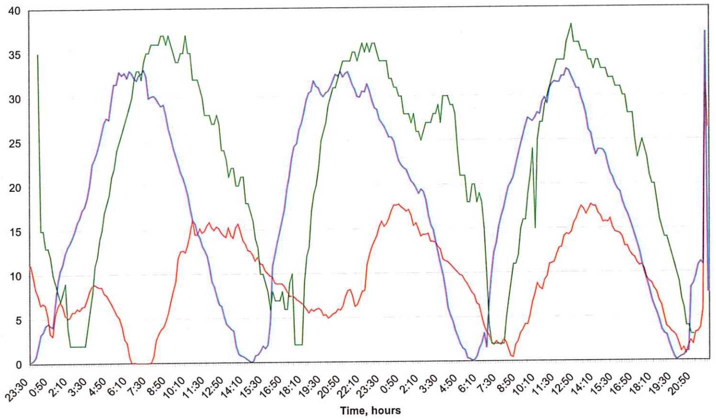

Fig. 3. *Plots of measured current speed (cm/s) at depths of 20 m (highest magnitude), 40 m and 85 m (lowest magnitude) within the Bornholm dump site. Water depth 94 m.*

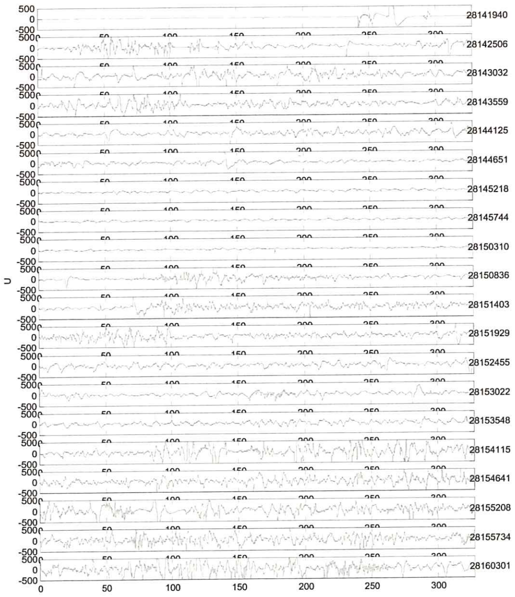

Fig. 4. *Sample of the record of current velocity fluctuations made by the autonomous bottom-installed turbulence probe (see Fig. 1(2)). The magnitude has an arbitrary scaling. Each line represents one data file, named by date, hours, and minutes, to provide the ability to detect the duration of records and to calculate the turbulence intermittence. Active/passive phases of turbulence are estimated as 50%, while each phase lasts about 30 min.*

Geo- and bio-environmental study

During former inspections of CW dump sites, experts tried to measure direct evidence of CW agents. On the cruises aboard the R/V "Professor Shtokman," a different approach was used. It is known that the chemistry of WPG in the marine environment is dominated by hydrolysis, and major products of hydrolysis have been identified. Some of these products can produce changes in seawater chemistry.

Because the existence of dumped CW was beyond question, the investigations were focused on finding changes in environmental conditions which could be caused by known hydrolysis products and which could be detected by techniques generally accepted in oceanology. The products that were concentrated on included arsenic, phosphorus, and acids able to change pH. Arsenic can accumulate in sediments. The other products, or their effects, become apparent during hydrolysis and mostly disappear after a definite time. Nevertheless, their detection is possible, owing to the slowness of their production. In particular, this is valid for poorly dissolvable mustard. Long acting sources of toxicants must have an influence on the marine biota, increasing of proportion of micro-organisms tolerant to WPG, and, above all, tolerant to the mustard. Increased concentration of heavy metals indicates the presence of some metal casings or shipwrecks.

Arsenic data

The main focus was on arsenic (As), since it can accumulate in sediments. As is part of Lewisite, as well as of some other WPG (e.g. Clark). Since Lewisite was often added in winter mustard (making up 37 % of the composition), this element is indicative of mustard, which constituted most of the dumped WPG.

Since 1997, the As detection limit was 9 mg/kg. Before 1997, the As detection resolution was much coarser, and these data were not used in our analysis. Table 2 presents minimum, maximum, and typical background As levels for all 3 dump sites. We note that minimum and background values differ from those presented in reports (Anon. 1993; HELCOM CHEMU 1994) with reference to Dr. H. Albrecht, BSH, Hamburg (personal communication). Experts have previously proposed a value of 100 mg/kg as a typical background for As contents in the Baltic. This value is much higher than our measurements in Table 2, which are 24 - 25 mg/kg, while our minimum As levels were 18 mg/kg for the Baltic water and below the detection limit for the Skagerrak water. We note that even measured maximum levels within the Gotland dump site were 3.5 times lower than the experts' background estimate.

The arsenic distribution at the Gotland dump site is characterised by low dispersion and the absence of high levels. However, the network of sampling points was insufficient to formulate final conclusions. The Bornholm and Måseskär (Fig. 5) dump sites are characterised by high dispersion and sharp anomalies of As levels, reaching up to 150-200 mg/kg.

Table 2. *Parameters of arsenic distribution (in mg/kg).*

Dump site	C_{min}	C_{max}	$C_{background}$
Gotland	18	28	24
Måseskär	<9	200	25
Bornholm	18	150	25

Consideration must be given to the fact that there are natural mechanisms of accumulation of As from its uniform background distribution due to processes typical for redox or sorption barrier zones (Emelyanov 1998). However, there is good reason to believe that the highest observed contents of As are related to the separate sources of this element. If in samples displaying increased As content, Fe and Mn are low, then a localised source is undoubtedly present. However, samples containing large amounts of Fe and Mn also show signs of deflection from the pattern typical for natural accumulation. So, in the Skagerrak, where the upper layer of the sea bed was oxidised, the largest levels of As were found both above and beneath the redoxcline, which was several centimeters below the bottom/water interface. This implies that a powerful source of As was present either on the seabed surface or was buried at a depth greater than the redoxcline.

pH data

Only the 1997 field data showed anomalies of pH values presumably linked with dumped CW (Emelyanov *et al.* 2000). At the Skagerrak (Måseskär) dump site, abnormally low pH values (6.52 - 6.31) were detected in the near-bottom layer in comparison with natural interval pH values (7.2 - 7.6), in only two of five sampling points. One of these points was close to the sunken vessel. At the Bornholm dump site, abnormally low pH values (6.36 - 6.78) were also detected at two sampling points. At the Gotland dump site, such anomalies were not found. In following years, no pronounced pH anomalies were found anywhere.

Phosphorus data

Natural increase of the total phosphorus (P_{tot}) concentration with depth is connected with an oxidation of organic suspended matter. This oxidation moves the phosphorus into the dissolved form, where the organic phosphorus (P_{org}) concentration sharply decreases by sinking from the photosynthesis layer down to the bottom and an inorganic phosphorus (P_{in}), as the final oxidation product, increases and finally dominates. Thus, an increase of P_{org} over P_{in} in the near-bottom water could be explained by the presence of an additional source of P_{org}. This increase could be explained by phosphorus containing gases in particular. Such conclusion will be more probable if the outliner for phosphorus distribution coincides with some another environmental anomaly - like lowered pH or dominating of a tolerant to mustard micro-biota.

Such coincidences were found in a few sampling points both within the Måseskär and Bornholm dump sites, where the P_{tot} and P_{org} concentrations in the near-bottom water were 2 to 5 times higher than the background values. Maximum measured phosphorus concentrations exceeded 10 µg-at/l, where the detecting threshold was 0.1 µg-at/l. One of the multi-parameter anomalies was found close to the sunken vessel and showed the highest Fe content in the suspended matter – 22 %, which indicates the origin of the anomaly. We did not find As and P anomalies jointly, and this could be explained by the fact that these elements were parts of different toxic agents (Alexandrov & Emalyanov 1993). Some of the phosphorus measurements are presented in Table 3.

Sarin data

One of the sampling points in the Skagerrak (58° 10,63′ N - 10° 45,68′ E) in 2001 showed the presence of trace amounts of Sarin (qualitative reaction) in the near-bottom water. This find can be considered as one more evidence of WPG release. Water samples in the Bornholm dump site at the same cruise did not show Sarin. It is necessary to note that Sarin was not mentioned in the HELCOM CHEMU documents. It was mentioned later by Russian and American authors that the total production of Sarin by German industry at the end of the war was estimated as 1200-2000 tons, but alternative suggestions were proposed whether it was captured by the USA or by the USSR (Alexandrov & Emelyanov 1993; MEDEA 1997). The detection of Sarin at the Skagerrak (Måseskär) dump site gives a qualitative confirmation to the assertion in Alexandrov & Emelyanov (1993).

Table 3. *Parameters of phosphorus distribution (in µg-at/l).*

Dump site/ parameter	C_{min}			C_{max}			$C_{background}$		
	P_{tot}	P_{min}	P_{org}	P_{tot}	P_{min}	P_{org}	P_{tot}	P_{min}	P_{org}
Måseskär	1.14	1.01	-	3.12	2.86	0.78	1.64	1.40	0.09
Bornholm	3.24	2.60	-	10.7	7.80	3.10	5.8	4.86	0.42

Microbiologic data

Qualitative and quantitative measurements of micro-biota were performed at all CW dump sites. In doing so, micro-biota were analysed for the presence of organisms being tolerant to mustard and its decay products, as well as for organisms capable of destruction of mustard and products of its hydrolysis. Samples of upper sediment and near-bottom and porous water were subjected to microbiological studies.

Sediment and water samples were analysed for microbiological parameters as follows: total amount of bacteria (calculation of filtered organisms), amount of heterotrophic organisms (calculation of organisms after sowing the samples onto standard nutritious agar), amount of micro-organisms being tolerant to mustard (calculation of organisms after sowing water samples onto special selective nutritious media, contained mustard and its hydrolysis products as a single source of a carbon). It was found that the quantity of micro-biota in the near-bottom waters of the study area was of the order of $3x10^5$ cells/ml, and the quantity of heterotrophic organisms was 1,1 - $3,0x10^3$ cells/ml.

At the Måseskär and Bornholm dump sites, the micro-biota of near-bottom water was found to contain large amounts of bacteria tolerant to mustard. Preliminary results indicate that these bacteria contribute 20 to 90 % of the total amount of heterotrophic organisms, which can be explained by mustard being released into the environment. It was found that the natural habitats of the tolerant micro-organisms are frequently coincident with areas of hydro-chemical anomalies. Micro-biota which are tolerant to mustard have also been found at the Gotland dump site, but here the interpretation was not as clear as for the pattern described for the two previously-cited dump sites. It should be noted that the sampling procedure was not completely systematic during these measurements, and this imperfection should be excluded in future measurements.

We note that Dr. Medvedeva of the Scientific Centre of Environmental Security in St. Petersburg has catalogued more than 100 active micro-organisms capable of destroying mustard. These organisms are able to accomplish their detoxication under a variety of environmental conditions, including low temperatures (+4 °C). This range of natural conditions under which detoxication is possible is evidence that some selected micro-organisms can provide natural self-cleaning of water and sediments.

Shipwrecks in the Skagerrak

At the Måseskär dump site in the Skagerrak 12 targets were mapped (Table 4, Fig. 5). One of those targets (No.5) was inspected using an ROV from MARISCOPE, Kiel. At first, strong tidal currents and large sea depth did not allow the vessel to keep a properly fixed position. The same difficulty arose during similar work of a Swedish group in 1992 (HELCOM CHEMU 1993b).

Table 4. *Positions of wrecks at the Skagerrak (Måseskär) dump site.*

Target	Coordinates	Target	Coordinates
t1	58°10.14′N - 10°44.56′E	t7	58°10.40′N - 10°45.61′E
t2	58°10.38′N - 10°45.28′E	t8	58°10.49′N - 10°46.08′E
t3	58°10.35′N - 10°45.26′E	t9	58°10.22′N - 10°45.21′E
t4	58°10.33′N - 10°45.28′E	t10	58°10.75′N - 10°45.55′E
t5	58°10.45′N - 10°45.57′E	t11	58°10.15′N - 10°45.45′E
t6	58°10.43′N - 10°45.57′E	t12	58°10.79′N - 10°45.65′E

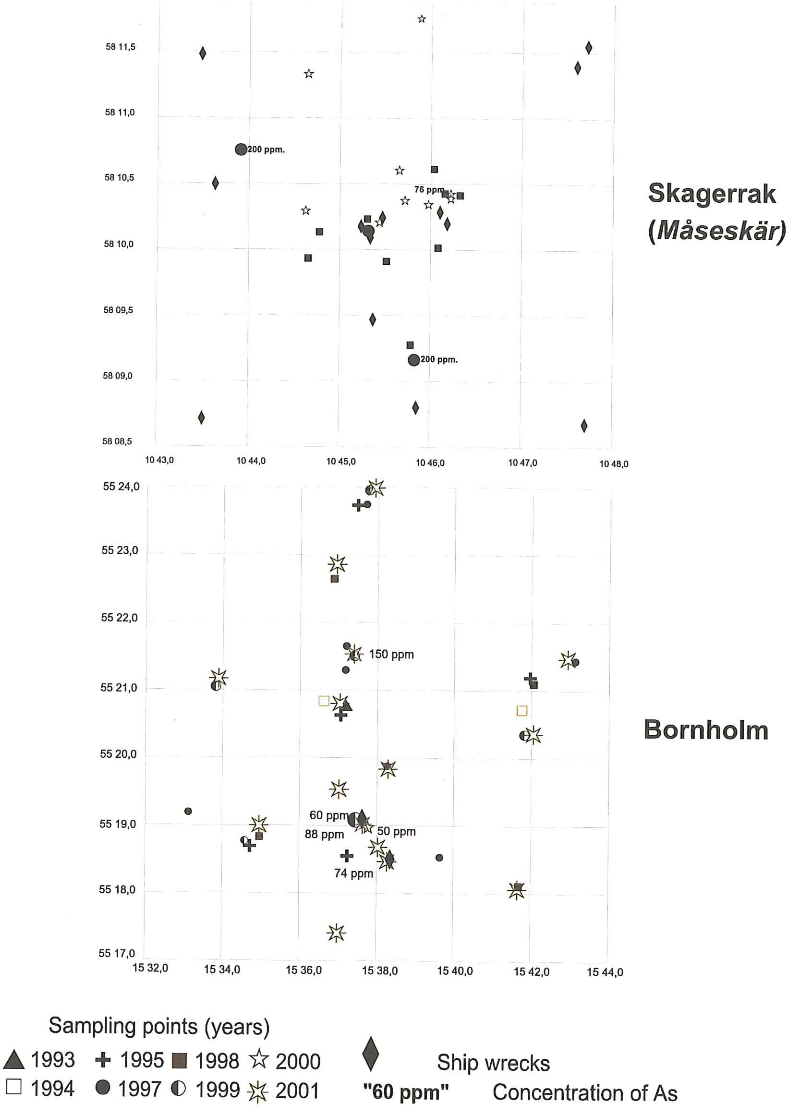

Fig. 5. Shipwreck positions and monitoring data at the Skagerrak (Måseskär) dump site (top) and at the Bornholm dump site (bottom).

The goal of the R/V "Prof. Shtokman" expedition was achieved only after the ROV was moved onto a motor-launch, which was fastened to the moored surface buoy by a rope of adjustable length. Using this technique, the shipwreck was found. The name of the vessel was not identified. Manoeuvring, which was necessary to evaluate the size of the vessel, was very limited. However from the anchor size it follows that the vessel was small.

Extensive destruction and strong corrosion of the metal hull, broken tubes and cables, and scraps of fishery nets were visible on the deck and bulwark. Nothing related to CW was found. In the vicinity of the wreck, and even in cracks of its boards, we observed lots of inhabitants. Thus, one can conclude that this wreck probably did not contain a large concentration of toxicants.

Shipwrecks in the Bornholm Deep

In June 2001 similar work with another ROV, the "SeeEye", operated from the R/V "Doctor Lyubethky", was performed in the Bornholm area according to an agreement with the Maritime Institute in Gdansk, Poland. Conditions for ROV operations in that area were better than for the ROV observations at the Måseskär dump site. In particular, the depth in the Bornholm area was two times less, and the sea was calm. We note, however, that the current was strong (see Fig. 3) and caused some difficulties. During these observations the vessel was able to use an anchor to keep its position close to the targets, which were searched out in the coordinates derived from magnetic measurements. Later, more exact measurements were obtained using the multibeam system on the "Dr Lubecki".

Discovery of sunken vessels in the Bornholm Deep has never been reported previously, so this description seems to be the first evidence of weakly argued affirmation (Anon. 1993). In total three objects were identified (Table 5, Fig.5).

Table 5. *Positions of wrecks at the Bornholm dump site.*

Target	Coordinates
t1	55°19′,748 N - 15°40′,837 E
t2	55°19′,441 N - 15°39′,597 E
t3	55°19′,004 N - 15°37′,290 E

Object No. 1 is 50 m long and 17 m wide, and its elevation above the bottom is about 4 m. A multibeam image of this wreck is shown elsewhere in this volume (Gorodnitski & Filin). The vessel is badly destroyed. Its hull is covered by fishery trawling nets, some of them still rising by floats which kept their buoyancy (Fig. 6a). These nets disfigure vertical dimensions of wrecks. Both the ROV inspection and sub-bottom profiler demonstrate deep immersion of the hull into silt. On the surface of the bottom there are many large fragments of shells identifiable by bull's-eyes. We also observed a bomb recognisable by its tail (Fig. 6b).

The second object was found to be even more destroyed and was almost fully immersed in silt. Artillery missiles were found on this vessel on the deck in cases (Fig. 6c). One may conclude that the two inspected vessels transported weapons as deck-cargo. It is not known what cargo was stored in the holds of these vessels, but it is reasonable to suppose CW.

Fig. 6. *Video-images of sunken vessels at the Bornholm dump site. Top: fishery nets. Middle: object looking like a tail of an aerial bomb. Bottom: corroded artillery missile*

A third shipwreck was discovered by the sub-bottom profiler, but no observations of this vessel were made by the ROV.

No living inhabitants were observed in the near-bottom water and sediments near the shipwrecks, but this lack of inhabitants might be connected with the deficit of oxygen, not with toxicity. Sediment and water samples taken very precisely nearby the wrecks showed *As* content within 60-88 mg/kg. Microbiological sampling was not performed.

In Fig. 6c it is seen that the missiles have corroded, but not fully. The commonly accepted rate of steel corrosion in salt water is about 0.1 mm/year (Borisov 1997; HELCOM CHEMU 1993a). If this rate were constant during 50 years, any walls thinner than 5 mm must disappear. For the poorly aerated Bornholm water, the rate of corrosion must be much lower, especially inside the closed holds. Consequently, there is high probability that the main cargo, if it is CW, remains unchanged and potentially dangerous. This hypotheses could be extended to the vessels scuttled in the Skagerrak, if we presume that the water inside the holds is poorly oxygenated.

Conclusions

We have numerous observations of leakage of some chemicals, which become apparent as anomalies of *pH* values, *As* concentrations, and *P* concentrations, and the appearance of micro-biota which are tolerant to mustard. The magnitudes of anomalies within the Måseskär and Bornholm dump sites were found to be similar. At the Gotland dump site, the only signs of leakage were specific changes of micro-biota.

It is not known what proportion of dumped CW is leaking or how much of the primary amount of WPG has already decayed. This knowledge seems to be not very actual for the scattered CW, which had been isolated from the sea water after deep immersing into mud, but is very actual for understanding further leakage and decay of the gases concentrated in holds of sunken vessels and poorly isolated from the sea water. It is therefore necessary to get samples of CW from the interior of sunken vessels. It seems reasonable to start this work at the Bornholm dump site. This site should be defined as the area where maximum available concentrations of WPG decay products could occur. At the same time the conditions of working underwater here will be much easier than in the deeper Skagerrak dump site.

Acknowledgements

The authors would like to express their sincere gratitude for the following persons for their support and contribution in the project: Tengiz Borisov, Maxim Vladimirov, Igor Volkov, Alexander Gorodnitski, Nikolay Rimski-Korsakov, Alexander Filin, Konstantin Popov, Victor Sytchev, Victor Kravtsov, Emelyan Emelyanov, Nikolay Kudryavtsev, Vadim Sivkov, Nadezhda Medvedeva, Andrey Grigoryev, Vladimir Zhamoyda, Pavel Moskalenko, Vladimir Baranov, Nikolay Golenko, Vladimir Gorbatski, Vladimir Egorikhin. Special gratitude is expressed to the team of the R/V "Professor Shtokman". We wish to thank Dr. Don Delisi and Dr. Tine Missiaen fore useful discussion during writing this paper.

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Tracing dumped chemical munitions in Pomeranian Bay (Baltic Sea) at former transport routes to the dumping areas off Bornholm Island

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Abstract - About 35,000 tons of German chemical munitions were dumped east of Bornholm Island in the Baltic Sea after World War II. It was suspected that a considerable portion of these weapons was thrown over board along the transport routes in the Pomeranian Bay. Area-wide acoustic and magnetic surveys within the part of the former transport routes situated in the present German Exclusive Economic Zone provided indications of considerable sediment dynamics and only a few number of objects likely to be remains of ammunition.

Introduction

After World War II over 30,000 tons of German chemical ammunition were dumped under responsibility of the Soviet military administration east off Bornholm Island. The transports were assembled in the harbours of Wolgast and Peenemünde.

According to reports by eye witnesses part of the munition was thrown over board already during transport in case of bad weather or simply to save time. In order to assess the dimension and state of this presumed threat to the environment detailed investigations have been carried out by the Federal Maritime and Hydrographic Agency of Germany assisted by the Baltic Sea Research Institute in the 1990's.

Methods

The transport routes within the present German Exclusive Economic Zone have been surveyed by acoustic and magnetic methods entirely (Fig. 1). During eight cruises with the research vessels "Deneb", "Atair" and "Wega" the transport routes have been covered by a sidescan sonar grid with a line spacing of 75 m. Additionally, a proton magnetometer has been used to locate magnetic anomalies at a grid spacing of down to 35 m (Fig. 2).

Setting

The investigated area is situated in the Pomeranian Bay within the southern Baltic Sea. The average water depth is about 15 m. Maximum water depths of more than 20 m were observed in the north-easternmost part of the former shipping lanes (see Fig. 3). The central part of the bay is characterised by the Oderbank, a shallow area with water depths less than 10 m.

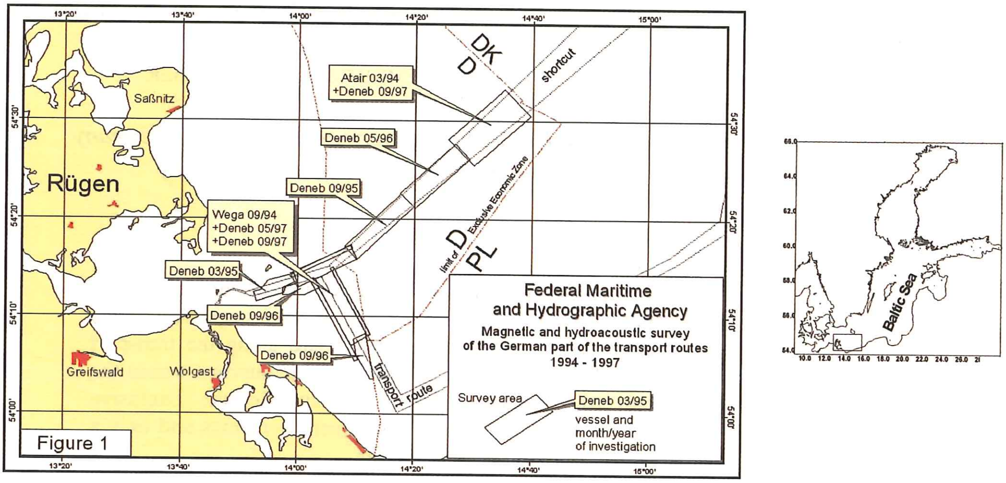

Fig. 1. *Investigation area in the Pomeranian Bay.*

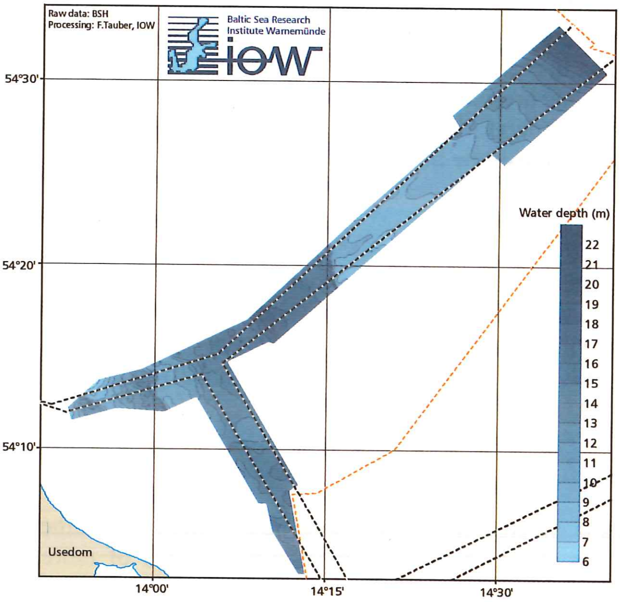

Fig. 2. *Bathymetry within the investigated shipping lanes.*

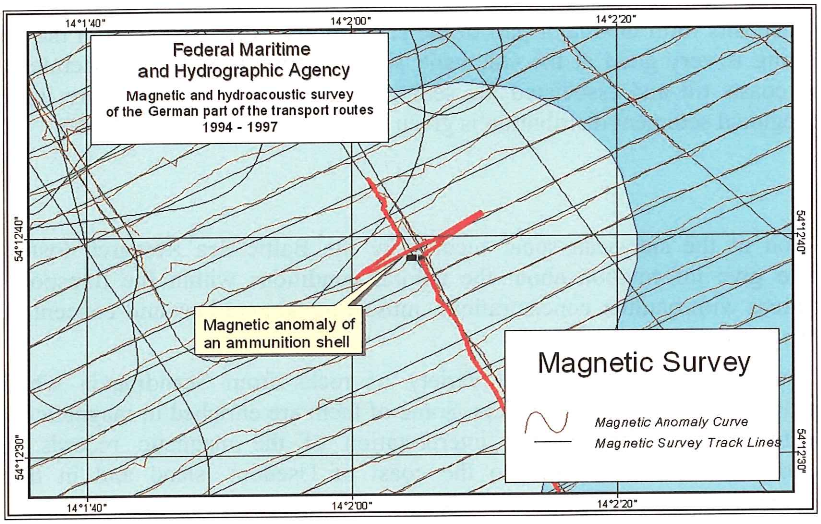

Fig. 3. *Spacing of the magnetic survey with an example of a magnetic anomaly.*

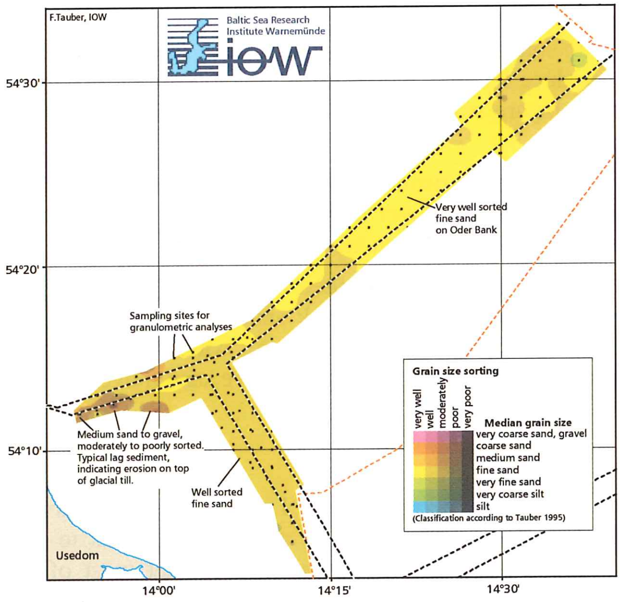

Fig. 4. *Distribution of surface sediments within the shipping lanes.*

The current system is highly variable and changes according to meteorological forcing (Lass *et al.* 2001).

Sandy deposits form the major part of the sea bottom. Their median is in the fine sand range. Sorting is very good at the Oderbank shallow. Elsewhere it is moderate to good. Along the coasts till and associated lag sediments dominate (Fig. 4). More information about the regional sediment distribution is given by Neumann & Bublitz (1969).

Results

Interpretation of the side-scan sonar records by the Baltic Sea Research Institute was supposed to give information about the natural conditions within the transport routes. Different areas with boulder concentrations, mussel agglomerations and concentrations of trawl marks could be identified.

The boulders consist of a wide variety of rocks from Scandinavia which were transported here by Weichselian glaciers. Some of them are enriched in magnetic minerals. This has to be considered during interpretation of the magnetic records. Boulder concentrations are observed close to the coast of Usedom Island and in the north-easternmost part of the investigated area (Fig. 5).

Small ripple marks recorded by side-scan sonar indicate relatively coarse sands in a rather dynamic environment. They occur mainly in the near-coast region (Fig. 6). Mussel concentrations are likely to obscure the side-scan sonar records with regard to artificial targets. Related features were observed at both sides of the Oderbank shallow (Fig. 7).

Trawl marks are indications of fishery contributing to sediment redistribution. Obviously the near-coastal area is especially exposed to fishery activities (Fig. 8). While recording by side-scan sonar also bathymetric data were stored every three seconds. These data were used to produce a comprehensive bathymetric map (cf. Fig. 3). Furthermore, it became possible to compare water depth data in overlapping areas covered by different surveys at different times.

In the result of these comparisons differences in water depth of up to 80 cm were detected (Fig. 9). The differences cover both positive and negative deviations in the same area. Therefore, substantial re-deposition has to be expected.

Processing of the bathymetric data resulted in a map of morphological gradients (Fig. 10). Besides the steep slopes of the Oderbank shallow, sandwaves, partly several km in length, and large megaripples could be identified this way. Sandwaves and megaripples are interpreted to characterise areas with ongoing intensive sand movement.

Conclusions

Finally, the results of both the acoustic (Fig. 11) and magnetic surveys (Fig. 12) were superimposed. This led to the verification of about 100 objects to be inspected at the seafloor surface. Detailed inspection by video showed that most of these objects were harmless (wreckage, anchors, debris, scrap) (Fig. 13). Only four of these objects are still under suspicion of being corroded remains of ammunition. Another 130 iron objects have been detected below the sea bottom. Many of these objects are located at the Oderbank shallow, where no suspicious side-scan sonar contact was observed. Their origin still remains unclear.

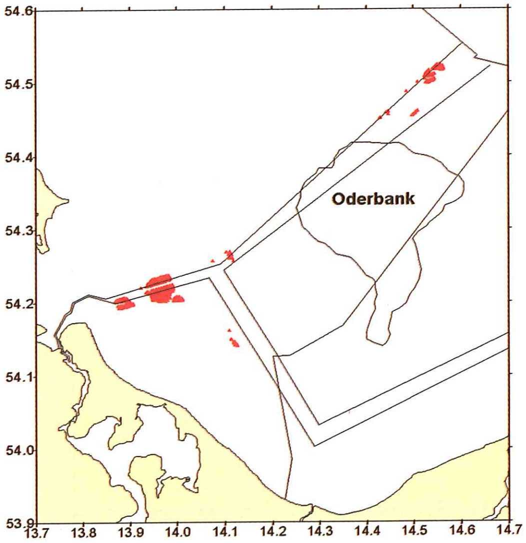

Fig. 5. *Boulders and pebbles in side-scan records.*

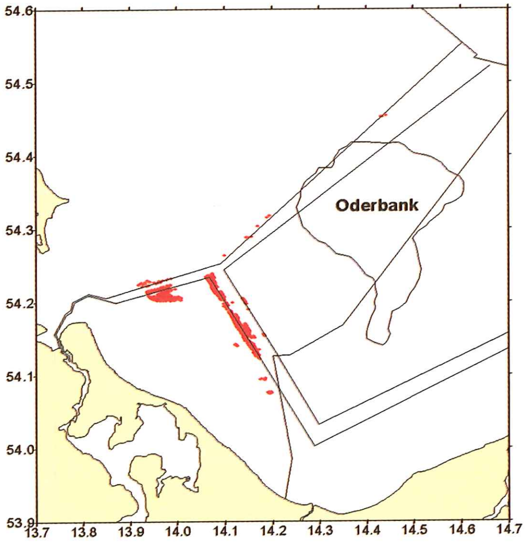

Fig. 6. *Ripple marks in side-scan records.*

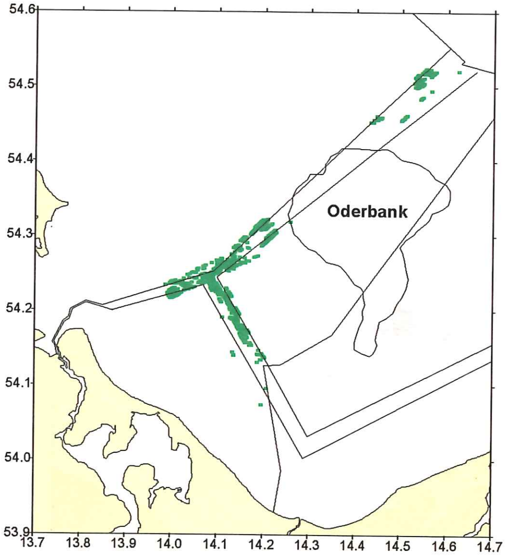

Fig. 7. *Mussel concentrations in side-scan records.*

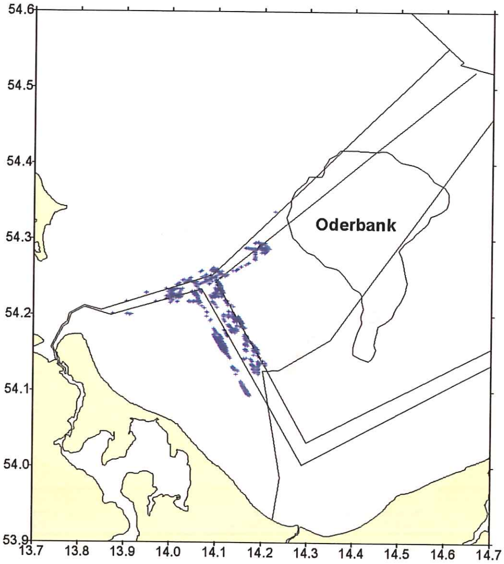

Fig. 8. *Trawl marks in side-scan records.*

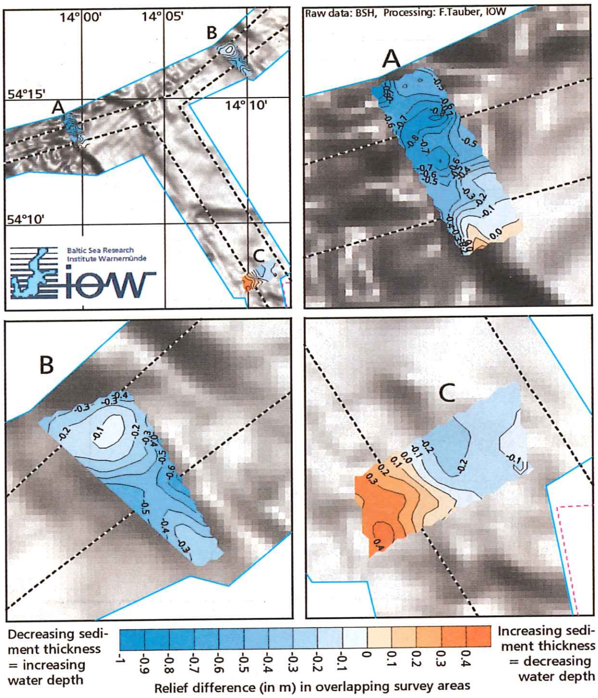

Fig. 9. *Varying relief during different surveys in overlapping areas.*

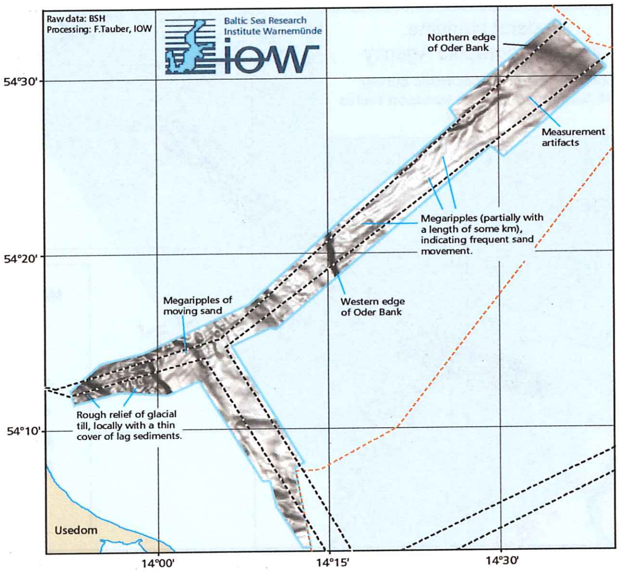

Fig. 10. *Interpreted morphology within the shipping lanes.*

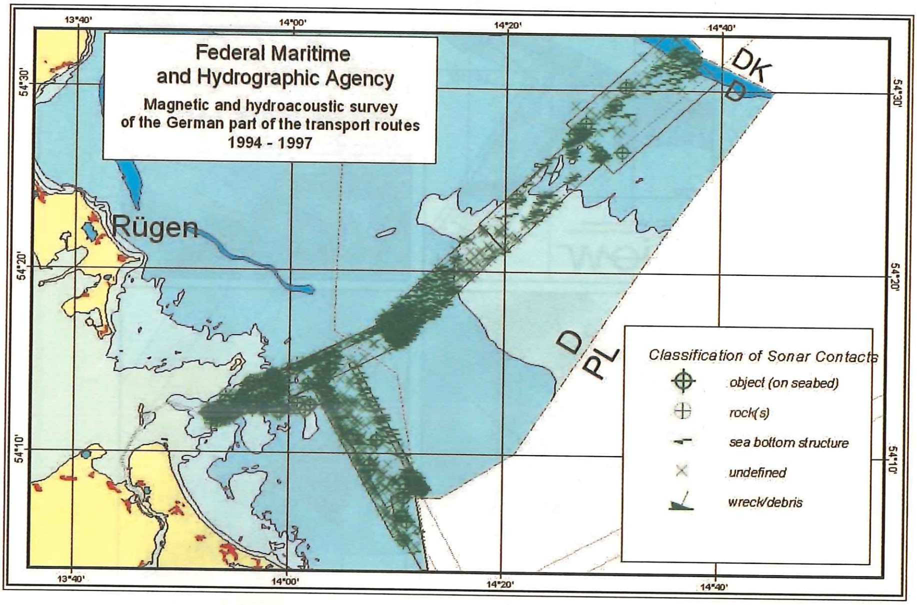

Fig. 11. *Classification of sonar contacts.*

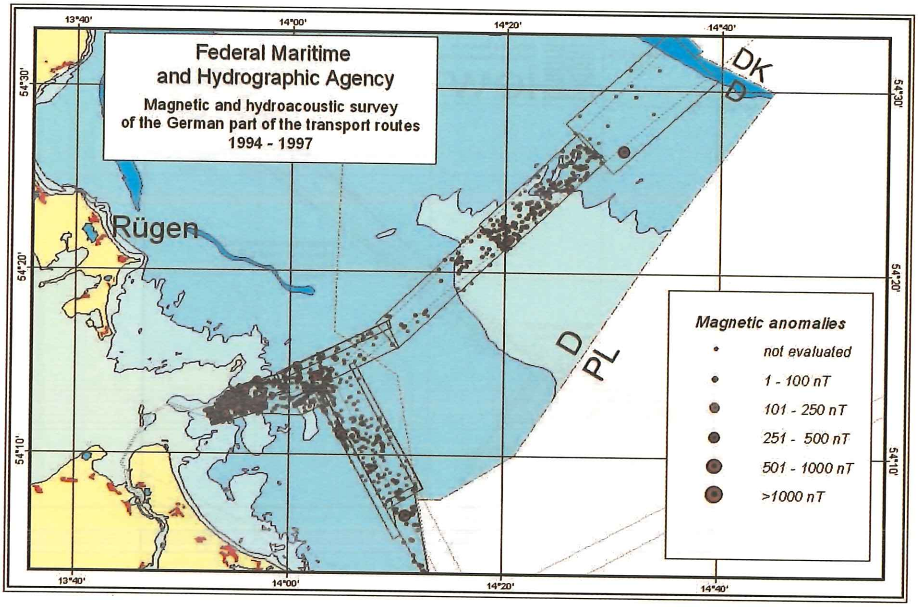

Fig. 12. *Magnitude of detected magnetic anomalies.*

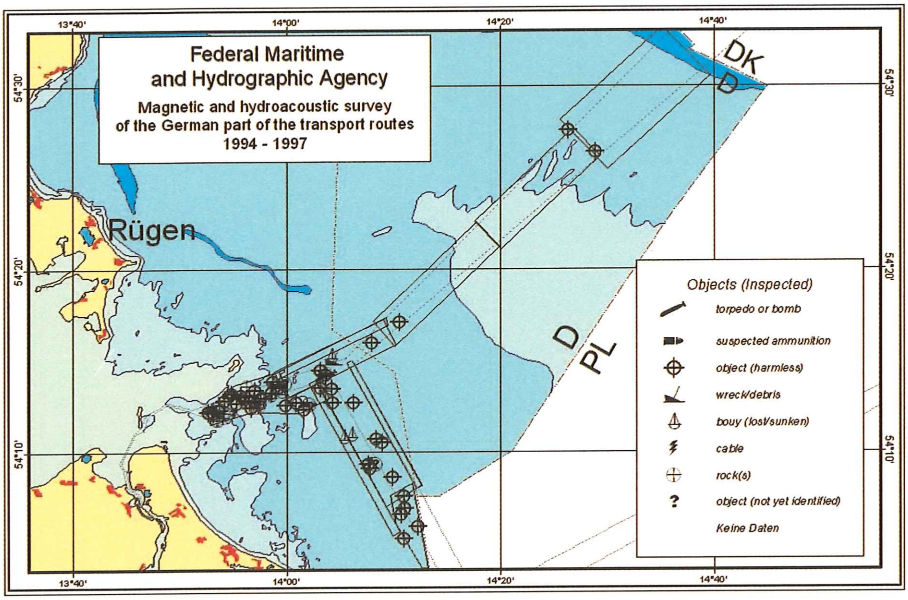

Fig. 13. *Interpretation of inspected objects.*

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Techniques and results of magnetic detection of dumped weapons in Bornholm and Skagerrak dump sites

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Abstract - Since 1997 Russian scientists have been monitoring dump sites of chemical weapons submerged after the Second World War in the Baltic Sea. The surveys involved the search of submerged ships in addition to sampling of water and soil at the dump sites. The results of geomagnetic investigations in the Bornholm Deep and Skagerrak Strait are presented here. In these areas large amounts of German chemical weapons were submerged. The magnetic measurements and side-scan sonar observations have allowed the detection of three submerged vessels in the Bornholm Deep and eight vessels in the Skagerrak Strait. A brief description of the technique of geomagnetic gradient measurements and used instrumentation is given. The efficiency of gradient magnetic measurements for the investigations of munition dump sites is demonstrated here.

Introduction

Over the last years the pollution of marginal seas by chemical, radioactive and other kinds waste has become a more and more acute problem. Some of the most dangerous ecological conditions subsist in the Baltic, Barents and Kara Seas. After the Second World War many countries considered dumping at sea an economic and safe way to eliminate the stockpiles of unused and out-of-date ammunition, including chemical weapons.

According to some estimations over 300,000 tons of German chemical munitions were dumped in the Skagerrak and Kattegat Straits and in the Baltic Sea (Borisov 2000). The dumped war material includes hundreds of thousand of conventional and chemical shells, mines, aerial bombs, and so on. The total amount of toxic compounds is estimated to be 60,000 tons. In the Baltic Sea alone 6 chemical munition dump sites are known (Kasyanenko *et al.* 1997).

A major problem complicating effective monitoring of the environment in these areas is the absence of accurate information on the exact coordinates of the dump sites and their internal structure. Sonar observations, magnetic measurements, hydrochemistry and hydrophysical investigations are applied in search of the dumped chemical warfare. A side-scan sonar "Mezoskan" and marine proton gradiometer "Gradient" were used in the search of submerged objects in the Baltic Sea and Skagerrak Strait.

Magnetic measurement techniques and instrumentation

The principal advantage of the gradiometry technique is the opportunity to obtain magnetic field data free of magnetic time variations. The gradiometry technique is based on the synchronous measurements of the Earth's total magnetic field intensity or its components at two or more points at some distance from each other (Gorodnitsky 1995). The ratio of the total field difference to the distance between points allows one to estimate the derivative of the field with respect to the vector joining the points of measurements.

The gradient of magnetic field $T(r)$ characterises the rate of field variation with respect to the vector $\boldsymbol{r}$ and may be expressed as:

$$\frac{\Delta T}{\Delta r} \approx \lim_{\Delta r \to 0} \frac{T_r - T_{(r+\Delta r)}}{\Delta r} = \frac{dT}{dr} \qquad (1)$$

where $\Delta T = T_r - T_{(r+\Delta r)}$ is the total field differential between two sensor positions spaced Δr apart; Δr is small compared to the distance to the nearest source of magnetic anomalies;

$\frac{dT}{dr}$ is the derivative or gradient of $T(r)$ in the direction of r.

Depending on the position of the sensors with respect to the direction of the vessel three principal gradient measurements can be used: longitudinal, transverse, and vertical. Measuring the vertical gradient seems to be most interesting, but is difficult to perform in marine conditions. Instead the longitudinal configuration was used, measuring the magnetic field gradient in the direction of vessel movement.

Expression (1) can thus be rewritten as:

$$\frac{\Delta T}{\Delta X} = \frac{T_1 - T_2}{\Delta X} = \frac{T_1(x) - T_2(x + \Delta X)}{\Delta X} = G(x) \qquad (2)$$

where T_1 and T_2 are the field values measured by the first and second sensor (which includes the constant $T(x)$ and variable $\delta T(t)$ magnetic field components); ΔX is the distance between the two sensors (so-called base of measurement); $G(x)$ is the longitudinal gradient (course gradient) of the magnetic field.

Since ΔX is small compared to the distance to the sources of magnetic field time variations (which are in the Earth's ionosphere and magnetosphere and are separated from the Earth's surface by several hundred km), the gradiometer measures the derivative of the geomagnetic field with respect to the given direction and these measurements are free of the geomagnetic variation effect.

The magnetic measurements in the Skagerrak and Bornholm dumping areas were carried out with the new proton gradiometer "Gradient" which was developed in the magnetic laboratory of the P.P. Shirshov Institute of Oceanology (Fig. 1). The basic part of the gradiometer consists of a microprocessor data registrator. It allows to carry out statistical processing of signals from two or three sensors and to observe the data on display in both graphic and digital form. The device is equipped with a non-volatile memory of 1 MB capacity, a timer of real time and RS-232 interface for connection to the computer. The depth of the tow fish is also recorded digitally.

The technical parameters of the gradiometer include the following:

- range : 20,000 – 70,000 nT
- sensitivity : 0.1 nT
- sampling time : 2, 3, 5, 10 or 20 s
- accuracy : 0.5 nT

Surveys

Within the framework of the international project "Marine ecological patrol" the Atlantic branch of the P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, together with the Geological Institute in St. Petersburg, began regular monitoring of the Baltic Sea ecosystem from 1997. The primary work was performed in the dump areas in the Bornholm Deep and Skagerrak (Måseskär) (Fig. 2). The multiple investigations included side-scan sonar, magnetic gradiometry surveys, hydro-physical and hydrochemical investigations, and detailed inspection of the submerged objects using underwater devices (Paka & Spiridonov, this volume).

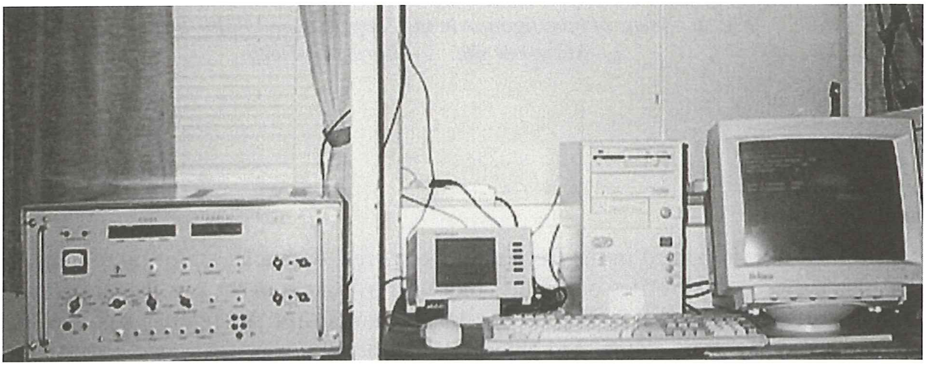

Fig. 1. *Sea proton gradiometer complex "Gradient".*

The magnetic gradiometry surveys were carried out during cruises 43 and 46 of R/V "Professor Shtockman" in 1999 and 2000, respectively (Gorodnitsky & Filin 2001). The sensor fishes were towed at a distance of 200 and 300 m from the vessel. Sampling time of the measurements was 2 s.

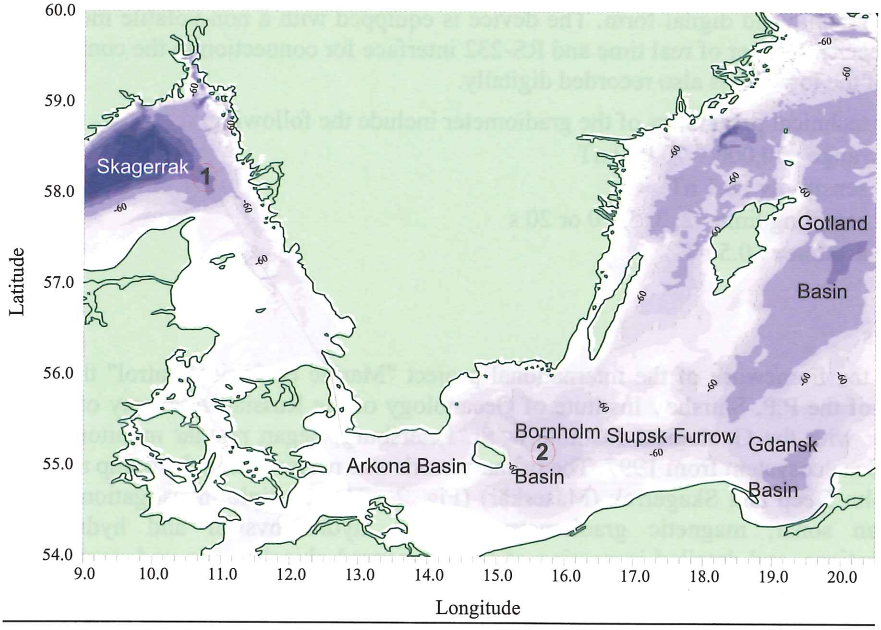

Fig. 2. *Areas of investigation in the Skagerrak and Baltic Sea.*
1 – Måseskär site; 2 – Bornholm Deep.

Bornholm Deep

Nine profiles were recorded in the Bornholm Deep area, with a length of up to 6 miles and a distance between the profiles of about 1 mile. An overview of the profile locations in the Bornholm area is presented in Fig. 3. The black triangles in the figure mark the sites of magnetic anomalies from submerged objects. Water depth in the area was about 100 m.

Analysis of the geomagnetic results in the Bornholm basin indicated the characteristic structure of the anomalous magnetic field (AMF) caused by a deep block structure and variation in depth of the magnetic crystal basement buried under the loose nonmagnetic sediments. The map of the AMF for the Bornholm area is given in Fig. 4. Towards the southeast blocks of magnetic rocks, probably intrusions, with amplitudes of 250 to 300 nT can be distinguished. These blocks are bound by a fault system marked by a NW and NE orientation. The latter seems to reflect the complicated tectonic structure of the magnetic basement.

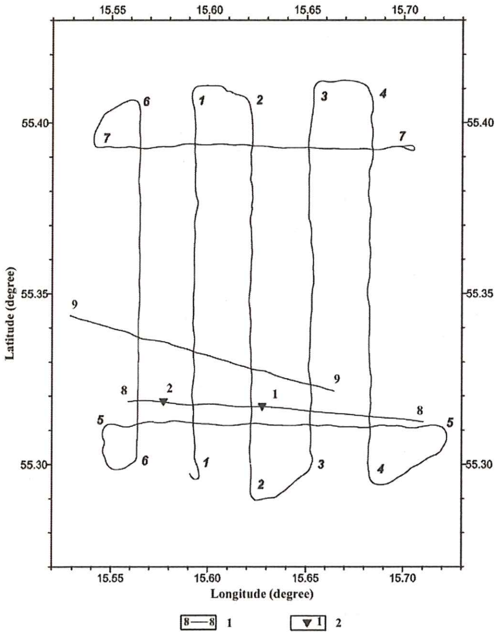

Fig. 3. Network of magnetic profiles and location of submerged objects in the Bornholm area (1 – profile numbers; 2 – submerged object location).

The complicated structure of the magnetic field in the Bornholm area is clearly illustrated in Fig. 5, showing the AMF along profile 8 and its course gradient. On this graph the arrows mark the two magnetic anomalies caused by submerged objects. Some magnetic anomalies from geological objects have the same amplitude as anomalies from metallic objects, but extend over a longer period. The geologic objects are located on deeper levels. The latter is also indicated by spectral analysis. The analysis of the AMF power spectrum allows to distinguish sources at different depths. The nature of these deep sources, which are located at a depth of 2.7 to 3 km, is connected to local block tectonics.

The sources of anomalies with intermediate depths, respectively ranging from 800 - 900 m, 450 - 500 m and 300 - 350 m, may well correspond to the upper edge of the blocks of the crystallic basement. The sources located at a depth of 90 to 100 m can be related to submerged objects lying on the sea floor surface or buried by sediments.

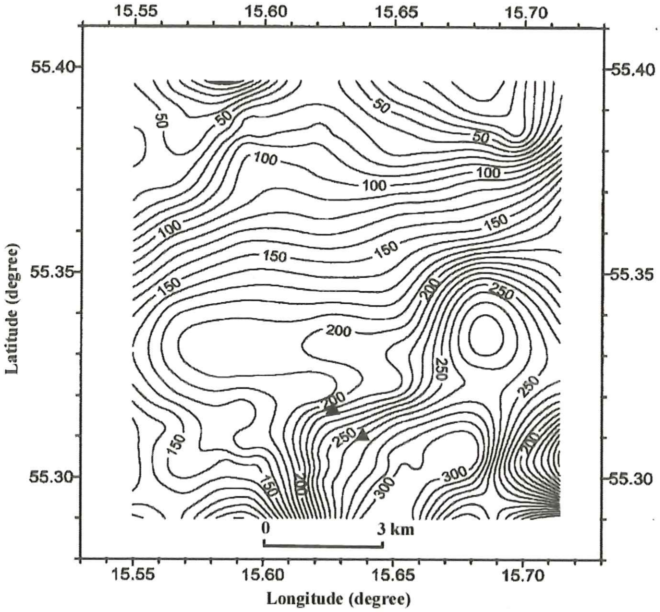

Fig. 4. *Anomalous magnetic field map of the Bornholm area. Isolines are in nT. Black triangles mark the location of submerged vessels (2001 survey).*

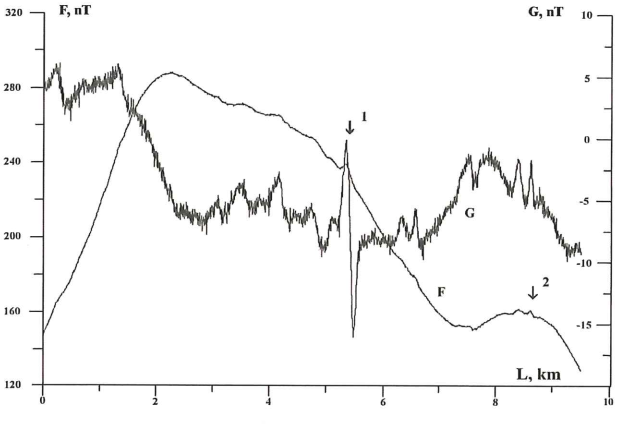

Fig. 5. *Anomalous magnetic field (F) and its gradient (G) for profile 8 near Bornholm (1 – submerged vessel anomaly; 2 – anomaly, probably from wreckage).*

Magnetic anomaly #1 is due to a submerged vessel with a weight of 200 - 500 tons. The presence of the vessel is confirmed by the side-scan sonar data.

Anomaly #2 on the same profile is more restricted and has a smaller amplitude. The latter is most likely due to the limited size of the submerged object. Probably it represents a small wreck.

A more detailed gradiometer survey with the "Gradient" was performed in 2001 during cruise 48 of R/V "Professor Shtockman" in the Bornholm Deep. In total 150 profiles were recorded in NS and EW directions. The spacing interval between the EW profiles was ~185 m, and between the NS profiles ~100 m. In addition to the known submerged vessel two more wrecks were found. The location of the submerged wrecks is shown on Fig. 4.

The coordinates of the submerged vessels were handed to Polish scientists from the RV "Doctor Lyubethky" who worked in the same area. The results of their multibeam data, as shown in Fig. 6, clearly confirmed the presence of three submerged vessels. An ROV was lowered at the site and the images obtained from the unmanned camera showed the presence of numerous aerial bombs and shells spread among the wrecks.

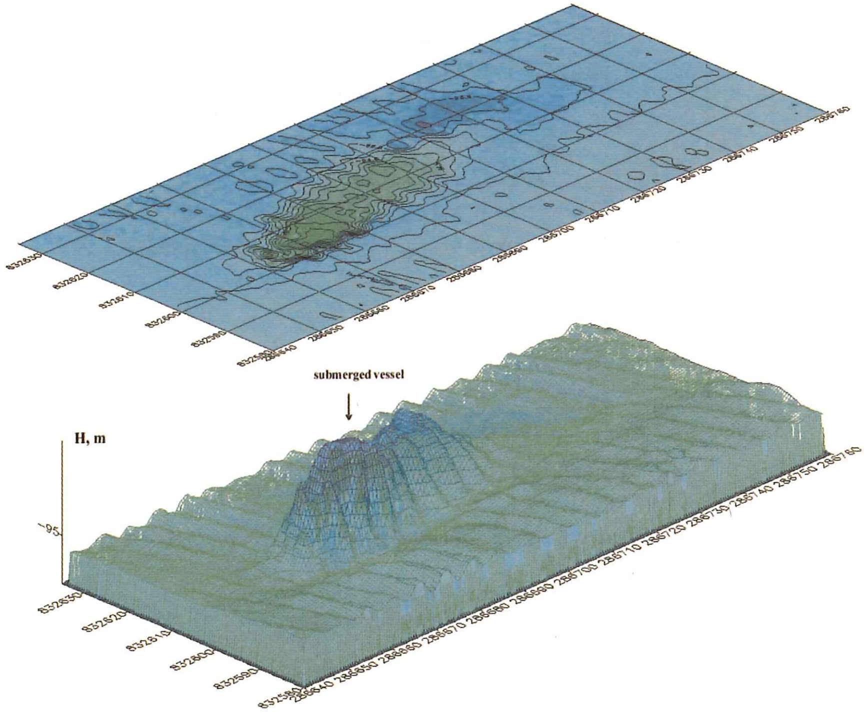

Fig. 6. Bathymetric map of the submerged vessel in the Bornholm Deep area (multibeam data from R/V "Doctor Lyubethky"). Contour line interval 0.5 m.

Skagerrak Strait

The Måseskär dump site in the Skagerrak Strait has a more confined character. At this site different vessels loaded with containers full of ammunition were sunk. The gradient magnetic network contained 22 orthogonal NS and EW profiles. Distance between the profiles was ~185 m. The total length of the profiles was ~70 miles.

An overview of the profile location in the Måseskär area is given in Fig. 7. The full black triangles in the figure mark the sites of magnetic anomalies from submerged vessels. All sites were confirmed by side-scan sonar data. The water depth in the area varied between 180 and 220 m. The dump site is located on the eastern slope of a large trough oriented to the north-west. The morphology of the slope is very complex, and marked by the presence of a large amount of small ridges.

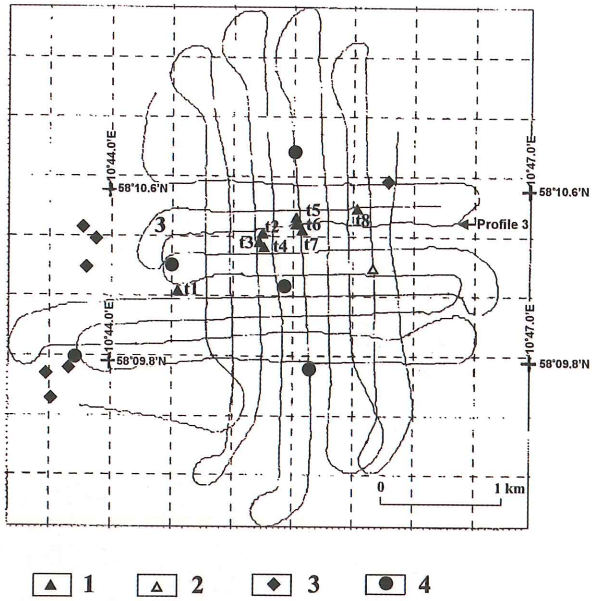

Fig. 7. Network of magnetic profiles and location of submerged objects in the Skagerrak area (Måseskär).
1 – submerged vessels and their fragments (magnetic and sonar data)
2 – small objects, probably of artificial origin (sonar data)
3 – geological objects (sonar data)
4 – objects that have not been expressed in a relief ("dark stains"; sonar data)

Most of the submerged objects were registered on several nearby located profiles. This allowed a more precise location of the sources of the magnetic anomalies. The complex form of the magnetic anomalies corresponding to objects t5, t6 and t7 indicates the presence of several sources. These objects are apparently at a close distance from each other and consequently result in a complex magnetic field.

It is necessary to note here that all the objects (t1 to t8) that were observed on the magnetic data coincide almost precisely with the sites determined from the side-scan sonar data. Others objects observed on the sonar data could not be related to the magnetic field data. They were therefore not submitted to further research.

The anomalous magnetic field of profile 3 and its gradient are shown in Fig. 8. The amplitude of most magnetic anomalies varies from 2 to 10 nT. The width of these anomalies suggests that their sources lay directly at the bottom.

The map of the anomalous magnetic field (AMF) for the Måseskär dump site area is shown in Fig. 9. The map is marked by (part of) a magnetic anomaly with an amplitude up to 200 nT, with expressed anomalous zones in the south-western and north-eastern parts of the survey area.

The maxima of the magnetic anomaly are apparently related to tectonic blocks of the basement divided by EW and NW oriented faults. Additional data processing has allowed to determine the borders of the magnetic blocks in the north-eastern part of the dump area and the EW zone in the southern part. The latter is interpreted as an axis of the fault.

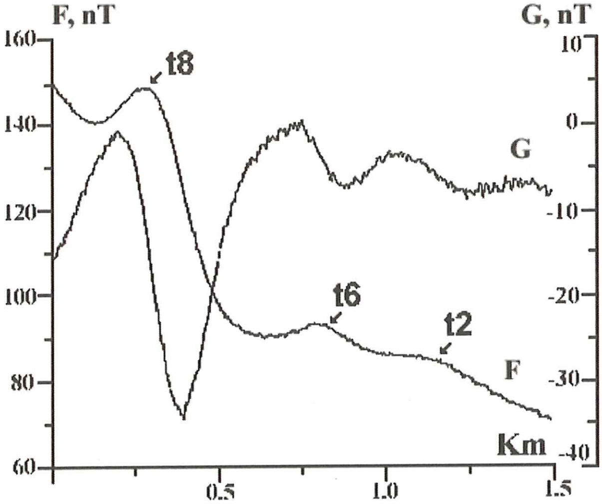

Fig. 8. Anomalous magnetic field (F) and its gradient (G) for profile 3 in the Skagerrak area (Måseskär). The anomalies t2, t6 and t8 represent anomalies due to submerged vessels.

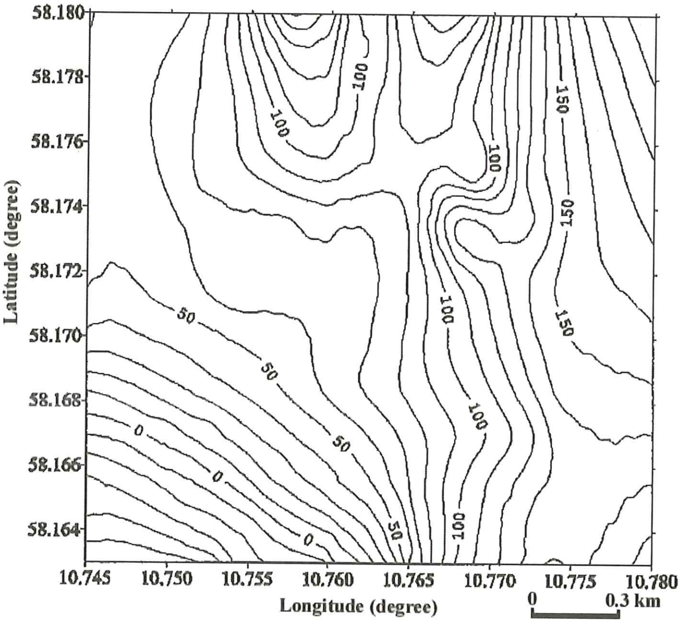

Fig. 9. Anomalous magnetic field map for the Måseskär dump area. Isolines are in nT.

Conclusions

The application of magnetic gradiometry techniques in marine environmental studies is important. The technique of precision magnetic gradiometry, whether or not in combination with other methods, can ideally be applied to the investigation of marine chemical munition dump sites. This was done for a number of munition dump sites in the Baltic Sea and Skagerrak. Precise location of many of the submerged objects was not known up to now. The dump sites constitute an environmental threat due to corrosion of the submerged vessels and the war material, resulting in the leakage of hazardous materials.

Magnetic measurements, combined with side-scan sonar investigations, allowed the detection and exact localisation of three submerged vessels in the Bornholm Deep and eight vessels in the Skagerrak (Måseskär site). This will finally allow better monitoring of these dump sites, resulting in a better control of the actual condition of these sites. In addition the magnetic gradiometry technique can also be applied for the search of other submerged objects forming a possible environmental threat such as oil and gas pipelines, cables, plane wrecks, containers, etc ...

The work presented here was supported by the Russian Fund of Fundamental Researches (project N 02-05-64247).

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Chemical munitions off the Belgian coast : an evaluation study

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Abstract - After World War I an estimated 35,000 tons of war material was dumped on the "Paardenmarkt", a shallow sand flat just off the Belgian coast. Probably about one third consists of chemical munition. The dumping site extends over 3 km^2, ranging in water depth between 1.5 and 5.5 m. The munition has been sagging and is largely covered under accumulating fine-grained sediments, mainly due to the construction of the outer port of Zeebrugge. The munition is most likely not too heavily corroded; complete corrosion could take hundreds of years. The most important threats seem to be related to mechanical disturbance of the munition shells (e.g. due to vessel grounding) and direct contact (with Yperite lumps). At this moment there are no strong indications for acute danger and the best option therefore seems to be to leave the dump site untouched - under the condition of regular monitoring. Geochemical sampling should involve specific screening for munition-related heavy metals, TNT, Yperite, Clark, and their respective breakdown products. Sea-bed monitoring is needed to map the erosion/accumulation processes and detect possible objects on the sea floor, whereas in-depth monitoring can gain further information on the internal structure of the dump site and its evolution. If monitoring would indicate potential surfacing of the munition the construction of an artificial island could be considered.

Introduction

After the first World War a considerable amount of war material was dumped on a shallow sand flat called "Paardenmarkt", offshore Knokke-Heist, Belgium. The dump site extends over 3 km^2, and is indicated on hydrographic maps with a pentagon where neither fishing nor anchoring is allowed.

Geophysical investigations in 1995-1996 showed the extreme complexity of the area, not only related to the dumped material (partly non-metallic, and thus "invisible" for magnetic methods) but also in relation to the natural settings and the (recent) evolution of the site. Despite these good results it was clear that complementary research techniques were necessary to analyse the full complexity of the Paardenmarkt in all its facets.

In 1999-2001 an integrated multi-disciplinary evaluation study took place combining geophysical, geochemical, sediment-dynamical, biological, engineering and ecological expertise. The main objectives of the evaluation study included the following:

- Detailed analysis and scientific evaluation of all available data related to the area, in order to make a correct evaluation of the actual dimension of the encountered problems.
- Analysis of possible strategies of scientific research with respect to the dumped munition and natural setting, and the possible perspectives for continuous monitoring of the area.
- Re-evaluation of the present-day "status quo" policy and the evaluation of different options for possible engineering solutions, including a nature conservation area.

History and general characterisation of the munition dump site

After the first World War large amounts of war material were left behind in Belgium. The clean-up operation was slow and very dangerous, and numerous accidents occurred. Because the situation was getting out of control and dismantling proved too risky, the Belgian government decided to dump war material into the sea.

The dumping operation started in November 1919. Each day during 6 months a shipload of munition (Fig. 1) was dumped in the proximity of the Zeebrugge harbour, just offshore Knokke-Heist, on the western edge of the Paardenmarkt tidal sand flat.

This dumping operation may not be the only one. Newspaper articles and parliamentary records from 1919 suggest an earlier dumping operation carried out by the British Admiralty in the middle of 1919 (indeed part of the country - including Mons and the greater part of the Province of Hainaut - was still under British rule). It is not sure however whether this British operation was carried out near the Belgian coast or further offshore - if carried out at all.

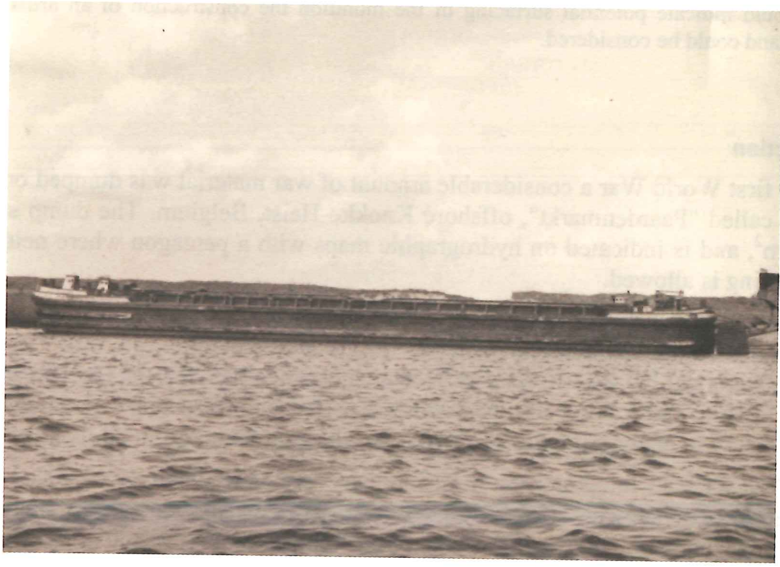

Fig. 1. Typical "klepbakschip" used for the dumping operations on the Paardenmarkt.

In 1971 dredging ships struck upon several objects on the sea floor during maintenance works for the Zeebrugge harbour. Diving operations carried out by the Belgian Navy in 1972 revealed the presence of munition on the sea floor, among which several toxic shells.

As a result the area was marked on hydrographic maps as a "no anchorage or fishing zone" with a total surface of ±1.5 km^2 (Fig. 2). During these diving operations a number of shells were recovered. According to the reports the state of the shells was "remarkably good".

Magnetometric investigations carried out in 1988 confirmed the presence of metallic objects at the site (Tijdelijke Vereniging Bergingswerken 1989). Due to the limited positioning accuracy and the absence of digital acquisition only a qualitative distribution of the magnetic zones could be obtained (Fig. 2).

A large number of the magnetic zones was located outside the first rectangular delimitation zone. Based on these results the no-fishing zone from 1972 was finally enlarged (mainly towards the west) to a pentagon with a total surface of ±3 km^2 (Figs. 2 and 3). For the time being no other measures were considered.

Nature of the dumped warfare

The total amount of dumped warfare is estimated to be 35,000 tons. Most likely it involves German ammunition, for the larger part 77 mm shells, and to a lesser extent 105 mm and 150 mm shells, as indicated by the diving operations in 1972. Other war material such as guns and explosives however cannot be excluded.

It remains unknown exactly how much of the dumped munition is toxic. German production figures from WW1 indicate that chemical weapons made up 6 to 7 % of the total amount of warfare produced (Lheureux 1990). However this expresses an average over the whole war period, thereby overlooking the fact that during the final stage of the war increasing amounts of chemical weapons were used. Statistics show that over 50 % of the total production of toxic agents was used in 1918 (Table 1). In Germany alone 92 % of the chemicals was used in artillery shells (Lheureux 1990).

Table 1. *Total production of chemical warfare agents per year (in %) (Source: V. Lheureux, L'utilisation du gaz de combat sur le front Belge pendant la guerre 1914-1918).*

	GERMANY	FRANCE	UK
1915	5.5	1.1	1.3
1916	13.3	13.3	11.1
1917	28.3	28.5	34.1
1918	52.9	57.1	53.5

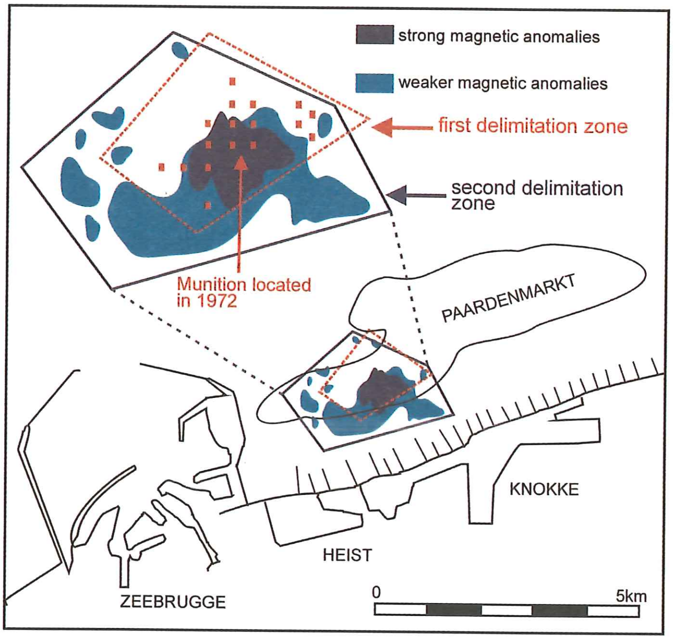

Fig. 2. *Location of the first and second delimitation zone of the Paardenmarkt dump site and results of the 1988 magnetometric survey.*

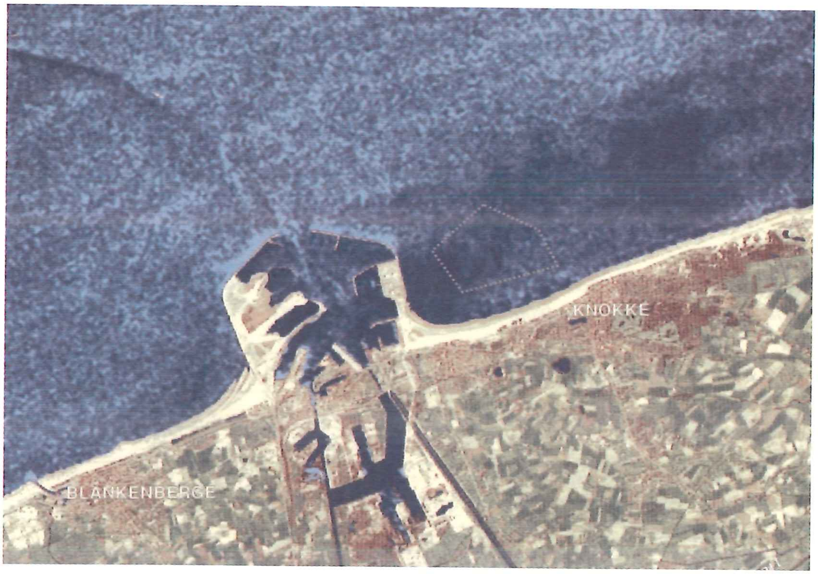

Fig. 3. *Satellite image of the coastal area near Zeebrugge. The pentagon marks the location of the munition dump site.*

These figures clearly indicate that toxic shells made up a much larger part of the artillery ammunition during the final months of the war. Furthermore it does not seem unlikely that some selection may have been carried out prior to the dumping operation, with emphasis on the "urgent" toxic ammunition. Keeping all this in mind, an estimation of about one third (of toxic ammunition) seems to be quite reasonable. Regarding the whole of 35,000 tons of dumped ammunition, this would imply a total amount of toxic shells of roughly 12, 000 tons.

German toxic shells from World War I were most commonly filled with (di)phosgene, chloropicrin, Clark and Yperite (mustard gas). According to their content they were referred to as blue, yellow or green cross shells (Fig. 4). The ratio between the different toxic shells dumped on the Paardenmarkt remains unknown. However, it is assumed that Clark and Yperite shells form the main part of the dumped toxic munition.

The munition shells roughly weigh between 7 and 40 kg and have a steel casing. The toxic shells are hard to distinguish externally from conventional shells. The originally painted green, yellow or blue markings have eventually disappeared by erosion.

The chemical warfare agents in general make up roughly one tenth of the total weight of the shells (blue cross shells form an exception: they contain a smaller quantity of toxic agent, Clark). For the Paardenmarkt this would imply a total amount of roughly 1200 tons of chemical compounds.

In addition to the warfare agents one should also take into account the explosive compounds (mainly TNT) which can be equally toxic. Although their part in toxic munition is very low (a few hundred grams per shell typically - except for Clark shells which contain more explosives), they make up one tenth or more of the weight of conventional shells. The total amount of explosives on the Paardenmarkt is estimated to be at least 2500 tons.

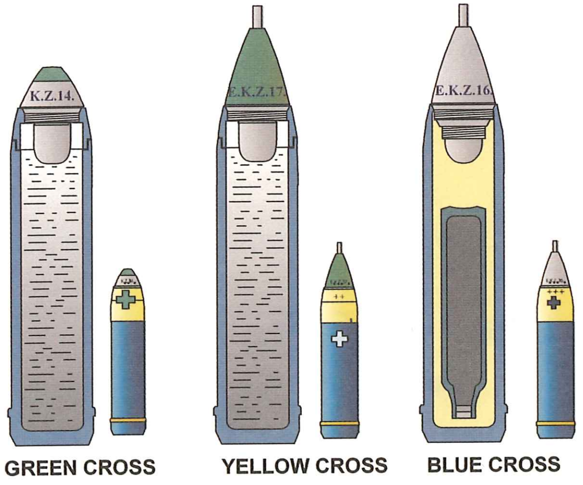

Fig. 4 . *Schematic representation of German toxic WW1 munition. Blue cross shells differ from the other toxic shells in the fact that the toxic agent is stored in a glass bottle (Source: DOVO).*

Geophysical / chemical investigations

In 1995-1996 a number of high resolution seismic, side-scan sonar and magnetometric measurements were carried out on the munition dump site. The results of these surveys indicated the high complexity of the area (Henriet *et al.* 1996), which was due to:

- the complex natural setting: nearshore zone with a high sediment input and strong sedimentation, presence of natural gas, small depressions;
- the complexity of the dumped material: both magnetic and non-magnetic;
- the complex evolution of the dump site: an early evolution (sagging of the dumped munition) and more recent evolution (dumping of dredged material and beach restoration works).

The magnetometric data confirmed the presence of different dump zones (G-Tec 1996):

- a central zone with several very large magnetic anomalies. Most likely this area represents the main part of the dumped material. The strong anomalies are separated by small, anomaly-free areas;
- a wide zone surrounding the central zone marked by a large number of anomalies, generally weaker. It is possible that some of these anomalies are not related to the dumped war material but have a different origin (e.g. small ship wrecks, iron objects).

A geometric model was created for a number of anomalies (Missiaen *et al.* 2001). The use of the vertical gradient of the magnetic field resulted in an important improvement of the horizontal resolution (Fig. 5). This made it easier to separate the different dumps and gave a more accurate position of the exact location of the different dumps.

Vertical gradient data also allowed a more accurate estimation of the actual burial depth of the dumped material (Missiaen *et al.* 2001). The obtained models indicated that in the central zone the munition is completely buried by more than two meters of sediment. Dredging operations carried out in 1988 seem to confirm this recent burial: only one time an obstacle was encountered in the dump area.

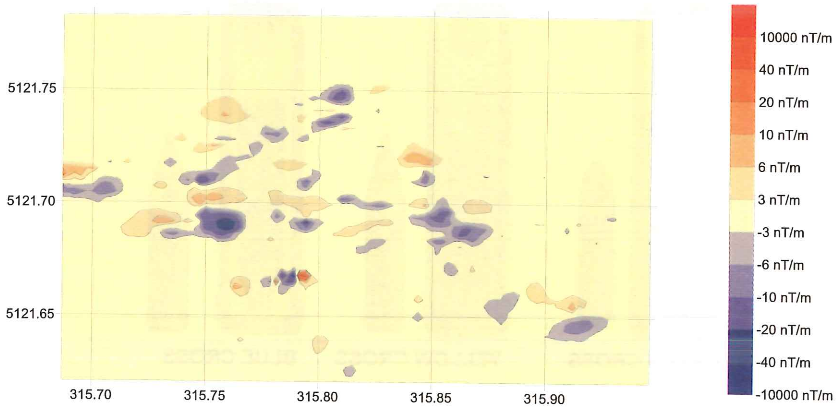

Fig. 5. Vertical gradient of the magnetic field in the central part of the dump site.

A number of side-scan anomalies were observed in the extreme SE corner of the dump site (Magelas 1996). However these could not be related directly to the magnetic anomalies, suggesting that the latter were due to buried objects. The side-scan anomalies were possibly caused by wooden ship wrecks or dumped rubble related to the construction of nearby breakwaters.

Over 70 sediment cores and water samples were taken at the site by Navy divers. The sampling locations were chosen based on the results of the geophysical investigations. The sediment cores were 50 cm long and 6 cm in diameter. Water samples were taken 1.5 m above the sea floor, at the same location as the sediment cores. In most cores samples were taken from the top and the bottom of the sediment core (Biorgan 1997).

Analysis included general organic screening and specific screening for Yperite and its main breakdown product thiodiglycol (TDG). None of the analysed water samples showed any contamination. The sediment samples did not indicate contamination except for one sample in the extreme southeast showing a low concentration of Yperite. Additional sampling in the vicinity of this point could however not confirm this.

Sediment dynamics

The Paardenmarkt dump site forms part of a shoal extending from the harbour of Zeebrugge to the Belgian-Dutch border. The site has a hydrodynamically sheltered position adjacent to the harbour jetties (tidal currents up to 1.5 m/s). The sea bottom slopes gently towards the NE and varies between 5.5 m MLLWS (mean lowest low water at spring tide) in the north and 1.5 m in the southwest corner forming a sediment wedge (Fig. 6 - top).

The surficial sediments in the area are generally very fine to fine sands with a strong enrichment of mud (Charlet 2001). They are marked by the presence of biogenic (methane) gas, most likely related to the presence of a thin peat-rich layer. Seismic data suggest a low concentration of gas, probably less than 1 % (Missiaen *et al.* 2002).

The munition dump site is located in a turbidity maximum area hydraulically trapping the muddy deposits. Residual transport directions indicate a coast-ward transport near the dump site. Towards the east the ebb tidal current seems to induce an important bedload transport likely enhanced by the outflow of the Westerschelde (Charlet 2001).

Topographic analysis has indicated that prior to the development of the Zeebrugge outer harbour in 1976 periods of erosion alternated with periods of sedimentation, resulting in important changes in seafloor morphology. Still the sediment volume at the dump site in 1976 was nearly similar to that observed in 1954. Between '54 and '76 a section of the dump site was subject to erosion. This explains the munition observed on the sea floor in 1972.

The extension of the Zeebrugge harbour induced an explicit sedimentation at the dump site and an erosion zone NW of the site. The sediment increase is not spread evenly across the entire site. Fig. 6 clearly shows that the increase is greatest in the southwest corner (up to 4 m), gradually decreasing towards the north. The most recent data seem to suggest a slow migration of the erosion zone towards the east and a trend towards stagnation in the sedimentation/erosion process. However, further verification is still needed.

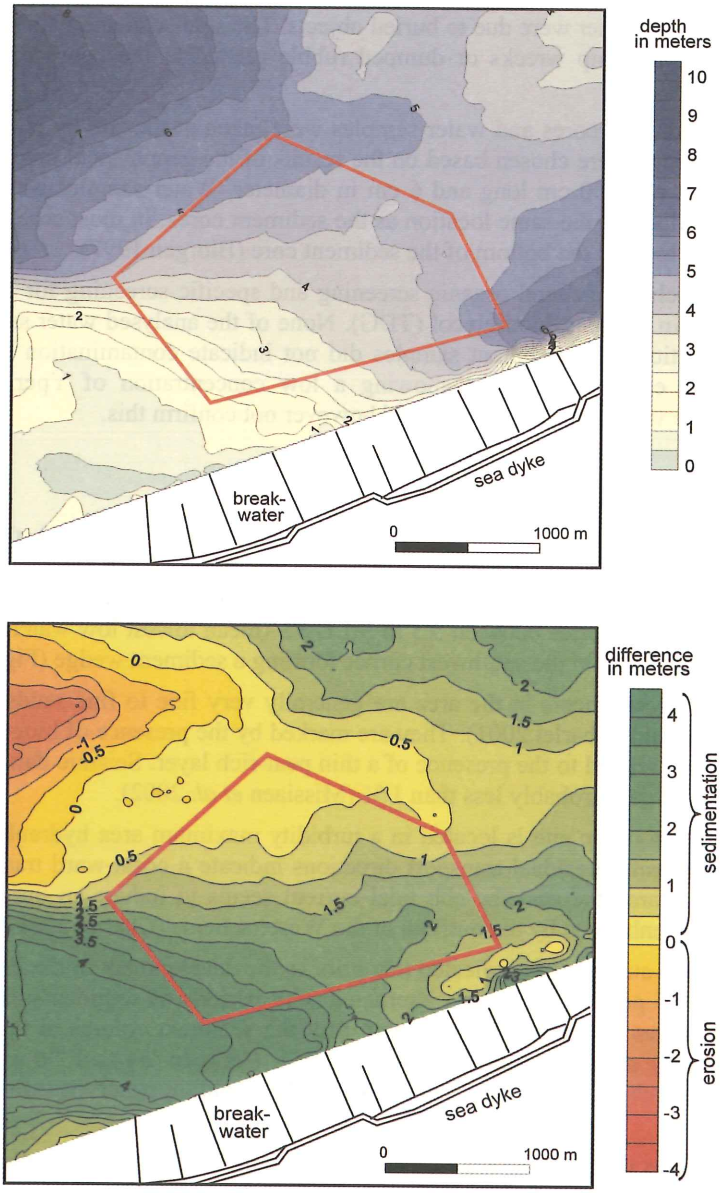

Fig. 6. Top: bathymetric map of the study area based on sounding from 1996. Bottom: difference map between soundings carried out in 1954 and 1996. The red pentagon marks the location of the munition dump site.

Ecological value of the dump area

The infaunal communities found along the eastern part of the Belgian coast (Oostende to the Dutch border) are poorer in species than those on the western part (Cattrijsse & Vincx 2001). The latter is not only due to the sedimentological heterogeneity of the western coast, but also to the pollution and the deposition of fine sediments by the Westerschelde (Vincx & Herman 1989). Also the dredge disposal activities along the eastern Belgian coast have a negative influence on the richness of the benthos species.

In September 2000, 24 stations located NW of the munition dump site were sampled for the macrobenthos using a Van Veen grab. At 63 % of the stations macrobenthos was completely absent. If macrobenthos was present, densities never exceeded 233 ind./m^2, with an average density of 62 ind./m^2. The bivalve *Abra alba*, present in 78 % of the samples with macrobenthos present, was the most abundant species. This impoverishment is not due to the presence of chemical munition but is most likely caused by the high mud content of the sediment, which is known to drastically decrease the density and diversity (Degraer *et al.* 1999c).

Some twenty bird species are regularly found at the dump site, another ten species only occasionally (mainly as migrants). The area is poor in species in autumn and winter with only gulls present in reasonable, though relatively small numbers. The major ornithological value seems to be its function as a feeding area for terns breeding in the outer harbour of Zeebrugge and at the "Baai van Heist" nature reserve, a protected beach east of the harbour. Maximal numbers of breeding Little Terns at Zeebrugge amounted to 425 pairs, i.e. 2.5 % of the biogeographical population of this highly threatened species.

The most important fish stocks in the area include flatfish (plaice, sole and dab), shrimp, and to a lesser extent whiting and cod. Commercial fishing in the munition dump area is relatively limited, and mostly involves small boats, often fishing for shrimps (large fishing vessels usually operate further offshore).

Toxic agent behaviour and ecotoxicological aspects

The (long-term) behaviour of the munition-related toxic compounds is not only determined by their physico-chemical characteristics, but also depends on external factors such as temperature, pH, salinity, physical surroundings, etc.

Already in the shell the toxic agent can be degraded. This process will depend on the physical stability of the agent, its chemical purity, and the corrosive action. For instance phosgene has no significant corrosive action when pure, but when hydrolysed it produces HCl which enhances corrosion. Diphosgene is unstable in anything but glass; most metals will catalyse diphosgene in phosgene. Clark compounds have no significant corrosive action with metals when dry, and they are very stable in pure form. Yperite has little corrosive action; it is very stable in steel or aluminium.

Once the munition has corroded and the agent is released into the marine environment the detoxification rate will largely be governed by the agent's behaviour in water (this is most likely also the case for buried munition because shallow marine sediments will be largely saturated by water). The most important factor will be the solubility of the agent in water. The latter will largely depend on the water temperature, pH, oxygen content, and current velocity.

Most chemical compounds (including phosgene, diphosgene and chloropicrin) are marked by a relative fast hydrolysis. Therefore, and also due to the large dilution involved, these compounds will most likely not pose a large threat to the marine environment. The main threats seem to be related to the presence of Clark, Yperite, TNT and heavy metals.

Clark

Clark I (diphenyl arsine chloride) and Clark II (diphenyl arsine cyanide) are highly toxic compounds. Finely divided they will hydrolyse rather quickly, in larger quantities however they will hydrolyse very slowly. They will decompose into the equally toxic tetra-phenyldiarsine oxide and HCl or HCN respectively.

Both Clark I and II and their breakdown product tetra-phenyldiarsine oxide can persist in sea water for months before being degraded to inorganic arsenic. Clark compounds are also known to adsorb easily onto sediments, and therefore form a potential risk to marine organisms living on or near the sea floor.

Yperite

Yperite will dissolve extremely slow. Once dissolved, however, it will hydrolyse relative rapidly into primarily thiodiglycol (TDG) and HCl. The solubility process is the determining factor in the degradation of Yperite. It will depend on a variety of external factors including temperature and water turbulence.

In still water a concentrated TDG layer will build up at the Yperite-water interface acting as a protective coating. As a result the agent can remain unaffected for a long time (even decades). If the water is subject to disturbance (currents, sand grating) the protective coating is likely to form less easily.

Yperite exposed on the sea floor will exist as a viscous liquid or solid. Small drops will tend to dissolve, but larger lumps can survive for a very long period (decades or longer). The contamination radius is likely to be local: studies have indicated that for a lump of 1 kg the Yperite concentration in sea water reaches the non-toxic level at maximum 14 cm from the source (MEDEA 1997).

In the case of buried shells the volume of sediment that will be affected by a release of Yperite will most likely be very small. The main threat therefore seems to be related to the direct contact of organisms with lumps of Yperite. The magnitude of this effect is a function of the probability of such contact and the injury that results.

TNT

TNT is known to break down very slowly in water, but once dissolved it will decompose easily. In the absence of oxygen TNT may break down rapidly. Some of its breakdown products (such as DNT) are also highly toxic. DNT dissolves more easily in water than TNT, but this effect will decrease for lower temperatures. DNT also has a tendency to adsorb onto sediment. Studies in The Netherlands indicate that DNT may be subject to biological degradation (van Ham *et al.* 2000). It seems unlikely that high concentrations of TNT or DNT may be expected at or near the dump site.

Heavy metals

Heavy metals do not degrade, and adsorb easily onto sediments and suspended matter in the water column. Therefore they could form a long-lasting environmental burden. Studies of conventional munition dump sites in the Netherlands have shown a clear increase in the concentration of nickel, copper and zinc (van Ham *et al.* 2000). Peak concentrations can therefore not be excluded in the vicinity of the munition. Due to the high dilution involved the encountered concentrations in the water column are expected to be low.

Risks related to the munition dump site

Corrosion and agent leakage

Most likely the munition is not yet too heavily corroded. The oxygen-poor conditions related to the presence of biogenic gas in the muddy sediments are expected to slow down the corrosion process. It could take hundreds of years, possibly 1000 years, before all of the munition has corroded completely.

But even a slow corrosion process cannot prevent long-term leakage of the toxic agents. Upon corrosion the chemical compounds will most likely be released very slowly. Peak concentrations may happen in case of mechanical disturbance (anchoring, fishing, recovery operations).

The release of Clark compounds may cause long-lasting contamination of the sediments, threatening the organisms living near or in the bottom. In general the threat will be relatively local and therefore rather limited, although a larger contamination radius is possible through sea-floor erosion.

Yperite is expected to largely remain in the shell after corrosion of the munition. However, due to mechanical disturbance lumps may be released, which could possibly reach the shore.

Accidents

Because the munition seems to be largely buried at this moment, the chance for shells to wash ashore is therefore very small. Nevertheless this cannot be excluded completely.

The Paardenmarkt dump site is located near one of the busiest harbours of NW Europe, in the vicinity of main shipping routes. The risk of shipping disasters (e.g. during severe storms) has to be considered. Indeed accidents with stranded ships on the beach have been known to occur over the last years in Belgium (Fig. 7).

Attention should also be paid to the long-term effects of global warming and sea-level rise. Global warming will enhance the storm frequency, thus increasing the risk for shipping disasters. Sea-level rise could result in salt water intrusion due to an induced groundwater flux from sea to land, causing a long-term effect on enhanced pollutants pathways (Van Meir 2001*)*.

Fig. 7. *A German container ship stranded on the beach near Blankenberge in November 2001, just a few miles off the Paardenmarkt dump site.*

Detonation

Recent studies carried out by TNO suggest that the risk for spontaneous ignition is very small (Van Ham 2002). However there may still be a slight chance that intact shells, especially larger calibres, could react under severe mechanical stress (such as due to grabbing, dredging or vessel grounding).

Fish contamination

The contamination of fish seems mainly related to arsenic. Fish feeding on sea-floor organisms are likely to have a greater increase in arsenic in their bodies. However under the present conditions (sediment cover, relatively intact shells, poor infauna) the changes for such increase are very small.

Studies have also shown that approximately 99 % of the arsenic in fish would be in organic form that is not carcinogenic (Goldman & Dacre 1989). Organic arsenic is not converted to inorganic forms by humans and is excreted unchanged in form. The present threat to human health related to the consumption of arsenic-contaminated fish is therefore likely to be almost negligible.

Future policy

At this moment a large number of factors remain unknown. Correct evaluation of the munition dump site and the risks involved requires additional in-situ measurements and monitoring. In order to evaluate the actual condition of the munition and their state of corrosion, it is necessary to recover a (representative) number of shells. The recovered munition can be used to model the degradation process.

Regular geochemical sampling is indispensable. The analysis of water and soil samples can give information on the actual state of potential leakage and detoxification processes. Specific screening should be done for munition-related heavy metals, TNT, Yperite, Clark, and their respective breakdown products. Samples should also be taken in the surrounding area for reference. Bioaccumulation of chemical compounds in benthic invertebrates can be used as an additional monitoring tool for munition leakage.

Sea-bed monitoring is crucial to map the erosion/accumulation processes and detect possible objects on the sea floor. Particular attention should be paid to the erosion zone NW of the dump site. Additional in-depth monitoring is needed to map the internal structure of the dump site and its evolution.

One of the main problems of the Paardenmarkt is its close proximity to the coast. Therefore it may be useful to keep a chemical watch (e.g. chemical sensors) between the dump site and the beach as a basic safety measure.

Together with the in-situ measurements and monitoring further fundamental research is needed. For example very little is known about the dynamical behaviour (pollutant release processes and transport pathways) of toxic agents in the marine sediments, and the influence of changing hydrodynamic controls and depositional or erosional fluxes on these processes.

More research is also needed to accurately estimate the short- and long-term ecotoxicological threat of the agents, the chronic and sub-lethal effects on the marine environment and toxicological effects of organisms living and feeding on the sediment. The latter is currently the subject of research performed in Sweden (Waleij 2002); the results of these studies could be of importance for the Paardenmarkt.

Technological developments are equally important. Up to recently, geophysical investigations of marine dump sites have been carried out independently. The use of combined and integrated geophysical techniques can provide an important improvement in high-resolution detection and localisation of dumped munition.

At this moment there do not seem to be strong indications for immediate danger. The best option therefore seems to be to leave the dump site untouched - under the condition of regular monitoring. The latter is needed to track the evolution of the site and to detect any possible hazards in the future.

Recovery of the dumped munition is in theory the only way to solve the problem at heart. However this will be a costly and highly risky operation, and may cause the release of unverifiable amounts of toxic compounds into the environment. Moreover, it requires an extensive dismantling capacity, and adequate transport. Recovery is therefore not considered to be the best solution.

Possible engineering options

If monitoring would indicate the possible surfacing of munition (e.g. due to erosion of the sediment cover), or in the case of present danger, the option to cover the dump site may be considered. The construction of an artificial island offers major opportunities as a nesting and feeding site for terns, gulls and plovers (which are now doomed to disappear due to increasing harbour development) and a roosting site for seals.

In order to construct an artificial island used as possible breeding place the site must be filled up to a level of Z+6.50 m. A "horseshoe" structure seems preferable: 3 sides formed by a rubble mound structure, 2 sides by a sand slope (Fig. 8). Still, the construction of an island does not totally solve the long-term environmental threat of the leaking agents, and monitoring will therefore still be needed.

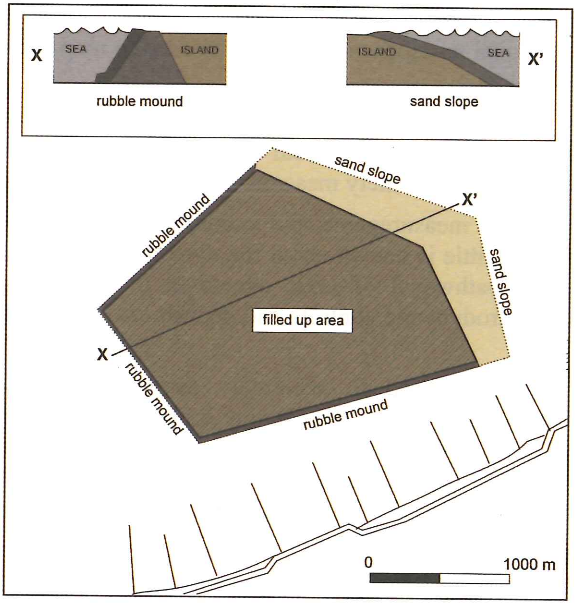

Fig. 8. Schematic overview of an artificial island covering the munition dump site (not on scale).

Acknowledgements

In total 8 research teams were involved in this study : Renard Centre of Marine Geology - Gent University, Magelas, G-Tec, TNO - Prins Maurits Laboratory, Cerege - University of Aix-Marseille, Marine Biology Department - Gent University, Civil Engineering Department - Gent University, and the Institute of Nature Conservation.

The authors would furthermore like to express their sincere gratitude to the following persons and institutions for their advise in the course of this project: André Cattrijsse, Brigitte Lauwaert, Michiel Maertens, Herbert De Bisschop, Belgische Zeemacht, DOVO-Poelkapelle, Afdeling Waterwegen Kust, Waterbouwkundig Laboratorium Borgerhout, Baggerwerken Decloedt & Zoon.

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Investigations of risks connected to sea-dumped munitions

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Abstract - Investigations have been carried out on conventional munition in the Netherlands, dumped in the North Sea and the Oosterschelde. After World War II a large amount of munition was dumped into the sea to mitigate the explosion risk. Today it is recognised that there are a large number of toxic compounds present in conventional munitions. Due to the corrosion by sea water the munition will lose its contents. This article will give a general outline of the toxic components present and how these toxic components can leak into the environment. A description of the possible reactions with sea water is given, as well as chemical decomposition or biological degradation from the components.

Introduction

At the end of World War II large areas of Europe were covered with munitions. The munition partly consisted of unexploded ordnance or so-called duds. As the latter formed a direct threat to the population, a tremendous effort to clean up the European countries was organised. Thousands and thousands of munition experts investigated the munitions. Main objective of this huge operation was to identify the duds and to neutralise them. The latter was realised by sympathetic detonation, using demolition explosives (mainly plastic explosives) that are carefully attached to the munitions and subsequently detonated from a safe distance. This is a time consuming and dangerous operation.

An even larger amount of the munition consisted of munition stockpiles that were left behind on the battlefields. These munitions were in principle safe for transportation, but as the numbers involved were extremely high it was almost impossible to detonate them. The main solution at that time was considered to be sea dumping. Massive amounts of munitions were dumped, mainly in the Baltic Sea, after World War II. In the Netherlands 90,000 tons of conventional munition was dumped into the sea.

Another important reason for sea dumping was to eliminate munitions filled with chemical warfare agents.

The dumping operation was realised in several ways. The munitions were transported to the dumpsite by ship. Upon arrival at the dumping location, the munitions were thrown overboard. In many cases, especially concerning chemical warfare munitions, a ship loaded with these munitions was sunk entirely at the dump site. In the first situation a large spreading of the munitions has been realised. In the case of sunken ships, the munitions are packed closely together in the wreck.

This article presents the results of investigations carried out in Netherlands on conventional munitions, dumped in the North Sea and the Oosterschelde. It will give a general outline of the toxic components present in the munitions and possible scenario's of leakage into the environment. A description of the possible reactions of these toxic components will be given, as well as chemical decomposition or biological degradation from the components.

Possible scenario's for the future include :

- No action, except from careful monitoring planning
- Recovery of dumped munitions followed by disposal
- Isolation of the dumping site

Munition components

Conventional munitions consist of metal containers filled with explosives, propellants and pyrotechnics. Fig. 1 depicts a 40-mm round, which includes most of the different components.

In some munitions white phosphorus is used for the purpose of generating smoke and fire. In chemical warfare munitions, the general structure of the munition is identical to the white phosphorus munition. Fig. 2 depicts the construction of a white phosphorus round.

The metal parts make up most of the total weight (70 %), followed by the propellants (16 %), explosives (11 %) and pyrotechnics (2.8 %) (Table 1).

Table 1. *General composition of conventional munitions.*

component	**Weight %**
Metal parts	70
Propellants	16
Explosives	11
Pyrotechnics	3

The metal parts mainly consist of the following metals as depicted in Table 2 :

Table 2. *Most common metals used in munitions.*

Component	**Weight %**
Iron / steel	76
Lead	12
Brass (Copper / Zinc)	9
Aluminium	3

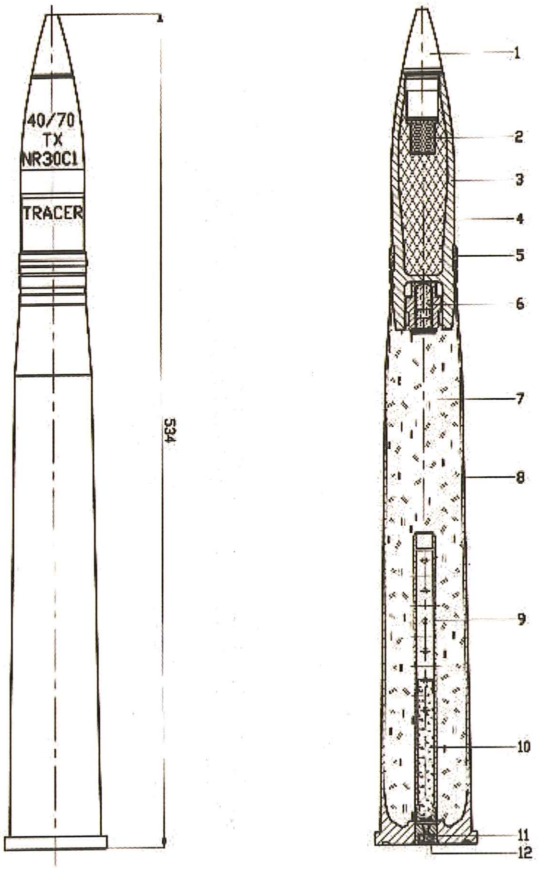

Fig. 1. *Construction of 40 mm round. (1) Fuse containing impact detonator, safety and arming mechanism, and lead; (2) Booster; (3) Shell body (steel) ; (4) High explosive (RDX / Al) ; (5) Rotating band (copper); (6) Tracer* ($Sr(NO_3)_2$ */ Mg) ; (7) Propellant ; (8) Cartridge case (brass) ; (9) Centre core igniter body (brass) ; (10) Black powder ; (11) Igniter composition ; (12) Igniter cap.*

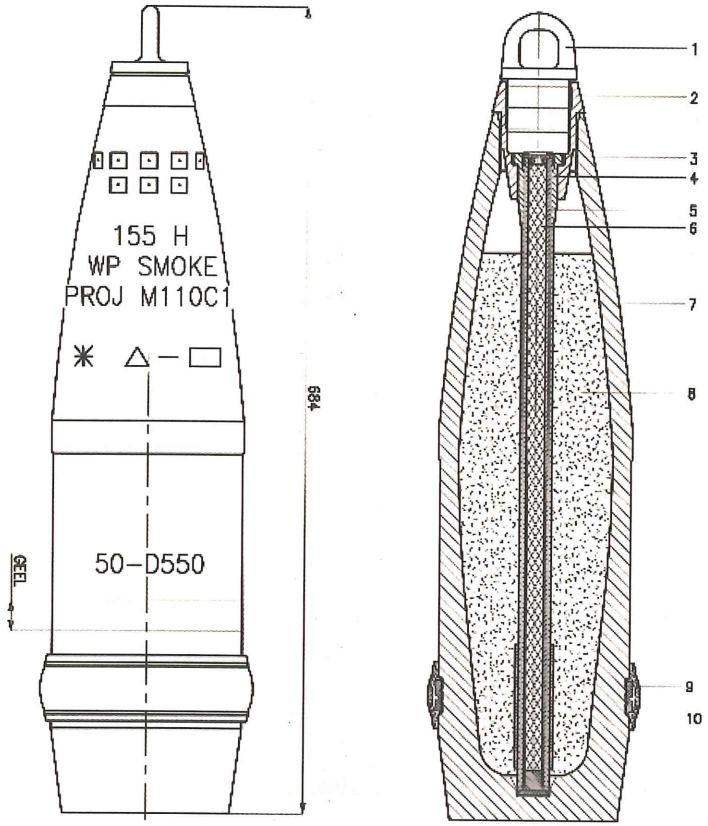

Fig. 2. *Construction of white phosphorus round. (1) Transportation screw (to be replaced by fuse); (2) Booster holder; (3) Lock nut ; (4) Burster charge holder ; (5) Central burster ; (6) Tetryl bursting charge; (7) Shell body (steel) ; (8) White phosphorus; (9) Gas seal ; (10) Protector for gas seal.*

The explosives mainly consist of the following compounds as given in Table 3:

Table 3. *Most common explosives used in munitions.*

Component	Weight %
TNT	90
RDX	5
Tetryl	3
PETN	2

Propellants consist of a matrix of nitro-cellulose filled with other energetic components such as dinitrotoluene, trinitrotoluene, nitro-glycerine, plastisizers (e.g. Dibutylphtalate), stabilisers like ethylcentralite or diphenylamine. Table 4 gives the general composition for a propellant:

Table 4. *General composition for propellant.*

Component	Weight %
Nitro-cellulose	70
Nitroglycerine	15
Diphenylamine	1
Dinitrotoluene	10
Potassiumsulfate	1
Dibutylphtalate	3

Pyrotechnics are a broad assembly of special effects used in munitions like smoke, incendiary, ignition, and sound effects. Most of the components are of inorganic nature, as can be noticed from the general composition in Table 5:

Table 5. *General pyrotechnic composition (only those components that might be an environmental burden are listed).*

Component	Weight %
Zincoxide	35
Bariumnitrate	5
Strontiumnitrate	3
Aluminium	11
Lead	1
Hexachloroethane	35

General composition of 1000 kg of various munitions

Based on the previous information it is possible to generate a list of different components present in 1000 kg of conventional munitions. This is depicted in Table 6 :

Table 6. *General composition of 1000 kg munition.*

Component	**Weight / kg**
Steel	532
Lead	84
Brass	63
Aluminium	25
Nitro-glycerine	25
Nitro-cellulose	112
Diphenylamine	1,6
Dinitrotoluene	**15,7**
Dibutylphtalate	4,7
Trinitrotoluene	**99**
RDX	5,5
Tetryl	3,3
PETN	2,2
Hexachloroethane	9,8
Zincoxide	9,8
Bariumnitrate	1,4
Strontiumnitrate	0,84
White Phosphorus	1,0

Other munition components will be present in small amounts. For the evaluation of the environmental impact these components will be neglected. From this list it is obvious that dinitrotoluene and trinitrotoluene have to be monitored as potential hazardous chemicals. Furthermore the large amount of metals such as copper, zinc, lead and aluminium also might cause environmental problems.

Corrosion of munitions by sea water

From the very moment the munitions are in contact with sea water the corrosion processes of the metal casing will start. The reaction rate of this process depends on the temperature of the water, the percentage of oxygen in the water, the quality of the steel and the current velocity at the dump side. A strong water current guaranties the presence of water saturated with oxygen. Sand particles that are dragged in the current will contribute to the degradation process by mechanical erosion.

Munition shells that are made from steel containing a high percentage of carbon are subject to high corrosion rates. The presence of different types of metals, e.g. a copper fuse on a steel shell body, or a brass burster charge in a steel body, causes contact corrosion.

TNO has investigated munitions that were dumped at sea in the period 1946 - 1967. These munitions exhibits strong corrosion, as can be clearly seen on Figs. 3 to 7.

Fig. 3. *Recovered anti-tank rounds. The corrosion already removed parts of the metal casing.*

Fig. 4. *Recovered 38 mm rounds. Contact corrosion between fuse and shell body is clearly visible.*

Fig. 5. *Recovered 60-mm mortar rounds. Part of the explosive payload is already dissolved in the water. The steel cases are strongly attacked by the sea water; sometimes only a carbon skeleton remains, that could be pulverised easily.*

Fig. 6. *Recovered 4,2-inch mortar rounds filled with white phosphorus. These rounds were leaking white phosphorus because of contact corrosion between the burster and the steel body.*

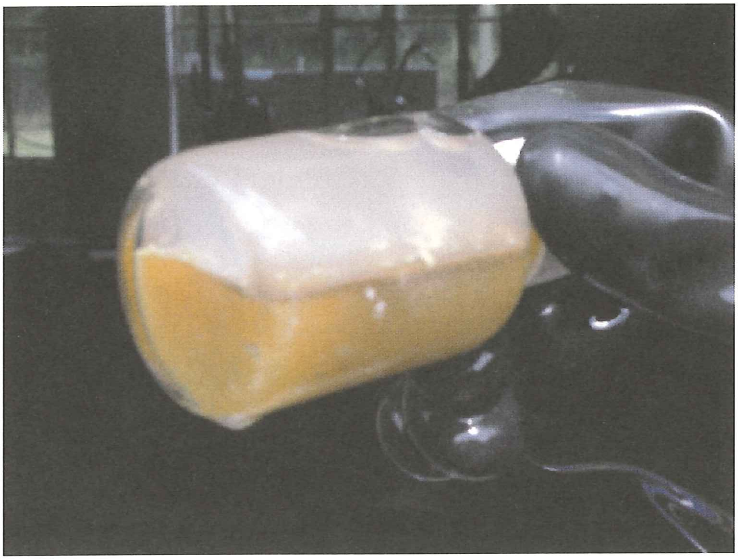

***Fig.** 7. White phosphorus from 4,2 inch mortar rounds.*

The general picture that emerged from the TNO investigation is that munitions will be degraded by the influence of the sea water. The time frame for this process strongly depends on the parameters mentioned above. This might happen after a period of 10 years, but it can also take hundreds of years if munitions are covered with a layer of oxygen-poor mud (as is the case for the Paardenmarkt site off the Belgian coast). The chemical compounds that are present in the munitions will subsequently be dissolved in the sea water. The corresponding concentration of hazardous chemicals leaking from munitions will generate Fig. 8.

The dissolved organic chemicals are subjected to chemical decomposition and biodegradation. This happens with TNT and DNT. Trinitrotoluene (TNT) decomposes under the influence of light and oxygen (Burlington, Kaplan *et al.* 1987). Further biodegradation will occur to 2- and 4-Amine Dinitrotoluene (DNT).

Inorganic contaminants such as heavy metals are not vulnerable for this mechanism and may contribute for a long lasting environmental burden. In general the concentrations are rather low due to the dilution in the sea water.

Chemical warfare agents react with water quite differently. Some of the chemical agents like phosgene and Tabun will hydrolyse rather quickly and degrade to non-hazardous compounds.

Arsenic compounds such as Lewisite, Adamsite, and Clark I/II will decompose into arsenic oxides that will be a permanent environmental burden. Only the danger of the original chemical warfare agent will be neutralised.

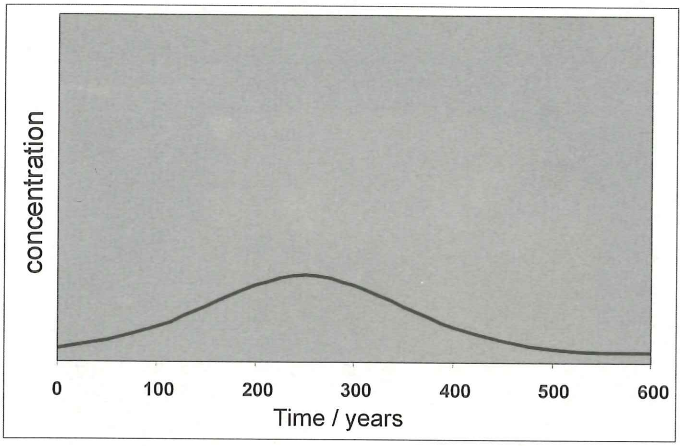

Fig. 8. *Concentration / Time profile for chemicals leaking from munitions.*

Mustard gas exhibits a rather unpredictable behaviour. The chemical compound will react with water: the dominant hydrolysis reaction is the formation of a sulfonium ion, followed by the swapping of chlorine and hydroxyl to give hemimustard and dissociated hydrogen chloride.

The hemimustard is a blister agent in its own right. The result is thiodiglycol and another dissociated hydrogen chloride molecule. Some of the hemimustard undergoes another final step in which an internal displacement gives 1,4-thioxane instead of thiodiglycol.

Sulphur mustard hydrolysis in sea water is about two to three times slower than in fresh water because the chloride ions in sea water affect the mustard - sulfonium equilibrium. Bulk Sulphur mustard is more stable in a wet environment than the hydrolysis data would indicate. The reasons for this are that Sulphur mustard is not very soluble in water, and also that some reactions take place at the mustard - water interface that slow down the mixing and the hydrolysis.

In turn, the sesquimustard may form sulfonium ions that react with water, mustard, thiodiglycol or sesquimustard molecules, forming higher homologues of sulfonium salts. The sulfonium salts widen the boundary layer and make it less reactive, thus slowing down the diffusion of water and mustard molecules. The result is that bulk mustard may be persistent in a wet environment for decades.

These effects may be pronounced under stagnant conditions, as in soil or in storage at the ocean floor. If the water is flowing, Sulphur mustard droplets will not persist for significant periods, since the water motion will not permit the formation of thick boundary layers.

Monitoring of dumping sites

In order to evaluate the actual environmental risk related to a munition dump site it is necessary to take a representative number of samples from the soil and the water directly above the soil at the dump site. For comparison it is mandatory to take samples at (geological) identical locations, but far enough from the pollution source, to measure the "natural" background of the pollutants. The water samples can be taken by means of containers that are opened remotely when they are at the correct location. The soil samples can be taken with the aid of a so-called "Van Veen Grabber".

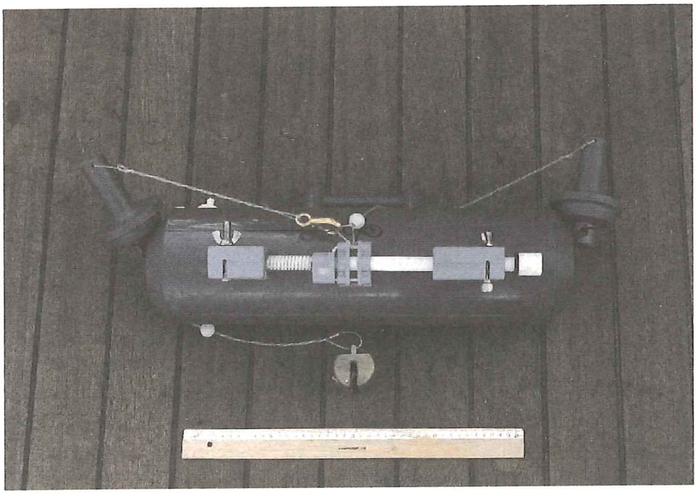

Fig. 9. Apparatus for water sample taking. Sample sizes 2-3 litres of water.

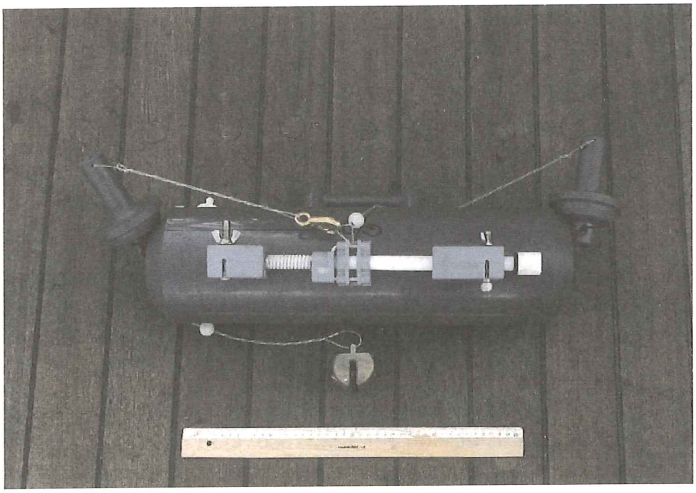

Fig. 10. Van Veen grabber to take samples from sea bottom / soil. Sample size ~1 kg.

The analysis of these water and soil samples gives an answer to the question which phase of the leakage and degeneration process has been reached (see Fig. 8). Will there be an increase to dangerous concentrations of leaking chemicals. Will the concentration remain stable over the years or will there be a decrease in concentration, indicating that we have reached the final stage of the leakage process.

In order to investigate the state of the munitions itself, it will be necessary to recover a representative number of shells. This can be realised by Navy divers, for munitions dumped in water up to a depth of 50 m. For depths greater than 50 m, the munitions have to be recovered by means of a so-called ROV (Remotely Operated Vehicle). This is a miniature submarine, equipped with underwater camera and manipulators. Another possibility is the use of electric magnets.

The recovered munitions can be studied for degradation phenomena and further modelling of the corrosion process.

Possibilities for reducing the environmental risks of sea-dumped munitions

The question remains what to do with sea-dumped munitions? Three scenario's will be discussed: no action, recovery, and isolation.

No action

When the munitions are leaking their chemical contents into the environment, the latter will be diluted by very large amounts of sea water. The resulting low concentrations of chemicals are subject to chemical decomposition and biological degradation. Calculations for the situation in the Netherlands resulted in concentrations of munition related components below ppb level. Nature can handle even hazardous chemicals in low concentrations. For example, chlorinated hydrocarbons are broken down, as was investigated by TNO (van Heiningen *et al.* 1999; Langenhoff *et al.* 1999; Bosma, Van Aalst-van Leeuwen, Gerritse & Van Heiningen 1998; Rijnaarts, Van Aalst-van Leeuwen, Van Heiningen *et al.* 1998).

It will be of the utmost importance to monitor the chemicals that may leak from the munitions. An adequate number of samples has to be taken at the dump sites, typically 10-20 water and soil samples need to be taken per square km. Sampling should be done every 2 years. In case the concentration is increasing, more frequent sampling is necessary.

Recovery

The recovery of munitions from dump sites is a high cost - high risk operation. Mechanical forces may induce a reaction of the munitions, leading to damage or even casualties. The handling of corroded munitions may cause the release of large quantities of toxic compounds.

In principle, however, recovery will be the only action that can actually solve the problem and reduce the risks. It is obvious that the recovered munition must be handled in a special disposal facility according to the present environmental standards.

Isolation

This implies the prevention of diffusion from chemicals from the dump site into the environment. It is possible to build an isolating screen around the site e.g by using steel or other construction materials. The top of the site can also be covered by concrete, sand, clay or other building materials. In this way it might even be possible to create an artificial island.

However this is also a highly costly operation. The short-term advantage is obvious: lower concentration of chemicals coming from the site. The main disadvantage is the long-term threat, because of the longer life time of the munitions. (Conventional munitions are always a threat to the surroundings because of the potential explosion risk. These explosions will damage the protective layer, the toxic content will subsequently leak into the environment. The explosion risk remains imminent as long as the explosive parts are not degraded by the sea water.)

Conclusions

Both conventional and chemical sea-dumped munitions form a long-term threat to the environment. Depending on the site characteristics, location, type of munitions, and quantity of munitions, specific actions may be necessary such as recovery of the munitions or isolation of the site. If no immediate action seems necessary at the moment, frequent monitoring will be mandatory to assure the safety of the environment and the public.

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Chemical munitions in the Baltic Sea

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Abstract - According to current information about 40,000 tons of chemical munitions (ca. 13,000 tons of warfare agents) were dumped in the Baltic Sea in the areas south of the Little Belt, around Bornholm and south of Gotland. By far the greatest amount was dumped by order of the Allies. Based on current knowledge, the possibility that chemical munitions or residues of chemical warfare agents from the dumping grounds in the Baltic Sea might be washed ashore by currents can almost be ruled out. A wide-scale threat to the marine environment related to dissolved chemical warfare agents can most likely also be ruled out. There is a risk in the Bornholm Basin that chemical munition shells or lumps of viscous mustard gas can be caught in bottom trawl nets, hauled on board and thus cause contamination of the fishermen. All known cases of contamination to date were caused by viscous mustard gas. Risks to consumers from contaminated fish seem unlikely and have so far not been shown to exist.

Introduction

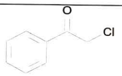
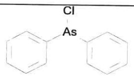
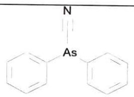
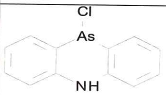
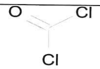
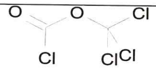
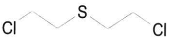
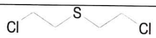
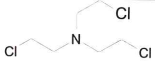
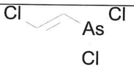
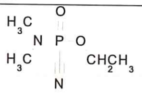
In the beginning of the 1090's expert groups in Denmark, Sweden and Germany prepared several national reports on dumped chemical munitions in the Baltic Sea. In addition, an ad-hoc working group was set up by the HELCOM Commission, which is the relevant commission dealing with the protection of the marine environment of the Baltic area. All these activities had the purpose to compile the information on the locations, quantities and types of chemical munitions dumped in the Baltic Sea, and to assess the situation and make recommendations for further action (Anon. 1993; HELCOM CHEMU 1994; Theobald & Rühl 1994; Theobald 1995).

The time seemed to be favourable for such an assessment because new sources from the former GDR (German Democratic Republic) became available, and it was hoped that because of glasnost information would be easier to get than in the years before. Based on these inquiries and expert opinions several reports have been produced. Both the national reports and the HELCOM report came to similar results, conclusions and recommendations; these - together with some new information obtained in the last years - will be presented here.

Properties of chemical warfare agents and the present condition of the dumped munitions

Table 1 gives an overview of the most important physico-chemical properties of warfare agents influencing their behaviour in the environment.

Table 1. Chemical and physico-chemical properties of warfare agents.

	Structure	Melting Point [°C]	Boiling Point [°C]	Density [g/cm^3]	log K$_{OW}$	Aqueous Solubility [g/l]
Tear Agents						
Chloracetophenone 2-Chloro-1-phenylethanone		54 - 56	244	1,32	~ 2,3*	1
Nose- and Throat Irritants						
Clark I Diphenylarsinchloride		38 - 44	307 - 333	1,422	2,5	2
Clark II Diphenylarsin-cyanide		30 - 35	290 - 346	1,45	2,5	2
Adamsite 10-Chloro-5-hydro-phenarsazine(10)		195	410	1,65	2,5 - 4,5 *	Neglig.
Lung Irritants						
Phosgene Carbon dichloride oxide		-128	7,6	3,4		9
Diphosgene Trichlormethyl chloro formate		- 57	127	1,65		
Blister Gases						
Mustard Gas 2,2′-Dichloro-diethyl-sulfide		14	228	1,27	1,36 - 2,73	0,8
Viscous mustard gas				1,3		Neglig.
N-Mustard gas 2,2′,2′′-Trichloro-triethylamine		-4	235	1,24	3,12	0,16
Lewisite Dichloro-(2-chlorovinyl)-arsane		-18	190	1,89		0,5
Nerve Gases						
Tabun P-Cyano-N,N-dimethyl-phosphonamide-ethylester		-50	246	1,07		120

The melting and boiling points show that most warfare agents are liquid or solid at 20°C; only phosgene is gaseous at temperatures above 8 °C. The term "poison gas" is thus misleading.

As the density values show, all compounds (with the exception of Tabun) are heavier than sea water and therefore do not float on the sea surface (like tar balls do). Some agents (Clark, Adamsite) are barely soluble and are at the same time slowly degradable. Thereby they can be rather persistent in the marine environment. The same is true for viscous mustard gas - a mixture of mustard gas (Yperite) and thickener. Mustard gas itself is easily degradable once it is dissolved in water. Tabun is the most toxic compound, it is well soluble in water and degrades rather fast. Phosgene is degraded spontaneously by water into CO_2 and HCl, so it poses no danger in sea water.

To summarise, many of the warfare agents are broken down in sea water at varying rates into less toxic, water-soluble substances. In the long term they pose no great threat to the marine environment as no higher concentrations are expected in the sea water.

However two groups should be observed more closely:

1. Viscous mustard gas can still be found in quite large, elastic lumps a long time after being released from shells. It can still prove an effective warfare agent when it is brought to the surface and comes into contact with the skin.
2. Clark I, II and Adamsite, compounds containing arsenic, can - because of their stability - persist in the marine environment over a long time and occur in locally elevated concentrations in the sediment. They do not, however, form lumps. Bioaccumulation is conceivable.

Chemical munitions

The chemical warfare agents in the Baltic Sea were mainly dumped in munitions, mostly in bombs and shells. In addition, part of the warfare agents were dumped in containers. The smaller munitions contained a few kg of warfare agent, the large ones up to 200 kg.

The munitions pose a threat only when the warfare agent inside is released. This can occur slowly as the walls of the shells corrode, or suddenly in an explosion (e.g. caused by mechanical stress during a recovery operation).

In view of the large number of parameters, theoretical considerations or calculations cannot be used to comment on the condition of the munitions in a particular dumping area. Investigations have shown that intact munitions as well as completely corroded shells no longer containing any warfare agents are both found.

Chemical warfare agents

In Table 2 the amount and type of chemical warfare agents are shown that were produced and developed during World War II in Germany (around 65,000 tons).

Mustard gas was the most widely produced agent, accounting for about 39 % of the total production, of which 20 % was converted into viscous mustard gas. Arsenic-containing compounds sum up to about 13,000 tons (20 %). Thus, about 1/3 of the agents are environmentally problematic.

Table 2. *Important chemical warfare agents produced in Germany between 1935 and 1945.*

Warfare agent	Quantity [t]
Chloroacetophenone	7100
Clark I	1500
Clark II	100
Adamsite	3900
Arsenic oil	7500
Phosgene	5900
Mustard gas	25000
Nitrogen mustard	2000
Tabun	12000

Dumping areas, quantities and types of dumped chemical warfare agents

The following amounts of chemical munitions and warfare agents were found, destroyed or recycled on German territory between the end of World War II and 1948 :

in the American occupation zone	93,995 tons
in the British occupation zone	122,508 tons
in the French occupation zone	9100 tons
in the Soviet occupation zone	62,505 tons
i.e. a total of	288,108 tons

On the orders of the British, French and American occupation authorities, about 130,000 tons of chemical munitions and warfare agents were sunk in the Skagerrak. The Soviet occupation authorities ordered dumping in the Baltic Sea only; in the Bornholm Basin and Gotland Basin about 34,000 tons of chemical munitions were sunk.

The map shown in Fig. 1 illustrates the known dumping areas for chemical munitions according to the present knowledge.

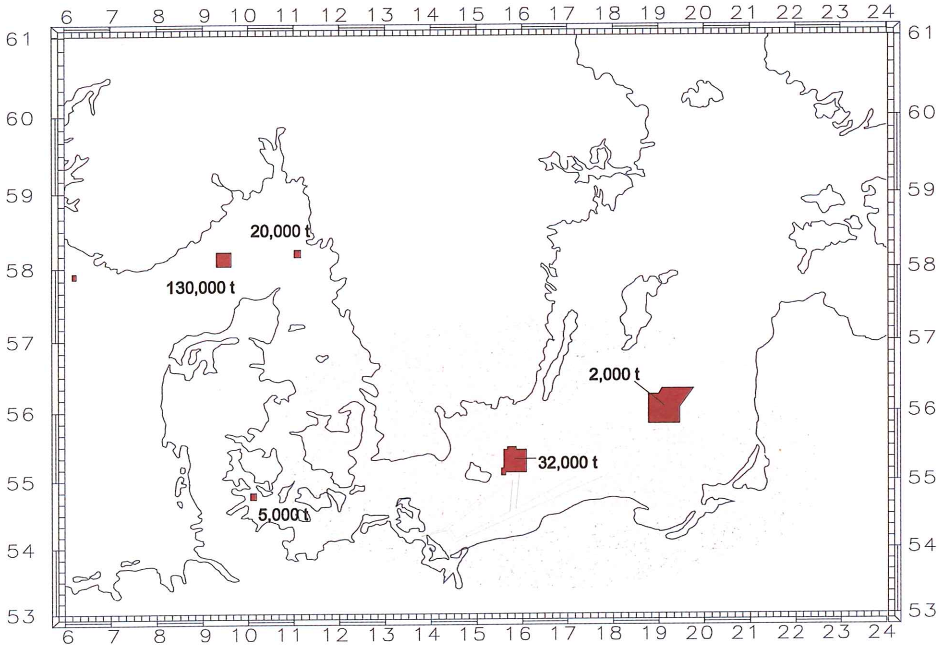


Fig. 1. Locations and amounts of dumped chemical munitions.

Little Belt

In the last days of the war, the German navy sank two ships containing about 69,000 Tabun shells and a further 5000 tons of chemical munitions (phosgene and Tabun) in the area south of the Little Belt. In 1959 and 1960, the Tabun shells were recovered from the ships, set in concrete blocks and dumped in the Bay of Biscay. Around 5000 tons of bombs and shells containing phosgene and Tabun were left in the area.

Gotland Area

In 1947, a total of 1500 to 2000 tons of chemical munitions was dumped in the area south of Gotland (west of Lipaya) on the orders of the Soviet military administration (SMAD). The dumped warfare contained almost 1000 tons (958 tons) of warfare agents; the composition is similar to that in the Bornholm area.

Because of the long distance between this dump area from the shipping harbour Wolgast, munitions were later transported only as far as the Bornholm area.

Bornholm Area

About 32,000 tons of chemical munitions were dumped east of Bornholm, containing about 11,000 tons of warfare agents (HELCOM 1994). The GDR dumped between 120 and 200 tons of chemical munitions.

According to Russian figures (Fig. 2), the munitions in the Bornholm Basin consist mainly of aircraft bombs (72 %). This is of some importance, as bombs contain larger amounts of warfare agents and have thinner walls than e.g. artillery shells.

Most of the munitions in the Bornholm Basin contain mustard gas (63 %) and to a lesser extent (31 %) warfare agents containing arsenic (arsenic oil, Clark, Adamsite) (Fig. 3).

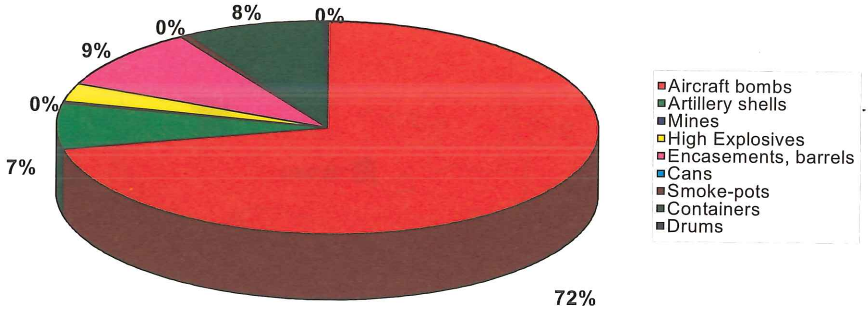


Fig. 2. *Types of chemical munition dumped in the Bornholm Basin (according to amounts of warfare agents).*

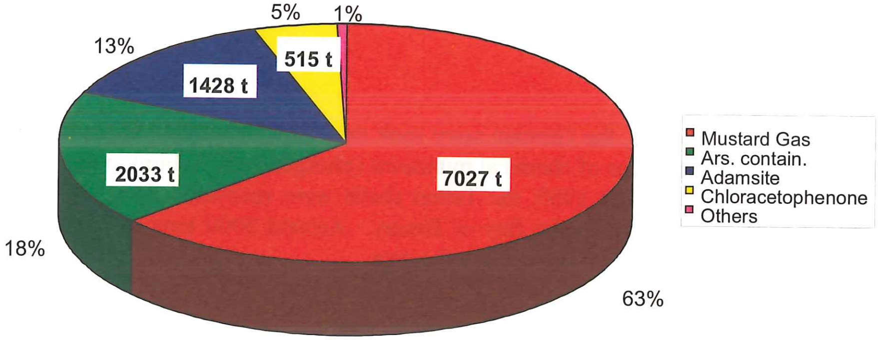


Fig. 3. *Amounts of Chemical Warfare Agents dumped in the Bornholm Basin.*

Based on munitions recovered from the bottom of Wolgast harbour, it cannot be ruled out that munitions containing Tabun were also dumped in the Bornholm Basin.

It is highly probable that chemical munitions were also dumped in the Baltic Sea outside the official dumping area east of Bornholm. Several witnesses report that when ships were en route to the dumping area from the ports of Wolgast and Peenemünde Nord, chemical munitions were cast overboard in poor weather or simply to save time long before the designated dumping area was reached. No details are available about the types or quantities of the dumped munitions.

In the 1990's several geophysical surveys were carried out in the transport route areas in order to detect dumped chemical munitions. The results are described in this volume (Schultz-Ohlberg, Lemke & Tauber).

Potential Danger

The main potential dangers related to the chemical munitions dumped in the Baltic Sea include the following:

- the threat to coastal areas from munitions and lumps of viscous mustard gas that are washed ashore;
- the threat to the marine environment from chemical warfare agents;
- the threat to crews of fishing vessels from munitions (bombs, shells) or lumps of viscous mustard gas caught in bottom trawl nets and hauled on board.

Threat to the coasts

All the warfare agents, except for Tabun, and all the chemical munitions are heavier than the sea water in the Baltic Sea. Near-bottom currents in the dumping areas are too weak to move the heavy munitions, which are mostly covered by mud, or to force them into upper layers of water. Lumps of viscous mustard gas which have a density of about 1,3 - 1,5 g/cm^3 are heavier than the sea water and will not be shifted far by the currents (the latter being weak, < 15 cm/sec, and moreover the lumps must be moved "uphill" in order to leave the Bornholm basin). The possibility that chemical munitions or lumps of viscous mustard gas can be washed ashore is thus extremely unlikely.

Conclusion: Based on findings to date, it can practically be ruled out that munitions or warfare agent residues from the dumping areas in the Baltic Sea can be washed ashore by currents. No supporting evidence has yet been presented.

Threat to the water, flora and fauna of the Baltic Sea

Corrosion of the chemical munitions over the past decades has led to the release of warfare agents into the marine environment. Depending on the rate of dissolution, solubility, rate of degradation and current conditions, different concentrations of liberated warfare agent can occur in the sea water.

In principle, when the warfare agent is released from its container, toxic concentrations can occur locally for a short time and organisms in the immediate vicinity can be damaged. The acute toxicity concentrations of mustard gas and nitrogen mustard were reported to be between 1 and 10 mg/l for algae, crustaceans and fish.

With the sparingly soluble warfare agents the maximum starting concentration will be around 100 mg/l (ppm), probably less.

Such a starting concentration is rapidly reduced in the sea due to dilution and degradative reactions. The possibility that a large body of water will contain toxic concentrations over a longer period of time is therefore small. It should also be borne in mind that the possibility of several shells rusting through simultaneously, and thereby releasing large quantities of poison into the marine environment, is also very small. When a shell corrodes, between 1 kg up to maximum 200 kg of warfare agent is released, with dissolution lasting between days and months.

In the case of readily soluble substances like phosgene and Tabun, the initial concentrations can be higher, but phosgene and Tabun are more easily degraded than the more sparingly soluble agents, and their concentrations fall below toxicity limits within a short time (minutes to days).

Viscous Mustard gas and the warfare agents containing arsenic, Clark and Adamsite, are relatively resistant and sparingly soluble. Thus elevated concentrations may occur in the sediment near corroded munitions but likely not in the water. Bioaccumulation in organisms is possible in theory, but has not yet been detected.

An additional problem in the case of warfare agents containing arsenic is that their products of hydrolysis still contain arsenic and so can still have toxic effects. The arsenic itself cannot be broken down and persists in the environment as an inorganic or organic compound. It must be borne in mind, however, that in relation to the surrounding water masses, the amounts of these warfare agents are very small and the natural arsenic content of the water and sediment is not significantly increased (although locally the arsenic content of the sediment near a corroded shell is likely to be higher).

Investigations by the BSH (Bundesamt für Seeschiffahrt und Hydrographie) in 1987 showed that the arsenic content of Baltic Sea water, including near-bottom water, does not exceed 1 μg/l (0,001 ppm) (unpublished report). Concentrations in the dumping areas were not higher than those measured elsewhere.

In order to investigate the concentration of warfare agents in the water phase and sediment, several studies have been performed in the close vicinity of dumped munitions. In the Little Belt and the Skagerrak areas no warfare agents were detected in the water, nor in the sediments. In the Bornholm area no warfare agents were observed in the water. However, in a few sediment samples Clark has been detected at the low ppm level.

Conclusion: Based on investigations and findings to date, a widespread risk to the marine environment from dissolved warfare agents seems to be ruled out. Elevated levels of Clark, Adamsite or viscous mustard gas may however occur in the sediment in the immediate vicinity of dumped munitions. Because of the limited extent of the agents and in view of the immobility of the sediment (compared to water), however, no threat is posed to marine flora and fauna according to current information. No detrimental effects on the marine environment due to warfare agents are yet known.

Threat to fisheries

Although the dumping areas are marked on nautical charts they are still used for commercial fishing despite warnings.

Since the end of the World War II fishermen have repeatedly found bombs, shells (or fragments thereof) and lumps of viscous mustard gas in their bottom trawl nets. Crew members have been injured, but no fatalities have occurred as far as is known. Because Denmark compensates its fishermen for destroyed contaminated catches, reliable statistics exist there. Since 1976, about 450 reports about finds of chemical warfare agent have been filed in Denmark. Until 1990, annual finds numbered between 5 and 48; in 1991, there were 101 reports.

The reasons for the increase in 1991 are still unclear, but several factors should probably be considered (a greater awareness on the part of Danish fishermen of the problems involved in transporting such finds to land; an increase in fishing activity because of dwindling stocks; local migration of fish stocks; fishing activity by Danish crews in the Baltic Sea who previously fished in the Atlantic and who use heavy bottom trawl equipment off Bornholm; fishermen transferring munitions to unmarked areas).

German fishermen are not obliged to notify the authorities of finds of chemical warfare agents. Thus, only incomplete figures exist on warfare agent finds by German fishermen. Only the incidents in which crews were injured are known - so far 13 cases, with no fatalities. All 13 incidents occurred east of Bornholm in an area marked "Foul (munitions) (chemical munitions)" and "Anchoring and Fishing Dangerous" or in the immediate vicinity.

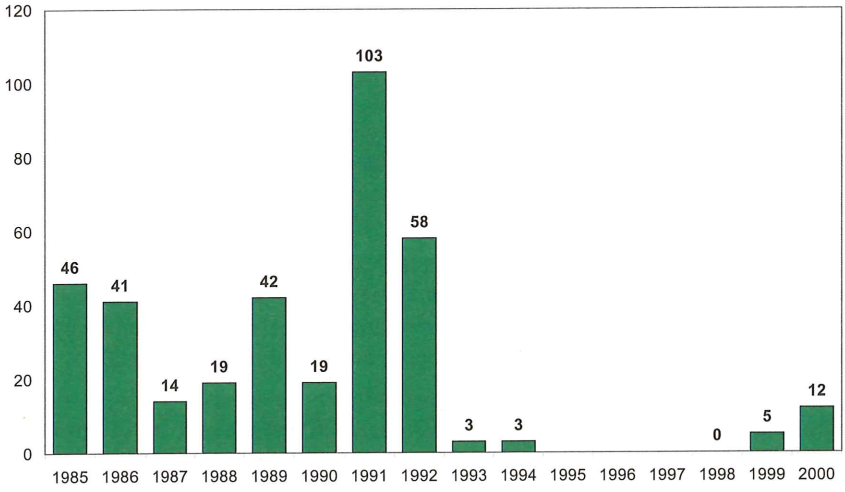


Fig. 4. *Findings of warfare agents or chemical munitions by Danish Fishermen.*

Risks are greatest in the dumping area off Bornholm as here the largest amount of chemical munitions have been dumped. It is likely that mustard gas has been dumped on the transport routes to Bornholm, as well as in the Gotland dumping area. Threats to fisheries can therefore be expected. However, due to the relatively small amounts that were dumped there, the probability of catching lumps of mustard gas or munitions in fishing nets is likely to be smaller. This is confirmed by the fact that far less finds of warfare agents have been reported from these areas.

In the area of the Little Belt only phosgene and Tabun munitions were dumped. Both substances are degraded rapidly in sea water. Viscous mustard gas was not dumped in this area, nor were persistent warfare agents containing arsenic. Leaking warfare agents therefore do not seem to pose a risk to the coast, the marine environment or fisheries. Due to the thick layer of mud (up to 8 m) and high sedimentation rates the munitions are mostly covered by sediment and it is therefore unlikely that intact munitions will be caught in bottom trawl nets here.

Moreover, mostly thin-walled bombs were dumped here whose casings rust through fairly quickly. Although the area is fished intensively, no accidents due to chemical munitions are known to have occurred. In recent decades, only two empty warfare agent bombs were caught in nets.

Risk to consumers

If a lump of viscous mustard gas is caught in a bottom trawl net, there is a risk of contamination of the catch. It is doubtful that fish contaminated in this way can reach the consumer. When a crew notices that its net and catch are contaminated, both are cast overboard or destroyed on land. This is done not only because it is required by law, but also because it is essential for the crew's personal safety. After being emptied, a net is cleaned and set out again and so fishermen have close contact with it. Fish are hand-sorted and gutted. If contamination is not detected in time, the warfare agent penetrates clothing and causes the injuries known from past experience.

On their way to the consumer, fish are quality-controlled several times: by the fisherman gutting and packing the fish, by the fish wholesaler when catches are landed as well as by the food inspection authorities in spot checks and the officer of the local Board of Fisheries and finally by the fishmonger when the fish are sold to consumers.

Even in the unlikely event that contaminated fish still reaches the consumer, despite the quality control checks, the risk from eating it seems improbable. Investigations during which fish poisoned with mustard gas were fed to laboratory animals showed that the consumption of raw, boiled or fried marine products does not pose an acute threat to mammals.

In specific analyses of fish, warfare agent residues have never yet been detected. The amounts of arsenic that have been absorbed are so small that they are irrelevant with regard to acute toxicity. However, further investigations are required into bioaccumulation and the long-term toxicology of warfare agents containing arsenic and their degradation products.

Conclusion: There is a risk in the Bornholm Basin that chemical munitions or lumps of viscous mustard gas can be caught in bottom trawl nets, hauled on board and thus cause contamination to the fishermen. All known cases of contamination to date were caused by viscous mustard gas. Risks to consumers from contaminated fish are unlikely and have so far not been shown to exist.

Conclusions and Recommendations

The main conclusions of the HELCOM Group were:

- According to existing knowledge dissolved warfare agents do not pose a wide-spread risk to the marine environment. Crews of fishing vessels operating in the dumping areas or in the immediate vicinity could be in danger if lumps of viscous mustard gas or chemical munitions are caught in bottom trawls and hauled on board.
- To increase the reliability of the assessment and to close remaining gaps in understanding, a phased programme of investigations is recommended.
- For all recommended measures, consideration should be given within the Helsinki Commission as to how far work and responsibilities can be co-ordinated with the other Baltic Sea states. Such an approach would make best use of resources, avoid the duplication of work and would ensure that measures are internationally consistent. Denmark accepted the role of the lead country.

The main recommendations were as follows:

- Investigations in the Baltic Sea
    - ➢ Examination of known and suspected dumping areas using appropriate techniques
    - ➢ Examination of the condition of the munitions
    - ➢ Chemical and biological investigations in the dumping areas
- Laboratory investigations
    - ➢ Investigations into the ecotoxicology of slowly degradable warfare agents
    - ➢ Investigations into how the warfare agents are degraded
- Review of instructions for finders of chemical and warfare agents.
- Revision of information for fishermen, doctors, hospitals, emergency services, shipping lines, port authorities and the police.
- No attempts should be made to recover dumped munitions as the risks for salvage crews and the environment would be greater than any existing danger.

The potential danger should be re-assessed and a decision taken on the necessity of further measures when the results of the proposed investigations become available.

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Quantifying the risks of unexploded ordnance drifting ashore or burying in the sea bed

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Abstract - This paper presents the results and conclusions from a feasibility study conducted to investigate how the risks associated with unexploded ordnance from sonobuoys might be quantified. The study examined how to assess the likelihood, under a range of simulated environmental conditions (e.g., tides, winds, waves and diffusion), of such ordnance either: (a) drifting to the shore on the surface, (b) drifting to the shore along the sea bed, or (c) burying in the sea bed. The principal conclusion from the study is that it is indeed possible to estimate the probability of such ordnance beaching or burying and thereby presenting a hazard to the public. The study concentrated on the Approaches to the Clyde region although the techniques examined are equally applicable to any shelf sea region of the world.

Introduction

This paper presents the results and conclusions from a feasibility study conducted to investigate how one might quantify the risks associated with unexploded ordnance from explosive sonobuoys. The particular risks of concern are the hazards to the public presented by unexploded ordnance either drifting to the shore or burying in the sea bed in regions where humans could come into contact with it (e.g. by trawling or diving).

The study examines how to assess the likelihood, under a range of environmental conditions, of such unexploded ordnance either:

- drifting to the shore on the surface before scuttling,
- drifting to the shore along the sea bed after scuttling, or
- burying in the sea bed.

When floating on the surface the sonobuoys will drift under the influence of currents, wind shear and waves. We have assumed that they will float for a maximum of twelve hours before a salt plug dissolves and they sink to the sea bed. When on the sea bed, the sonobuoy ordnance may drift along the bottom, if the currents are sufficiently large, or even bury in the sediments if the conditions are conducive. We have confined the study to the continental shelf where tidal currents predominate; the particular region of interest is the Clyde Approaches.

Surface Drift

Lagrangian Particle Drift Model

A Lagrangian particle drift model (Martin & Heathershaw 1995) was employed to simulate sonobuoy drift on the sea surface. This model is installed on QinetiQ's COMPASS shallow water forecast system and may be used to simulate the drift of one or more particles under the influence of some or all of the following physical processes:

- tidal advection
- wind shear
- diffusion
- Stoke's (i.e. wave) drift
- buoyancy
- decay

The model can output the percentage of particles which have beached after a particular time in the simulation.

For this application, only the first three phenomena were considered; Stokes's drift being a second order effect and buoyancy and decay only being applicable to the modelling of oil and chemical spillages. In order to simulate particle drift due to tidal advection, it is first necessary to set up and run a tidal model for the region concerned. The tidal current predictions can then be stored for subsequent accessing by the particle drift model. To predict the effect of wind shear on surface drifters, wind speed and direction data are required, and it is also necessary to specify a surface current drag factor appropriate for the type of drifter being simulated. The diffusion of either a single particle or multiple particles is simulated using a simple, random walk algorithm.

Fig. 1 shows some example predictions of the Lagrangian particle drift model set up for the Clyde Approaches. The release location is marked with a cross in a box and the predicted positions of 100 particles a time later are also shown.

For the tidal simulations, the SPMOD depth-averaged model developed by QinetiQ (Jones 1993) was used. This model solves the depth-averaged equations of motion and continuity in spherical polar form. It predicts tidal elevations and depth-averaged currents and is driven by the imposition on its open boundaries of sea surface elevations taken from the global tidal model due to Schwiderski (Schwiderski 1979). In the form used in this study the model was used to predict just tidal currents and elevations, surge effects were ignored.

For the application to the Clyde Approaches, the model was set up for the region defined by the limits: 54° 30′ N - 58° 00′ N; 009° 30′ W - 003° 20′ W, at a resolution of 5′ x 5′. Bathymetry data were was taken from the ETOP05 database although the open boundary on the western side of the domain was confined to the 200 m contour in order to prevent the model timestep from having to be too small (it was set at 20 s).

The model was forced on the open boundaries by the elevations of the M_2, S_2, O_1 and K_1 tidal constituents and run for a period of eight days to cover both spring and neap tides. Fig. 2 shows some example model output; the vectors representing the depth-averaged current predictions and the colours the tidal elevation relative to mean sea level.

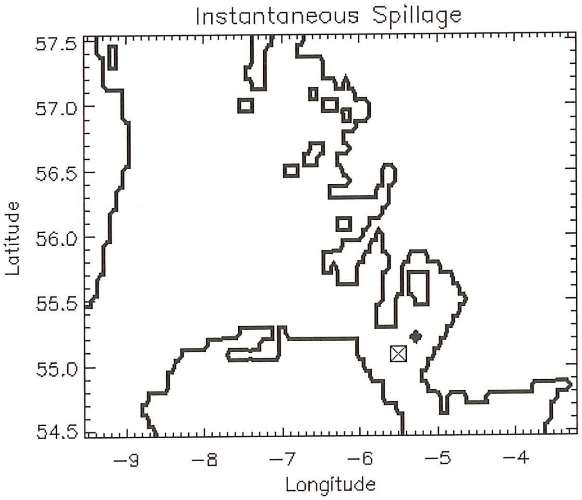

Fig. 1. Example Lagrangian particle drift model output.

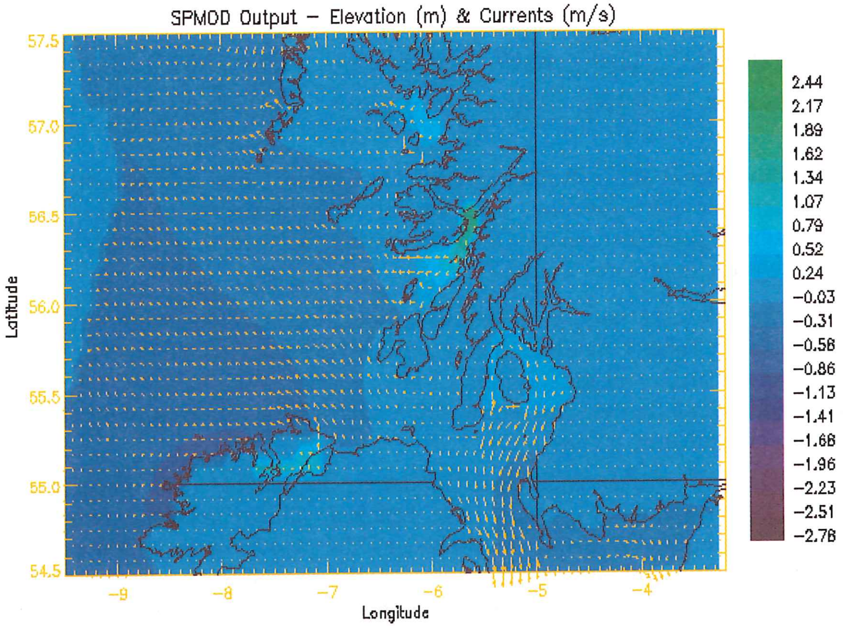

Fig. 2. Example tidal model predictions for the Clyde Approaches.

In order to force the wind shear component of drift in the particle drift model, climatic wind speed and direction data for the region were extracted from the US Navy Marine Climatic Atlas of the World (US Navy 1992). This is a 1° x 1° global marine meteorological climatology which contains, amongst other information, the percentage occurrence of wind speeds for eight points of the compass for each month.

For the purpose of this feasibility study, data from this database were extracted for just one grid point in the Clyde region (54° 30′ N, 004° 30′ W) and applied for the whole domain. By way of example, and to illustrate seasonal extremes, Table 1 below shows the climatological, average percentage wind occurrence data for the months of January and July.

Table 1. *Percentage Wind Occurrence Data.*

January								
Direction	N	NE	E	SE	S	SW	W	NW
Speed (knots)	28.09	13.27	14.40	16.08	20.71	25.06	20.55	17.68
% occurrence	9.17	9.17	4.17	10.00	14.17	25.83	9.17	18.33
July								
Direction	N	NE	E	SE	S	SW	W	NW
Speed (knots)	12.28	12.60	10.33	6.79	12.93	13.89	11.34	15.24
% occurrence	10.34	2.40	2.88	7.93	16.11	22.60	16.11	19.71

To get some idea of the overall probability of sonobuoys beaching within 12 hours (i.e. the maximum time the sonobuoys will stay afloat before scuttling) after having been launched from a particular launch position during, say, January at Spring tides, the following steps might be carried out :

a) Perform 8 x 12 hour particle drift simulations using the eight wind speed and direction sets as in Table 1. The simulation start time is set at, say, High Water Springs and the appropriate tidal current data for the 12 hour period automatically extracted from the SPMOD model output. In each simulation 100 particles are released from the same location (convenient for estimating probabilities).

b) At the end of each individual simulation the particle drift model predicts the percentage of the sonobuoys which have beached. This percentage (expressed as a probability between 0 – 1) is then multiplied by the percentage occurrence of the wind direction used in the simulation (again, expressed as a probability between 0 – 1) to give a probability of beaching associated with the particular wind direction used in the simulation.

c) The probabilities calculated in (b) for each of the 8 wind directions are then added up to give an overall probability of sonobuoys beaching during spring tides in January, taking into account the known (i.e. climatological) variation in wind speed and direction during January.

Steps (a) – (c) can then be repeated for a series of launch locations to enable contour plots of overall probability of beaching for particles released at that position to be drawn. Every grid point in the model domain (i.e. 1262 sea points at a resolution of 5′ x 5′) is chosen in turn as a launch position to enable a fairly detailed contour plot to be produced.

Figs. 3 and 4 show some example output for January and July at Spring tides. The contour values at each position on the chart illustrate the "overall probability of sonobuoys beaching within 12 hours during Spring tides in January/July when launched from that position".

The contour plots are useful in that they give a general impression of how close to the coast the release location would have to be in order for the sonobuoys to beach and present a hazard. The results indicate that there is some, but not much, variation with each month (only January and July shown here) and very little variation between spring and neap tides (plots for neap tides are not shown as they are virtually identical to those for springs).

In January, as one would expect from the generally stronger westerly winds, the launch locations that result in a finite probability of beaching cover a slightly greater area than in July. The extensive white areas offshore of the 0.01 probability contour represent launch locations for which there is effectively zero probability of the sonobuoys reaching the shore within 12 hours.

However, the contour plots in Figs. 3 and 4 give only a general picture and do not indicate where sonobuoys will beach for any given scenario, or illustrate how the probability of beaching is influenced by the various forcing mechanisms.

Bottom Drift

Forces Acting on the Payload – Critical Current Speed for Munition Movement

For a sonobuoy payload to drift along the sea bed the forces acting on it must be greater than the frictional resistance, F_r between it and the sea bed. There are two current-induced forces that act on a body, namely, the form drag, F_f, and the skin drag, F_s. So, the condition for movement over the sea bed is:

$$F_f + F_s > F_r \qquad (1)$$

The following expressions are used for estimating these three forces:

$$F_f = \frac{1}{2} C_{fh} \rho U_{fh}^2 A_{csa} \qquad (2)$$

where:
U_{fh} = upstream flow velocity at body's maximum height above sea bed
C_{fh} = form drag coefficient associated with U_{fh} = 0.74 in this case (Arya 1975)
A_{csa}= cross-sectional area exposed to the current
ρ = density of sea water = 1,025 kgm^{-3}

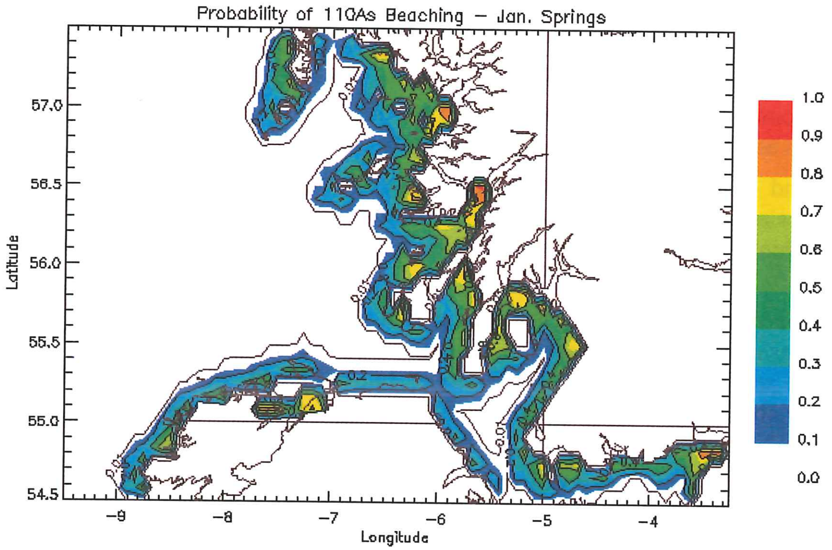

Fig. 3. *Overall probability of sonobuoys beaching – January, Spring tides.*

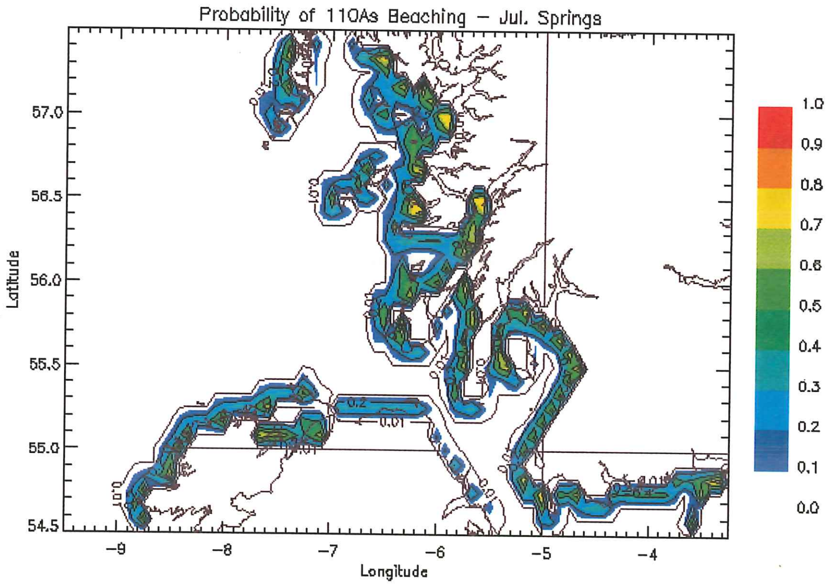

Fig. 4. *Overall probability of sonobuoys beaching – July, Spring tides.*

$$F_s \approx \tau_0 A_{seabed} = \rho C_{100} U_{100}^2 A_{seabed} \qquad (3)$$

where:

τ_0 = bed shear stress
U_{100} = flow velocity at 1m (i.e., 100 cm) above sea bed
C_{100} = form drag coefficient associated with U_{100}
A_{seabed} = area of body resting on sea bed

$$F_r = \mu g M_w \cos(\beta) \qquad (4)$$

where:

M_w = mass of the body altered by buoyancy (mass in water) = 7.305 kg
μ = coefficient of static friction = 0.3 (Ewald, Poschl & Prandtl 1930)
g = acceleration due to gravity = 9.81 ms^{-1}
β = seabed slope angle

The dimensions and mass of a typical sonobuoy have been used in these estimates.

To estimate the frictional resistance force we make the assumption that the cosine of the seabed slope angle is always effectively going to be equal to 1, so equation (4) gives for the sonobuoy payload:

$F_r = 0.3 \times 9.81 \times 7.305 \times 1 = 21.5$ N

So, for the payload to move over the sea bed, the sum of the form and skin drag forces acting on it must be greater than 21.5 N. The form drag will, in practise, dominate the skin drag to the extent that we can safely ignore it.

In the expression for form drag A_{csa} has been taken as being equal to the length of the payload section multiplied by its diameter, which gives:

$A_{csa} = 0.466 \times 0.115 = 0.054\ m^2$

The next stage is to derive a critical current speed, U_{crit}, at the maximum height of the payload above the sea bed at which the payload will be induced to move. This is done by rearranging equation (2) and substituting F_r for F_f (whilst ignoring F_s). This gives:

$$U_{crit} = \sqrt{\frac{2F_r}{\rho C_{fh} A_{csa}}} = \sqrt{\frac{2\times21.5}{1025\times0.74\times0.054}} = 1.02 ms^{-1} \qquad (5)$$

So, if the current at the height of the payload above the sea bed (i.e. 11.5 cm) is greater than 1.02 ms^{-1} then the payload is likely to move.

Bottom Tidal Currents

The tidal model we have predicts depth-averaged currents, however, it is still possible to deduce from them an estimate of the current at the height of the payload by assuming the existence of a logarithmic bottom boundary layer. This enables the current at the height of the payload to be derived from either the depth-averaged current, $\overline{U}$, or the current at 1 m,

U_{100}. The depth-averaged and 1 m currents may be related by the various forms of the expression for the bed shear stress, τ_0:

$$\tau_0 = \rho C_{100} U_{100}^2 = \rho C_D \overline{U}^2 = \rho U_*^2 \qquad (6)$$

where:
U_* = friction velocity
C_D = drag coefficient referencing the depth-averaged current = 0.0025 (Soulsby 1983).

Rearranging (6) gives the following expression for the current at 1 m in terms of the depth-averaged current:

$$U_{100} = \overline{U}\sqrt{\frac{C_D}{C_{100}}} \qquad (7)$$

where the appropriate value of C_{100} may be derived from the sediment type as presented in Table 3. Similarly, the friction velocity, U_*, may be written as:

$$U_* = \overline{U}\sqrt{C_D} = U_{100}\sqrt{C_{100}} \qquad (8)$$

It is generally accepted that the tidal current in the bottom few metres of the water column adopts a logarithmic profile of the following form:

$$U(z) = \frac{U_*}{\kappa}\ln(z/z_0) \qquad (9)$$

where:
$U(z)$ = current velocity as a function of depth
κ = von Karman's constant = 0.41
z_0 = bottom roughness length (related to sea bed type in Table 2)

Substituting (8) in (9) gives:

$$U(z) = \frac{\overline{U}\sqrt{C_D}}{\kappa}\ln(z/z_0) \qquad (10)$$

which allows one to derive the current at the height of the payload, $U(z = 0.115 \text{ m})$ from the depth-averaged current predicted by the tidal model:

$$U(z = 0.115) = \frac{\overline{U}\sqrt{0.0025}}{0.41}\ln(0.115/z_0) \qquad (11)$$

Wherever the value of $U(z = 0.115\ \mathrm{m})$ as computed from (11) is greater than $1.02\ \mathrm{ms}^{-1}$ the sonobuoy payload is likely to move over the sea bed. The tidal model gives the variation of $\overline{U}$ over daily and springs-neaps cycles and we can derive the distribution of z_0 from the sediment type data presented in geological charts. Hence, it is possible to produce charts showing where the sonobuoy payload will be able to move over the sea bed at different stages of the tidal cycle.

Equation (11) was used to compute the tidal currents at the height of the payload's height above the sea bed (i.e. at 11.5 cm and hereafter referred to as bottom currents) for the eight days period, and the results were compared with the critical bottom current speed necessary to make the payload move (i.e. $1.02\ \mathrm{ms}^{-1}$). As is apparent from equation (11) these predictions are critically dependent on the value of the roughness length, z_0. The roughness length was related to the seabed sediment type (as in Table 2) and then varied over the model domain by reference to a British Geological Survey chart showing sediment and (where known) bedform distributions.

The results of this simulation for spring tides are illustrated in Fig. 5 below, which shows computed bottom current (maximum flood). At neap tides the critical velocity is never exceeded, but at spring tides it is exceeded at one point on the southern open boundary.

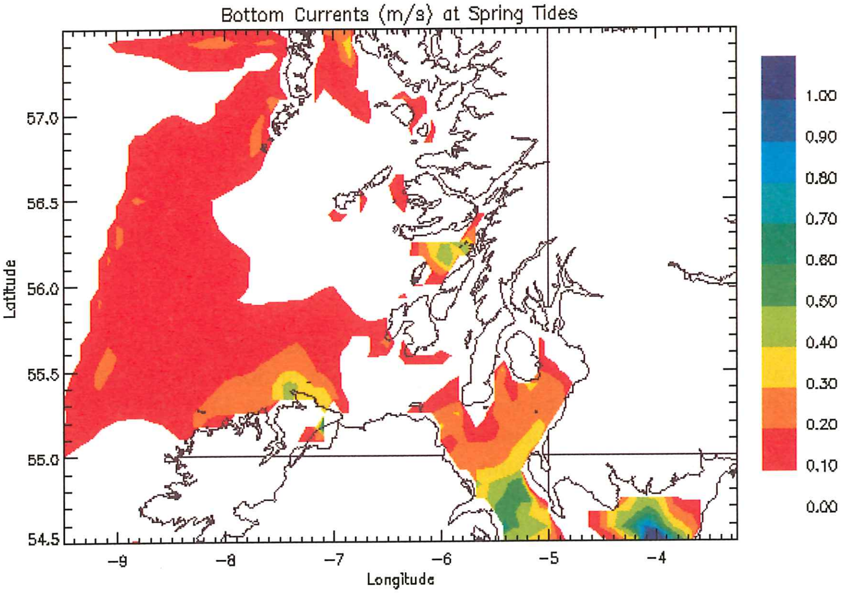

Fig. 5. Bottom currents at maximum flood springs, variable z_0.

Table 2. Variation of roughness length & drag coefficient with seabed type

Bottom type	z_0 (m)	C_{100}
Mud	0.0002	0.0022
Mud/sand	0.0007	0.0030
Silt/sand	0.00005	0.0016
Sand (unrippled)	0.0004	0.0026
Sand (rippled)	0.006	0.0061
Sand/shell	0.0003	0.0024
Sand/gravel	0.0003	0.0024
Mud/sand/gravel	0.0003	0.0024
Gravel	0.003	0.0047

Bottom Currents Induced by Waves

Waves in shallow waters also generate bottom currents which, if they exceed the critical velocity estimated above, may induce payload movement. The following two expressions may be used to estimate the near-bed maximum horizontal orbital velocity associated with the passage of waves, u_m, from the wave height, H, wavelength, λ, and water depth, h:

$$u_m = \frac{\pi H}{T\sinh(2\pi h/\lambda)} \qquad \text{for} \quad \frac{\lambda}{20} < h < \frac{\lambda}{2} \qquad (12)$$

$$u_m = \frac{H}{2}\sqrt{gh} \qquad \text{for} \quad h < \frac{\lambda}{20} \qquad (13)$$

In order to illustrate how estimates of u_m may be made, the Surface Waves Nearshore (SWAN) wave model (Holthuijsen et al. 1999) was set up for a portion of the Clyde Sea. SWAN is a third generation coastal wave model developed by TU Delft in the Netherlands. Though its basic scientific philosophy is based on the WAM deep water wave model (WAMDI Group 1988), it has various modifications to account for the physics of the shallow water regime. In summary, it can simulate the following physical wave processes: linear growth by wind, exponential growth by wind, whitecapping, quadruplet wave-wave interaction, triad wave-wave interaction, depth-induced breaking, and bottom friction.

For this application the high resolution bathymetry needed was obtained by digitising an Admiralty chart of the area rather than relying on the coarser resolution ETOP05 database used for the tidal model simulations. The computational grid had 54 x 60 grid points and was rotated such that it could be forced by the imposition on its SW open boundary by south-westerly waves of period 2, 4 and 6 s, with heights of 0.3, 1.2 and 2.7 m, respectively. For these example simulations, the model was not forced directly by the wind field. Values of u_m were subsequently computed.

Fig. 6 presents the near-bed maximum horizontal orbital velocity, u_m, computed from equations (12) and (13), produced by 6 s, 2.7 m waves imposed on the model's south-western open boundary:

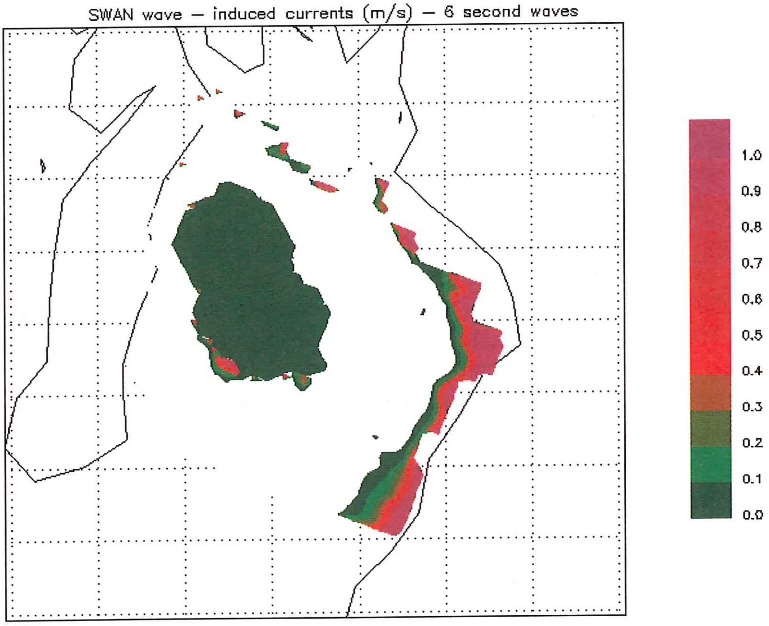

Fig. 6. *Wave-induced currents (ms^{-1}) generated by 6 s, 2.7 m waves from the south-west.*

These results indicate that the wave-induced bottom currents are only likely to exceed the critical value needed for sonobuoy payload movement (i.e. 1.02 ms^{-1}) along the eastern edge of the Firth of Clyde. In fact, for this set of simulations, payload movement is not predicted anywhere in the narrow Kilbrannan Sound to the west of Arran. Wave-induced bottom currents will, however, be oscillatory so even when the critical velocity is exceeded the payload is likely to roll back and forth.

This set of simulations is admittedly quite limited, but it does indicate how one might assess the likelihood of scuttled ordnance drifting in currents generated by waves in shallow waters. It would appear from these simulations that such a possibility is real in the Firth of Clyde.

Munition Burial

Time-stepping scour model

An object on the sea floor may become buried through a number of mechanisms, including impact, scour, liquefaction, and sandwave migration. The degree to which each of the processes acts is dependent on both the spatial and temporal variation in environmental parameters such as bathymetry, sediment type, wave climate, and tidal regime. The processes considered in this study by which cylindrical sonobuoy payloads may become buried are impact and scour. Liquefaction is unlikely at the depths considered, and there is insufficient data concerning bedform migration in the region of interest.

An object placed on the sea floor disrupts the bottom flow, accelerating that flow (by a speed-up factor m) in the region immediately surrounding the object, increasing the likelihood of scour. Thus, even when flow is insufficient to cause scour in the general area, it can occur in the vicinity of the object.

Scour "pits" tend to develop at the object's extremities, which enlarge and merge through time, so that the bearing area beneath the object becomes insufficient to support its weight, and the object subsides. Thus, as scour continues subsidence proceeds in a stepwise fashion. It is important to note that scour and subsidence do not bury an object *per se*. Burial of the object will only occur if, in a subsequent period of relative quiescence, material is deposited in the scour pit, covering the object.

A scour burial model has been developed for DERA (now QinetiQ) by Hydraulics Research Ltd. (Wallingford 1992), for application in predicting ground mine burial (the model has limited verification for that purpose (NATO 1999)). Although ground mines are somewhat larger than sonobuoy payloads, the model algorithms were derived semi-empirically using scale-models in flume tanks, and so it is reasonable to assume that the model is applicable to this application.

The stepwise subsidence process described above is difficult to model, thus an approach has been adopted to model subsidence as a continuous process in time steps, simulating the depth which would be attained when the next subsidence occurs. During actual burial, the development of the scour pits at either end of a cylindrical object tends to develop unevenly. This cannot be modelled accurately, so the scour pit depth predicted by the model is assumed to be an average of the two ends. The model also assumes a cylindrical object with a 5:1 length to diameter ratio, slightly different to the approximate 4:1 ratio of the sonobuoy payload, although the effect of the difference is likely to be minimal.

Inputs to the models are: seabed type, seabed hydraulic roughness length, seabed drag coefficient, sediment thickness and the tidal currents over a 24 hour period predicted by the tidal model.

The scour model was applied to the Approaches to the Clyde, the region defined by data points in a coarse 76 × 37 grid. The model was used to give scour development maps, i.e. the status of scour at a given time for the entire region, and time-series plots of scour evolution at specific points of interest:

- 55°48′N, 05°18′W (north of the Isle of Arran)
- 55°10′N, 05°50′W (in the North Channel)

Fig. 7 shows a time history plot of the model-predicted bottom current at the site in the North Channel, and the corresponding scour depth evolution during 24 hours of spring tides. No scour occurs at the site north of the Isle of Arran.

From the 24 hour tidal cycles given, it was apparent that scour develops gradually throughout the period, whilst it develops fully very early in the neap cycle and remains fairly constant afterward. This is simply a function of the current magnitude cycle. Scour does develop sufficiently within the Approaches to the Clyde for both spring and neap tides so that a sonobuoy payload could become partially buried within 24 hours, and fully buried in some locations. In the muddy regions it is also likely that the payloads may bury through impact with the sea bed.

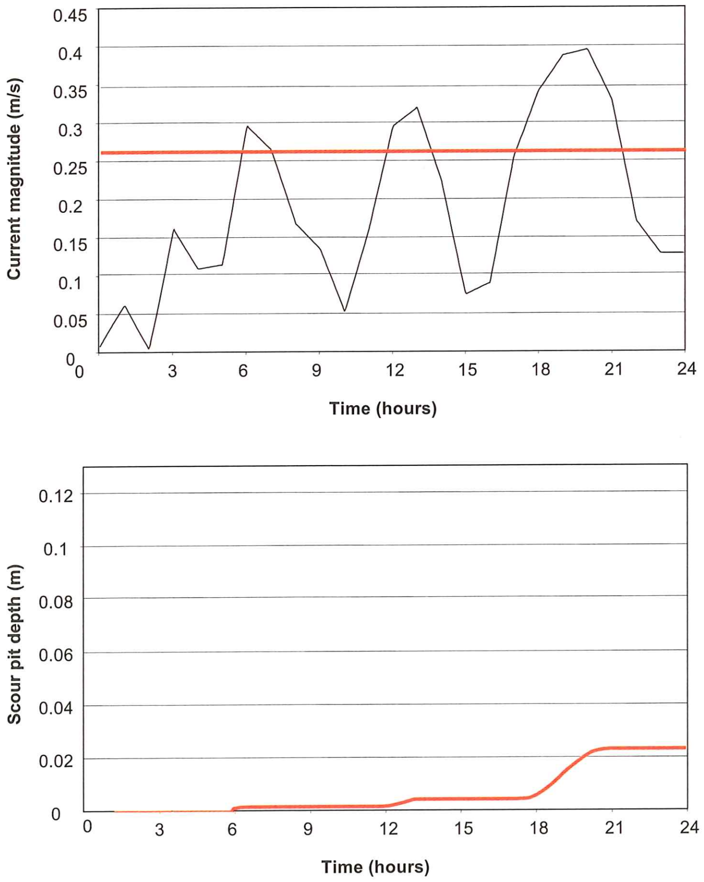

Fig. 7. Time history of spring tidal current magnitude & corresponding scour depth evolution at site in the North Channel. Red line marks the threshold for scour.

Summary

A methodology has been developed to assess the likelihood of explosive sonobuoys drifting to the shoreline on the sea surface under either typically representative or specific environmental conditions.

This methodology can, in principle, be applied to the case of munitions drifting along the sea bed, although in this study we have gone no further than predict areas of the sea bed where such ordnance may be induced to move given specific forcing conditions.

The study has demonstrated that QinetiQ's mine scour burial model can be applied to smaller munitions.

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Ecotoxicity of mustard gas, Clark I, Clark II and the metabolite tetraphenyldiarsine oxide occurring in sea-dumped chemical munition

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Abstract - Mustard gas, Clark I (diphenylarsinechloride) and Clark II (diphenylarsinecyanide) were investigated for their acute toxic effect on *Daphnia magna* in brackish water at different temperatures. After 48 h exposure the EC50 values for the Clark compounds were significantly higher in the low temperature experiments than in the high temperature experiment. However, after 6 days the EC50 values were nearly the same for all temperatures. This suggests that the minimum EC50 value of a substance is independent of temperature and that the important factor is the exposure time. A sediment experiment was also conducted with Clark I, indicating that it absorbs to sediment. In this experiment the acute toxicity of the water phase and the sediment samples were also tested, on *Daphnia magna* and *Nitocra spinipes* respectively. The results showed that the toxicity decreased with time in the water phase test series, and that the toxicity was lower in the vials containing sediment than in the vials without sediment. The results also showed that the sediments were toxic even though the chemical analysis could not detect any of the substances.

Background and aim

The areas of sea-dumped chemical munition of most concern to Sweden are probably the dumping sites in Skagerrak (Måseskär), in the Gotland Basin and east of Bornholm.

The main problems concerning the dumped chemical munition are related to the accidental catching by trawling fishing boats. In Swedish territorial waters the latter must be reported to the Swedish Coast Guard. During the period from 1980 to 2000 eight reports have been filed, all of them before 1992. As a comparison the number of reported findings in Denmark, where fishermen are financially reimbursed, a total of 342 findings were reported between 1985 and 1992. Recently, in April 2001, a trawler brought in a suspected bomb at Blekinge, in Sweden. The bomb was found to contain mustard gas.

All of the reported findings of dumped chemical munition in Sweden are in the Baltic. The latter is most likely due to the fact that in the Baltic the ammunition was dumped into the sea from ships. In the Skagerrak, where whole ships containing chemical munition were sunk, no findings have been reported.

Following reports in the news media in 1990 the Swedish Maritime Administration conducted an investigation of the dumping site Måseskär off the Swedish West Coast. The Swedish Defence Research Agency (FOI) participated in this research and performed a number of chemical and toxicological tests. Sediment samples were found to contain traces of mustard gas (in the ppt-range) but no effect was found on the enzyme activity of mussels and crabs placed in cages near some of the wrecks. The results of these studies have been reported elsewhere (Granbom 1996).

In order to increase the knowledge of the toxicological properties of some selected chemical warfare agents occurring in dumped chemical munition, two studies were carried out at FOI in 1997 (Muribi 1997, Muribi and Eriksson 1997). The aim of the first study was to investigate the toxic effect of mustard gas, Clark I and Clark II in brackish water on *Daphnia magna*. In the second study the aim was also to study if and to what extent Clark I, Clark II and the metabolite tetraphenyldiarsine oxide adsorb to sediments from the Baltic, and if the presence of sediment influences the agents toxicity on *Daphnia magna*. The sediment was also tested for acute toxicity on *Nitocra spinipes*. The results of this second study are discussed in this paper.

Except for the investigations listed above no other research has been performed on the environmental risks of dumped chemical munition in Sweden. This is not the case for conventional ammunition. During the last five years the FOI has been conducting extensive environmental risk assessments concerning conventional ammunition dumped in the sea, lakes and mines after World War II. These investigations have been financed by the Swedish Armed Forces according to the Polluters Pay Principle.

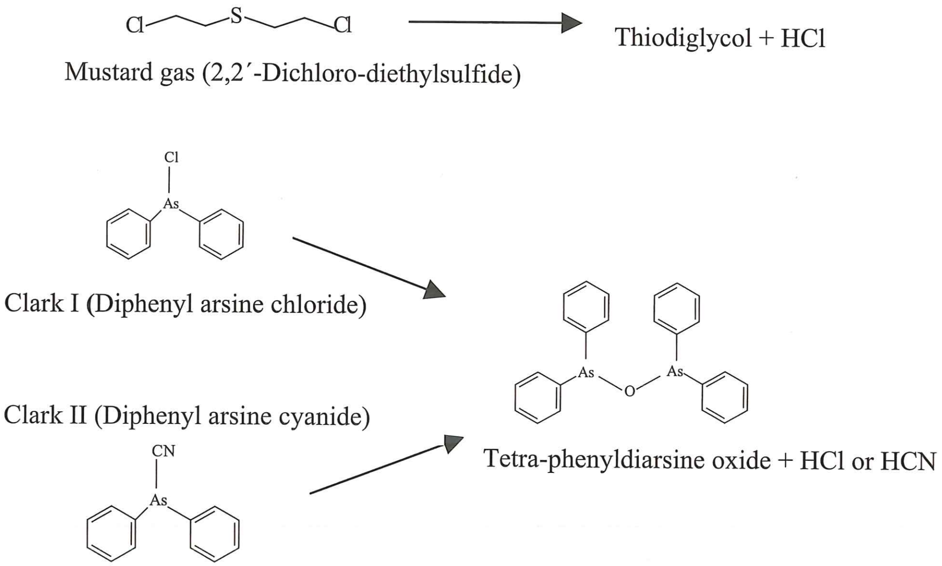

Fig. 1. Chemical structure of the test substances mustard gas, Clark I, Clark II and their products of hydrolysis.

Test substances and test organisms in the ecotoxicity tests

The mustard gas used for the tests was produced at Åkers krutbruk, Sweden, in the fifties. The Clark compounds originated from recovered chemical warfare agents. Fig. 1 shows the structure of the tested substances and their breakdown products.

The test organisms used were the harpacticoid *Nitocra spinipes* and the crustacean *Daphnia magna* (Figs. 2 and 3).

Nitocra spinipes is a sediment living organism, 0.7 to 0.8 mm long. It is eurohaline (capable of living and reproducing at a wide range of salinity) and can tolerate salinities in the range of 1-35 $^0/_{00}$. It is therefore a good complimentary organism to *Daphnia magna. Nitocra spinipes* has been used in toxicological tests since the 1970′s. Test animals were used from a culture maintained at FOI since 1996.

Daphnia magna is a pelagic invertebrate, approximately 5 mm long. It tolerates salinities up to 7 $^0/_{00}$. *Daphnia magna* was chosen as a test organism because it is easy to breed and handle and is also a good representative organism for grazers and filtrators. *Daphnia magna* has frequently been used in toxicological tests since the beginning of the century. For this test juvenile animals, from a culture maintained at FOI since 1995, were used.

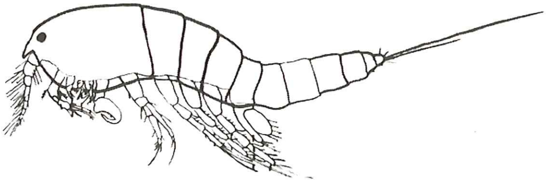

Fig. 2. *Nitocra spinipes.*

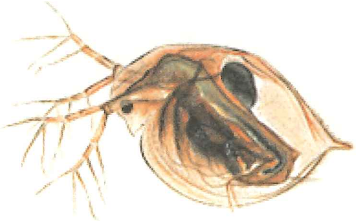

Fig. 3. *Daphnia magna.*

First study

Acute toxicity test

Th test was performed in 50 ml beakers with:

- 50 ml test medium (= tap water + salt, added to a concentration of $6 \pm 0.33\ ^{0}/_{00}$)
- 5 µl test solution (= different concentrations of C-agent in solvent, e.g. ethanol or acetone)
- 2 controls (= test medium or test medium + solvent)

After stirring, 5-10 juvenile *Daphnia magna*, acclimatised to the test medium for 24 h, was added. The exposure continued for 48 h at room temperature and for 72 h at the lower temperatures. After that the beakers were kept and examined for another five days. The experiment was conducted with 4 replicates. The concentration ranges, temperatures and light conditions are shown in Table 1.

Table 1. *Concentration ranges, temperature and light conditions of the acute toxicity test.*

Agent	**Conc. range [mg/l]**	**T [°C]**	**Light conditions**
Mustard gas	0.5 - 0.01875	19.5 ± 1	9 h light, 15 h dark
Clark I	0.125 - 0.0005	19.5 ± 0.5	9 h light, 15 h dark
	0.5 - 0.00195	4.0 ± 0.5	dark
Clark II	0.125 - 0.0005	19.5 ± 0.5	9 h light, 15 h dark
	0.5 - 0.00195	8.0 ± 0.5	dark

Acute toxicity test with sediment

The sediment was collected outside Norrbyskär, south of Umeå. Before use it was dried and stored in an open vessel at room temperature for two months.

The test was performed with 5 g dried sediment, spiked with 40 µl Clark I. Dilutions to different concentrations (10-0.03125 µg/g) were made with uncontaminated sediment. 30 ml test medium was then poured over 0.36 g treated sediment in Petri dishes. To each dish 5-13 *Daphnia magna* was added. The experiment was conducted at room temperature, 19.5±1°C. The exposure time was 48 h, in a 16 h light, 8 h dark cycle. Uncontaminated sediment was used for control. The experiment was conducted with 3 replicates.

Results

The results from the first study are shown in Table 2, Figs. 4 & 5, and Table 3.

In the acute toxicity of mustard gas on *Daphnia magna* no effects were observed at room temperature (19.5 °C) after 48 h exposure to 0.5 mg mustard gas /l test medium (Table 2).

In the acute toxicity of Clark I and Clark II on *Dapnia magna* the EC50 values were significantly higher in the low temperature experiments than in the high temperature experiments after 48 h exposure. However, after 6 days the EC50 values were nearly the same for all temperatures (Figs. 4 and 5). This suggests that the minimum EC50 value of a substance is independent of temperature and that the important factor is the exposure time.

The sediment experiment conducted with Clark I indicated that Clark I absorbs to sediment (Table 3).

Table 2. *Acute toxicity of mustard gas on D. magna. The number of dead animals in the controls and in the highest concentration tested are shown for two different solvents, acetone and ethanol, at three different exposure times. The test was conducted in triplicate with 4-7 D. magna in each beaker.*

Time [h]	**Solvent**	**Number of dead**				**Temp [°C]**	**Salinity [$^0/_{00}$]**
		0,5 mg/l	0,3 mg/l	control with solvent	control without solvent		
24	acetone	-	0	0	0	19,5	6,19
	ethanol	0	-	0	0	19	6 ± 0,33*
48	acetone	-	0	0	0	-	-
	ethanol	0	-	0	0	-	-
72	acetone	-	0	0	0	-	-

* This value was not measured. The water was made in exactly the same way as for the other media and should therefore be within this range

- Not determined

Table 3. *Acute toxicity of Clark I mixed with sediment on Daphnia magna. The number of dead animals in the controls and in the highest concentration tested are shown for two different exposure times. The test was conducted in triplicate with 4-7 Daphnia magna in each dish.*

Time [h]	**Number of dead**		**Temperature [°C]**	**Salinity [$^0/_{00}$]**
	10 µg/g sed.	control		
24	0	0	19	6,11
48	0	0	19	-

- Not determined

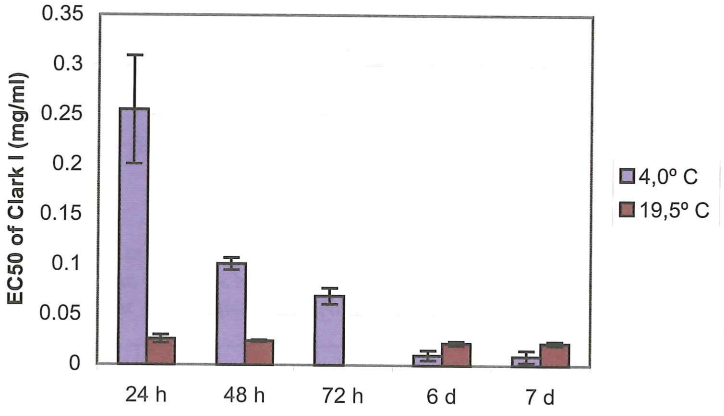

Fig. 4. *EC50 values of Clark I on Daphnia magna after 24 h, 48 h, 72 h, 6 d, and 7 d exposure in saline water (6± 0.33 ⁰/₀₀) at different temperatures (19.5°C and 4.0°C). The error bars indicate standard deviation. The EC50 values at 72 h, 19.5°C were not determined.*

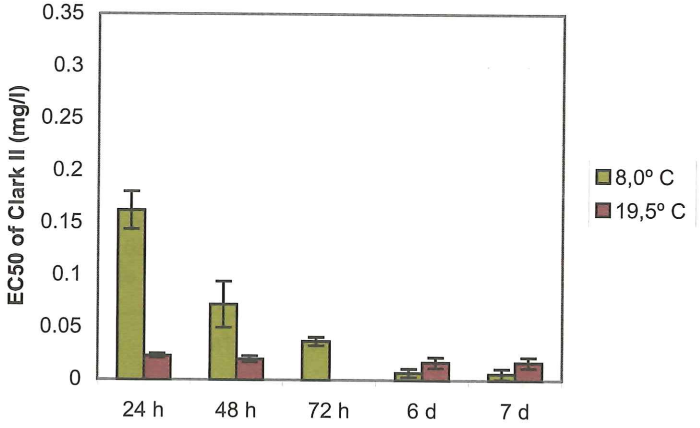

Fig. 5. *EC50 values of Clark II on Daphnia magna after 24 h, 48 h, 72 h, 6 d, and 7 d exposure in saline water (6± 0.33 ⁰/₀₀) at different temperatures, 19.5°C and 8.0°C. The error bars indicate standard deviation. The EC50 values at 72 h, 19.5°C were not determined.*

Conclusions of the first study The conclusions drawn from the first study were the following:

- Mustard gas does probably not pose any acute toxicological threat to organisms living in the water mass. However, sub-acute or chronic effects cannot be ruled out. Clark compounds do constitute a potential ecotoxicological risk to these organisms.Clark compounds probably adsorb to sediment.

Second study

Adsorption test

The adsorption of Clark I and Clark II onto sediment was investigated in batch studies. The substances were tested in two series, one containing the test substance and brackish water and the other the test substance, sediment and brackish water. The vials were shaken for different periods (0-30 days). The water and the sediment were then separated, extracted and analysed regarding Clark agents and their metabolite tetraphenyldiarsineoxide.

The test was performed with:

- A test series with 300 ml brackish water (6 $^0/_{00}$), 20 ppm Clark I and 15 g sediment. A "Control" series with 300 ml brackish water (6 $^0/_{00}$), and 20 ppm Clark I.Shaking (200 rpm) for 15 min/h at 19.5°C. Samples were taken for chemical analysis (GC-MS) and toxicity test at 0 h, 4 h, 24 h, 48 h, 4 d, 8 d, 15 d.

Acute toxicity test

The water phases from adsorption test were tested on *Daphnia magna* for 48 h, in a 16 h light - 8 h dark cycle at 20 ± 1°C.

The sediments were diluted with uncontaminated sediment to the following concentrations: 100%, 50%, 25%, 12,5%, 6,25% and tested on *Nitocra spinipes* for 96 h. Uncontaminated sediment was also used for control.

A toxicity test with washed sediment on *Nitocra spinipes* was also conducted to verify that the toxicity was not caused by the pore water.

Results

The results from the adsorption study are shown in Table 4, Table 5 and Table 6.

The analyses showed rapid hydrolysis of Clark I and that higher concentrations of Clark I and tetraphenyldiarsineoxide in the series containing only the test substance and brackish water. This indicates these substances absorb onto sediment. Unfortunately the chemical analysis could not verify this.

The results from the acute toxicity test are shown in Fig. 6, Table 7 and Table 8.

Table 4. *Concentration of Clark I and tetraphenyldiarsine oxide in the control series after shaking 6 $^0/_{00}$ water and 20 ppm Clark 1 for different lengths of time.*

Time	**Clark I** (μl/ml H_2O)	**Tetraphenyl-diarsine oxide**
0,17 h	3,19	**

Table 4. *Concentration of Clark I and tetraphenyldiarsine oxide in the control series after shaking 6 $^{0}/_{00}$ water and 20 ppm Clark 1 for different lengths of time.*

Time	**Clark I** (µl/ml H_2O)	**Tetraphenyl-diarsine oxide**
0,17 h	3,19	**
4 h	2.39	**
24 h	2,89	-
45 h	0,23	*
95 h	0,83	**
198 h	0,84	**
15 d	1,56	**

* = approximately the same concentrations as for Clark 1
** = much higher concentrations than in Clark 1
\- = not detected

Table 5. *The concentration of Clark I and tetraphenyldiarsine oxide in the water phases of the test series after shaking sediment, 6 $^{0}/_{00}$ water and 20 ppm Clark I for different lengths of time.*

Time	**Clark I** (µl/ml H_2O)	**Tetraphenyl-diarsine oxide**
0,4 h	2,66	*
0,4 h	2,61	**
4 h	2,47	**
4,5 h	2,17	**
24 h	0,23	*
24 h	0,32	*
48 h	0,12	*
50 h	0,1	*
94 h	-	-
96 h	-	-
189 h	-	-
190 h	-	-
14 d + 16 h	0,12	-
14 d + 16 h	0,23	-

* = approximately the same concentrations as for Clark I
** = much higher concentrations than in Clark I
\- = not detected

Table 6. *The concentration of Clark I and tetraphenyldiarsine oxide in sediment from the test series after shaking sediment, 6 $^{0}/_{00}$ water and 20 ppm Clark I for different lengths of time.*

Time	**Clark I** (µg/g sediment)	**Tetraphenyl-diarsine oxide**
0,4 h	0,49	-
4 h	2,86	-
24 h	1,94	-
48 h	-	-
94 h	-	-
96 h	-	-
189 d	-	-

- = not detected

The acute toxicity of the water phase samples on *Daphnia magna* showed that the toxicity decreased with time in the test series, and that the toxicity was lower in the vials containing sediment, as illustrated in Fig. 6. In the samples shaken together with sediment for less than four days, all daphnids died within 30 minutes. After four days of shaking the water phases were less toxic and longer exposure times were needed to kill the daphnids. The water phases from the Control series killed all daphnids within 40 minutes, even after 15 days of shaking.

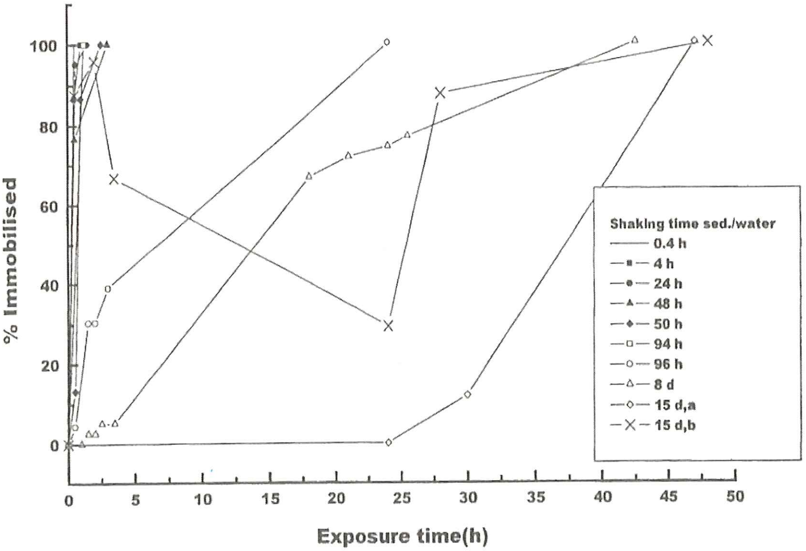

Fig. 6. *The toxicity of the water phases from the Clark I Test series samples on D. magna at different exposure times. The results after 0.4 h, 4 h, and 8 d of shaking are based on approximately 40 animals and the results from the other samples are based on only 20 animals. 15d, a and 15d, b are two replicates.*

The toxicity of the sediment sample from the Clark I experiment was tested on *Nitocra spinipes* and showed that the sediments were toxic even though the chemical analysis could not detect any of the substances (Table 7). The strongest concentration killed all test organisms within 24 h. Longer shaking time decreased the toxicity which supports the assumption that Clark substances adsorb onto sediment.

The experiment with washed sediment shows that even if the toxicity decreased compared to the unwashed sediment, the sediment was still toxic (Table 8).

Table 7. *The toxicity of Clark I Test series sediment on N. spinipes after shaking sediment, 6* $^{0}/_{00}$ *water and 20 ppm Clark I for different lengths of time. The toxicity is shown for different exposure times. Three replicates have been added. The pH-value to the left shows the value of the highest concentration where animals were still alive and the value to the right shows the value of the control.*

Shaking time [h]	**Exposure time [h]**	**Number of dead**					**Control**	**pH**
		100%	50%	25%	12,5%	6,25%		
24	24	15/15	15/15	18/18	16/16	6/16	0/16	6,05-6,2
	48					15/16	0/16	6,2-6,25
	72					16/16	0/16	5,98-5,72
48	24	15/15	14/14	14/15	10/15	2/10	0/5	6,7-6,35
	48				15/15	4/10	0/5	6,4-6,2
	72					6/10	0/5	5,94-6,0
	96					9/10	0/5	-6,0
96	24	15/15	14/14	0/15	10/15	1/16	0/15	6,55-6,34
	50		16/16	10/15	2/15	2/16	2/15	
	72			13/15	4/15	2/16	2/15	5,9-6,0
	96			15/15	4/16	2/16	3/15	5,82-5,73
8 d	24	16/16	16/16	11/16	0/15	0/15	1/15	
	48			16/16	9/15	1/15	1/15	6,37-6,4
	72				10/15	1/15	1/15	6,4-6,4
	96				11/15	1/15	3/15	
15 d	24	16/16	10/17	1/21	0/15	0/15	0/15	
	48			12/21	0/15	0/15	0/15	6,6-6,6
	72			13/21	0/15	0/15	0/15	6,5-6,65
	96			13/21	1/15	0/15	0/15	6,2-6,2

Table 8. *Toxicity of the 96 h Clark I Test series sediment on N. spinipes after having being rinsed with clean water. The toxicity is shown for different exposure times. Three replicates have been used.*

Shaking time [h]	**Exposure time [h]**	**Number of dead**					**Control**
		100%	50%	25%	12,5%	6,25%	
96	24	16/16	7/15	1/17	0/15	0/17	0/11
	48		10/15	3/17	2/15	0/17	1/11
	72		10/15	7/17	4/15	0/17	1/11
	96		10/15	14/17	5/15	2/17	1/11

Conclusions of the second study

The conclusions drawn from the second study were the following :

- The Clark substances seem to adsorb to sediment, since the concentration of both Clark I and tetraphenyldiarsine oxide is higher in the Control series than in the Test series. This could however not be confirmed in the chemical analysis.
- The toxicity of the water phases on *Daphnia magna* decreases with time in the Test series and is lower than in the Control series. This supports the assumption that Clark substances adsorb onto sediment.
- The toxicity of the sediment on *Nitocra spinipes* shows that the sediment is toxic although chemical analysis could not detect any of the substances.

Discussion

The first study showed that mustard gas probably does not pose any acute toxicological threats to organisms living in the water mass, but sub-acute or chronic effects cannot be ruled out.

The second study showed that the hydrolysis of Clark I was very rapid. Therefore it is not likely that these substances constitute any acute ecotoxicological risk to organisms living in the water mass. However, the sediment acute toxicity test on *Nitocra spinipes* implies that there might be a risk of negative effects for bottom living organisms.

Further studies should be carried out in order to investigate chronic and sub-lethal effects of chemical warfare agents in marine environment along with toxicological effects on sediment living organisms and organisms feeding on the sediment.

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Deep marine munition dump sites: example from Arendal, Norway

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Abstract - After World War II about 38 ships were dumped in the Skagerrak near Arendal, containing an estimated 50,000 tons of mustard gas and unknown amounts of Tabun and phosgene. Less extensive dumping is known from at least three additional Skagerrak sites and two Norwegian fjords. The Norwegian Defence Research Establishment investigated the Arendal site in 1989. Five wrecks were visually inspected using an ROV. All wrecks showed signs of heavy corrosion; flight bombs on the sea floor and inside the wrecks were mostly intact, some showing corrosion holes with the content possibly leaked out. Water samples taken at 13 locations did not show contamination by mustard gas or Tabun. The report concluded that pollution from the site will be minor and of no practical consequence. However there is some major criticism on this report. The conclusions were based on the investigation of only 5 (out of 15 located) wrecks - the contents and position of the remaining 23 wrecks remains unknown. Furthermore the sediments in the area have not been analysed, and the influence of bottom current activity was neglected. After strong media pressure it was admitted that there might be a potential for a new investigation. However no action will be undertaken before publication of the conclusions of the new OSPAR working group DUMP in 2002. Preliminary DUMP-results indicate the same line of arguments with regard to the Skagerrak dump area.

Introduction

Dumping of chemical and conventional weapons occurred in marine basins and coastal waters of the Northeast Atlantic after World War II (Kaffka 1996). Since then, most countries involved have identified and investigated the dump sites within their area of responsibility. Fig. 1 illustrates the location of about 80 documented chemical and conventional munition dump sites (red dots) within the Northeast Atlantic, excluding the Baltic Sea, as published in a preliminary report by the OSPAR working group on dumping, DUMP (OSPAR 2000).

In the Norwegian coastal waters two dump sites have been identified by this group so far. The dump site off Arendal is located in the deepest part of the Skagerrak at 600 to 700 m water depth containing chemical and conventional munition. The dump site off Farsund is located at about 300 m water depth and contains unspecified types of chemical warfare.

Fig. 1 also shows five additional dump sites (green dots) in Norwegian waters as marked on sea charts. Two of these sites are located in the Skagerrak: the Hvalerdeep (350 m) containing explosives and off Kristiansand (600 m) containing unspecified munition. The remaining three marine dump sites are located in fjords, i.e. the Sognefjord (Leirvik, 1000 m; Fresvik, 900 m) and the Nordfjord (10 nm west of Nordfjordeid, 550 m). The content of the fjord sites is not specified. Geographical positions of the dump sites are found in Table 1. None of these five additional sites is mentioned in the preliminary DUMP report (OSPAR 2000).

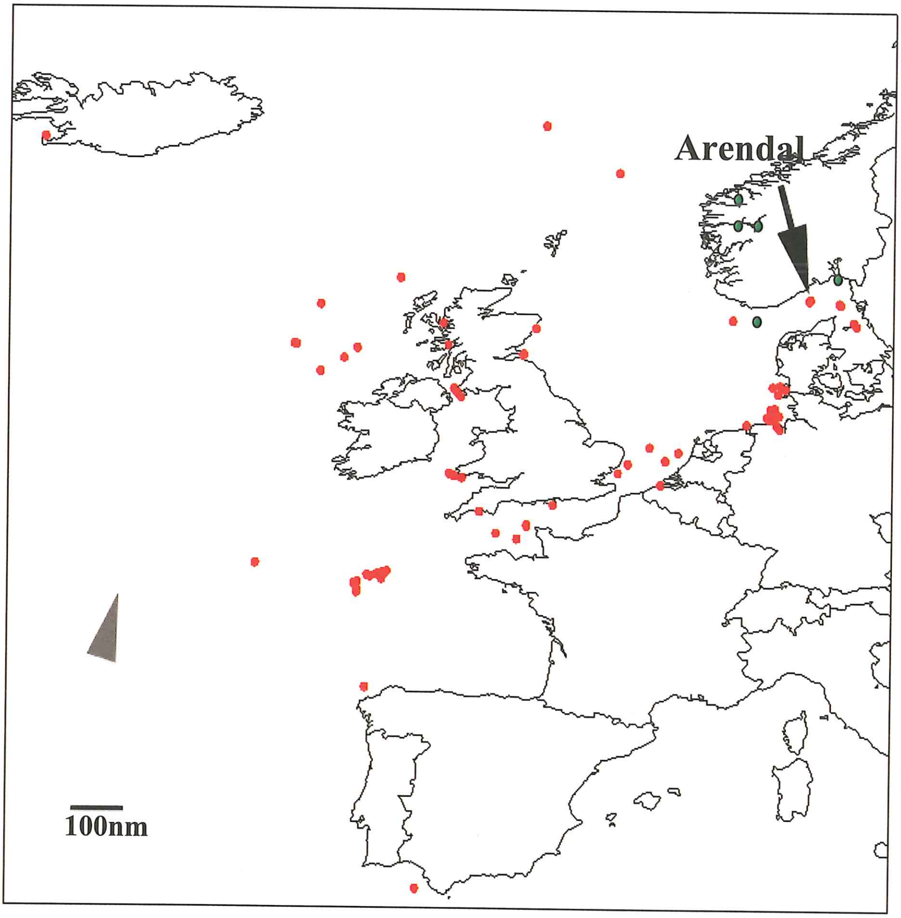

Fig. 1. Location of chemical and conventional munition dump sites in the North-East Atlantic, including the British Seas and the North Sea. Red dots indicate dump sites as reported by the DUMP working group (see text). Green dots indicate additional dump sites as indicated in sea charts. The black arrow marks the position of the Arendal dump site. Map from OSPAR (2000).

The Arendal munition dump site

Between 1945 and 1947 some 38 warships and container ships were dumped in the deepest part of the Skagerrak, about 25 nm southeast of Arendal, at 600 - 700 m water depth (Fig. 2).

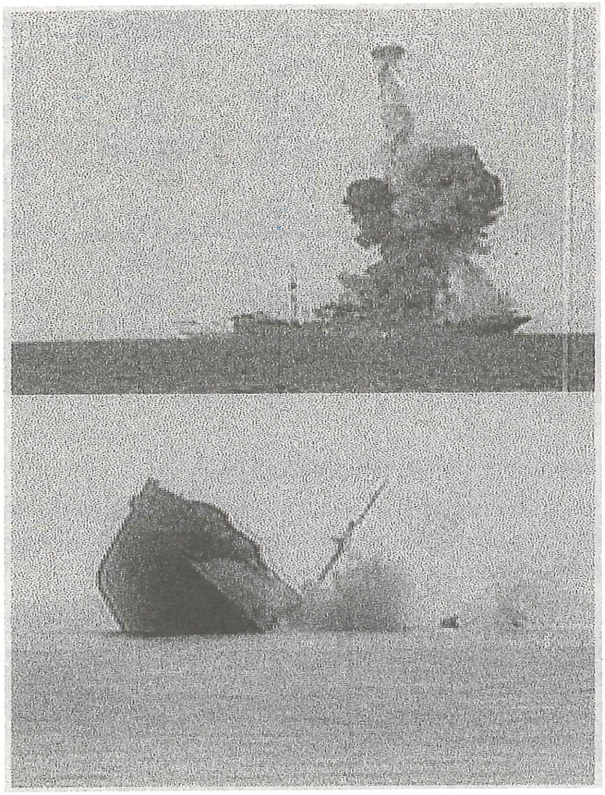

Fig. 2. *Dumping of munition in the Arendal area. Ships loaded chemical and conventional munition were bombed and sunk in the deepest part of the Skagerrak. Figure from TV2-Norway (Olsen 2001a).*

The ships had a total load of about 168,000 tons of chemical and conventional munition (OSPAR 2000). Estimations indicate that the wrecks might contain as much as 50,000 tons of mustard gas, in addition to unknown amounts of Tabun and phosgene. Table 1 lists the coordinates of the central parts of the Arendal dump site and the other Norwegian marine dump sites as mentioned above.

Table 1. *Position of the Norwegian munition dump sites (central part) located in the Skagerrak and in fjords.*

	site	latitude	longitude	water depth (m)	type of munition
Skagerrak	Farsund	57°52'	06°16'	300	poisonous gas
	Kristiansand	57°57'	08°03'	600	unspecified
	Arendal	58°17'	09°34'	600-700	chemical and conventional
	Hvalerdeep	58°55'	10°38'	350	explosives
Fjords	Leirvik	61°05,4'	05°19,3'	1000	unspecified
	Fresvik	61°05,6'	07°00,0'	900	unspecified
	Nordfjordeid	61°53,9'	05°42,3'	550	unspecified

The Arendal munition dump site investigation of 1989

The Norwegian Defence Research Establishment (FFI) investigated the Arendal dump site in 1989. It is the first and only published investigation of Norwegian munition dump sites since 1947. The results are summarised below (Tørnes *et al.* 1989).

The position of the wrecks was determined using a EG&G Model 990 side-scan sonar. The wrecks were visually investigated using a Superscorpio unmanned remote controlled submersible (ROV). Water samples – taken by the ROV – were analysed in the laboratory for Tabun, mustard gas and thiodiglycol (TDG, a decomposition product of mustard gas) using gas chromatography-mass spectrometry (GC-MS).

Results:

- 15 of the 38 wrecks were localised (indicated by stars on Fig. 3)
- 5 wrecks were visually investigated (indicated by red stars on Fig. 3)
- 13 water samples were taken at and above 6 wrecks (indicated by blue dots on Fig. 3)

The water samples were localised (a) at loading hatches: 3, (b) above bombs: 2, (c) at wreck walls: 2, (d) outside the wrecks: 3, in addition to (e) blind samples: 3.

All wrecks showed sign of heavy corrosion. Flight bombs of 200 to 250 kg were found spread across the sea floor and inside the wrecks (Fig. 4). Most of the bombs were intact. Some bombs showed corrosion holes with the content possibly leaked out (Fig. 5). In addition, closed gas-containers were observed.

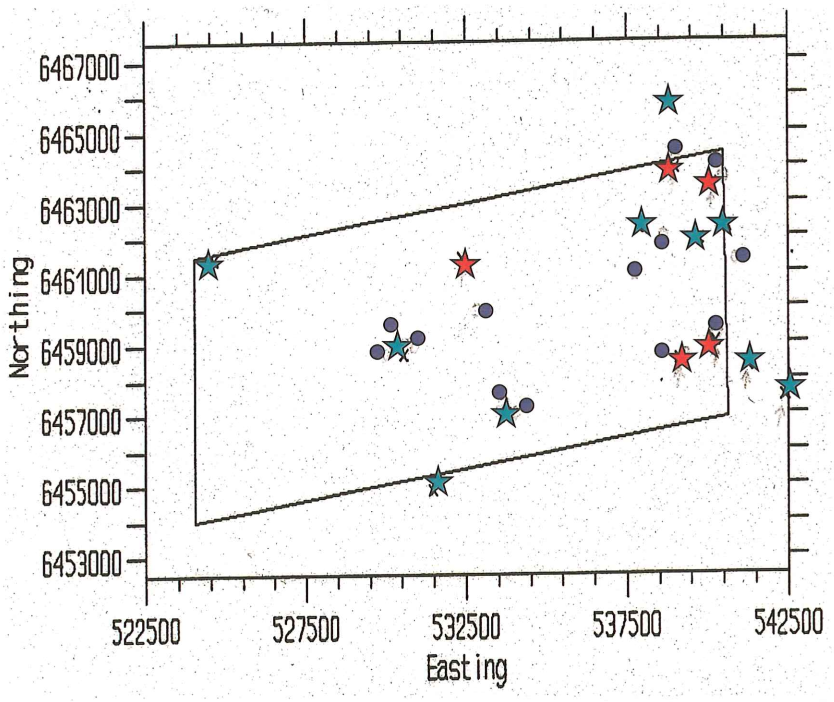

Fig. 3. *Position in UTM of the 15 wrecks (stars) that were localised during the 1989 Arendal munition dump site investigation. Red stars mark the position of the 5 wrecks that were investigated using the ROV. Blue dots indicate the position of water samples. Figure from Tørnes et al. (1989).*

The concentration of mustard gas, TDG and Tabun was below the detection limit in all water samples.

Based on the ROV observations and the results from the water samples, the report concluded that pollution from the dump site will be minor although certain types of mustard gas would remain for a long time at the sea floor if exposed to water. In addition, chemicals would be diluted in the water column in case of leakage. Pollution would be of no practical consequence as fishing and other commercial activity is prohibited in the area. Recommended action according to the report was to leave the site as it is. Recovery of the dumped munition was described as very expensive and hazardous.

Fig. 4. Intact flight bomb, probably larger than 250 kg. Figure from Tørnes et al. (1989).

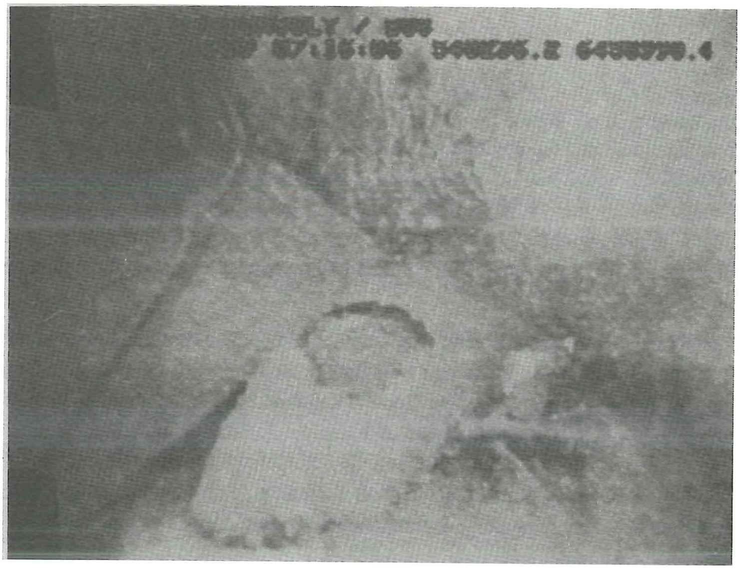

Fig. 5. Flight bomb with corrosion hole. Content has leaked out. Figure from Tørnes et al. (1989).

Consequences and criticism

The report of the 1989 Arendal munition dump site investigation (Tørnes *et al.* 1989) was used nationally by the Norwegian State Pollution Authority (e.g. SFT 2000) and by the Norwegian Ministry of Environment (e.g. MD 2000) as an argument for calming down the public concern and for not taking action to further investigate the site during the last 12 years. OSPAR (e.g. OSPAR 1992, 2000) and NATO (e.g. Martens *et al.* 1996) used the results from the Arendal report in their international documentation of activities at munition dump sites to point out that no further action is needed at that particular site.

There is, however, some major criticism on the Arendal investigation:

- Only 15 out of 38 wrecks have been localised.
- The conclusions are based on the investigation of 5 out of 15 possibly located wrecks.
- Sediments of the area have not been analysed.
- Pollution other than that from mustard gas or Tabun has not been investigated.
- The influence of bottom current activity has been neglected.
- In-situ chemical behaviour and transport mechanisms of the chemicals are not discussed.
- The occurrence of the warfare agents has not been documented: gaseous, liquid, solid, in containers or other.

This lack of documentation leaves open a number of uncertainties that need to be addressed in future investigations. The conclusion of the Arendal report does not necessarily apply to the wrecks other than the 5 that were investigated. The condition of the remaining 33 wrecks, and partly their position (23 wrecks), still remains unknown, as is the true amount, type and position of chemical and conventional munition distributed in the area.

Only limited information can be gained from the performed sampling investigations. Water samples should be taken on a regular basis from permanent stations across the whole area. In addition sediment analysis should allow a clear indication of the current pollution, especially if mustard gas remains on the sea floor as suggested by Tørnes *et al.* (1989).

Furthermore the sedimentological approach can be used to quantify leakage over time and identify the spreading pattern of any given and measured chemical component (Paetzel *et al.* 1994). The sedimentological investigation should also include other polluting elements (e.g. arsenic) and non-polluting elements for reference (Thorsnes *et al.* 1997).

Bottom current dynamics should be carefully investigated in the area. Van Weering (1981) documented persistent bottom currents greater than 10 cm/s at 516 m water depth in the Skagerrak south of Mandal. His maximum bottom current velocity of 13.8 cm/s was exceeded by measurements of up to 20.8 cm/s at a nearby location in an earlier investigation conducted by Larsson & Rohde (1979). The occurrence of bottom nepheloid layers at 620 m water depth in the central Skagerrak also indicates the capacity of bottom currents for erosion and transportation of particulate matter (van Weering *et al.* 1993).

A combination of oceanographic and sedimentological investigations might reveal transport pathways of polluting chemical agents. Of major concern would also be the monitoring of the progress of erosion.

Recent development

The Norwegian State Pollution Authority (SFT) admitted after pressure from newspapers (Andersen 2000, Sømme Hammer 2000, Hammerfjeld 2000), from the Local Authorities International Environmental Organisation (KIMO 2000) and from the Norwegian Society for the Conservation of Nature (Blagov 1999) that there might be a potential for new investigations in the Arendal area (SFT 2000), including some of the aspects mentioned above. However, no action was taken.

The pressure increased in 2001 when TV2-Norway took an initiative and focused on unsolved questions concerning the Arendal munition dump site (Olsen 2001a, 2001b). This time the SFT stated that there was no risk for pollution at the moment, citing the Arendal report from 1989 (SFT 2001). The SFT also referred to the OSPAR working group on dumping (DUMP) of which the SFT had become a member. With regard to the Skagerrak, the preliminary report of the DUMP group refers to the conclusion of the Arendal report, as pointed out above (OSPAR 2000). The final report will be available in 2002.

In their reaction on the TV2-Norway initiative the SFT suggests to prepare information-sheets for fishermen working in the vicinity of the Arendal dump site. They also suggest that future action might include a second investigation of the same 5 wrecks that were surveyed by Tørnes *et al.* (1989). However, the SFT will not give priority to dump site investigations and passed the responsibility for further initiatives to the FFI (SFT 2000, 2001).

Investigation of the remaining marine Norwegian munition dump sites is not mentioned within the ongoing discussion.

Future perspectives

One of the major problems arising in the discussion of deep marine munition dump sites seems to be the public concern. Norwegian politicians and governmental authorities did not succeed in convincing the public in the harmlessness of the Arendal munition dump site. This lack of public understanding originates most probably from (a) the incomplete investigation of the dump site and (b) the incomplete information to the public. The credibility of the 1989 Arendal investigation depends thus on the results of the remaining work.

The handling and consequences of the Arendal 1989 study have increased the concern with respect to how investigations of marine dump sites should be carried out. The public will be concerned about these sites as long as they are not fully investigated and the risks involved are fully understood. A first step in solving these problems could be a standardisation of handling munition dump sites. Fig. 6 suggests that marine munition dump site investigations should include four steps of assessment:

1. ***Total Inventory*** The four step marine munition dump site investigation chart suggests that marine dump sites are all investigated in a similar fashion. First, the type and the geographic extension of the site have to be identified, followed by an inventory of chemical and conventional munition that is found at the site. The geographic classification includes (a) tidal zones, (b) shallow waters affected by surface currents, (c) shallow waters

not affected by surface currents, (d) deep water affected by bottom currents and (d) deep water not affected by bottom currents. This classification has to be extended where necessary. Furthermore it should be stated whether the munition has been dumped in ships, separately or in other ways. This munition inventory is a time-consuming task, which involves a literature search on type and amount of munition dumping, as well as in-situ investigations where possible. At least the exact position of the dumped munition needs to be documented. A complete inventory also includes the oceanography of the area, i.e. tidal activity, direction and strength of bottom and surface currents, water temperature, salinity, primary productivity etc. As long as the basic inventory is not complete no risk assessment should be made.

2. ***Risk Assessment*** The total inventory provides the basis for the development of a site-dependent sampling strategy for risk assessment. Sediment samples can be used to quantify leakage over time and to document the spreading of contamination of any parameter through space and time. The sedimentological approach might also point out source areas. Additional water samples need to be taken on a regular basis at key locations to identify leakage from recent point sources. The progress of corrosion should be estimated on an "immediate risk / no immediate risk" basis. Possible hazards of the site have to be determined, based on sediment analyses, water sample analyses and corrosion estimation. Monitoring should not start before the risk assessment is completed.

3. ***Monitoring*** The monitoring programme includes long-term and short-term monitoring in those cases where the cleaning of the site is not recommended. Long-term monitoring involves sediment analysis of key locations. The frequency of long-term sediment monitoring depends on the sedimentation rate and the sediment dynamics of the area. Key locations and sedimentation rates are to be determined during the risk assessment. Short-term monitoring involves water samples at key positions or across key areas. Water sampling should be carried out according to the oceanography and the location of potential contamination source areas as determined during the inventory and the risk assessment. The erosion process could be monitored with the same frequency as sediment sampling. Monitoring should also take place after cleaning at those sites where cleaning is recommended. This might include short- and long-term monitoring depending on the type of contamination, type of cleaning and the nature of the site.

4. ***Public availability*** Public concern about munition dump sites will continue as long as the incertitude of the risks involved exists. It is therefore not only of interest to politicians and scientists to calm down the public. The latter also needs to be convinced that there is no immediate danger and that the site is constantly monitored and under control. The public should be informed on the steps that are or that will be undertaken. Information sheets and conclusions from scientific reports should, however, not be distributed to the public as long as the inventory and the risk assessment are not completed.

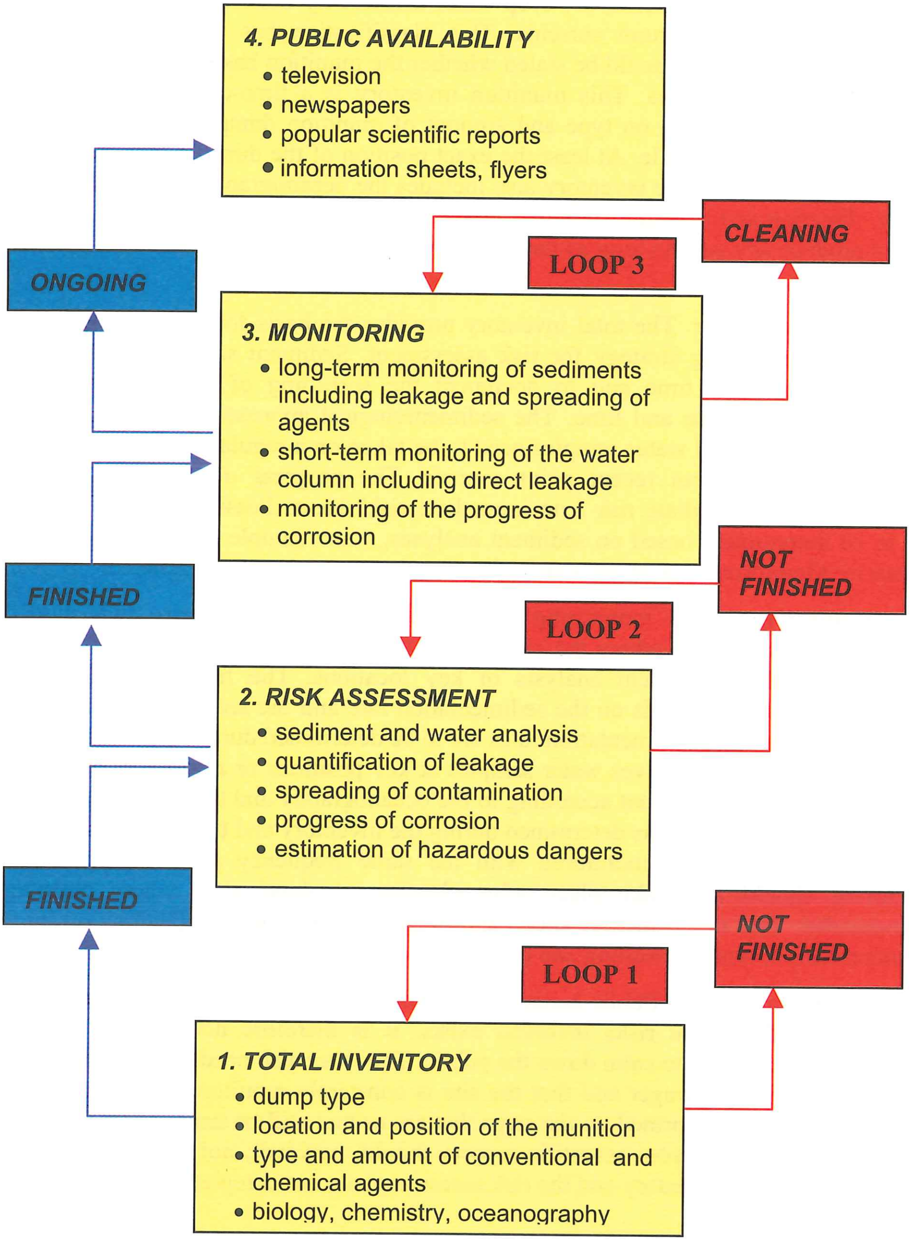

Fig. 6. Four-step investigation chart for marine munition dump sites. The red Loops 1 and 2 indicate the necessity for complete analyses within the different steps of the investigation before moving on to the next step (blue line). Loop 3 indicates the need for monitoring also at sites that have been cleaned up. Note that the results should be made available to the public while monitoring is going on.

The four-step investigation chart needs to be adjusted to the specific nature of each site, although the main steps should be similar. This type of standardisation will allow mapping the need for further investigation at each single marine munition dump site. According to the four-step investigation chart the state of the Arendal munition dump site investigation is located within step 1.

Conclusions

- The investigation of the Arendal marine munition dump site is incomplete.
- No inventory of the total site has been made.
- Any risk assessment will be uncertain as long as it is based on an incomplete inventory of the site.
- The supply of information sheets to the public should be based on complete site investigation.
- Complete site investigation might follow the four-step marine munition dump site investigation chart as outlined in this article.
- According to this chart, the state of the Arendal marine munition dump site investigation is classified within Step 1.
- Future investigations should also include the remaining Norwegian marine dump sites.

Acknowledgements

Sincere thanks to Prof. Dr. Jean-Pierre Henriet and Dr. Tine Missiaen at the Renard Centre of Marine Geology, University of Gent, Belgium, for the organisation of the workshop on Chemical Munition Dump Sites in Coastal Environments, July 2001. A special thanks to Asbjørn Olsen at TV2-Norway for providing information during the TV2-Norway news-campaign on the Arendal munition dump site in the Norwegian part of the Skagerrak.

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Dealing with chemical weapons dumped in bodies of water

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Abstract - Large amounts of chemical munitions were disposed of in the seas and other bodies of water across the world. Some of these once remote dumping sites are now being disturbed as a result of expanding economic activities. The likelihood of human contact with dumped chemical munitions increases accordingly. The Chemical Weapons Convention (CWC) was opened for signature in January 1993 and entered into force in April 1997. One important disarmament aim is the world-wide destruction of all chemical weapons (CW). The CWC, however, does not specifically encourage parties to the convention to remedy sites with CW dumped in bodies of water. The paper introduces the concept of chemical weapon under the CWC and describes the different classes of CW and their respective declaration and destruction obligations. It then analyses how the CWC deals with CW dumped at sea and in internal waters and discusses some of the legal issues that may arise if such weapons are recovered. The paper concludes with some recommendations to remove ambiguities surrounding the status of recovered dumped munitions under the CWC.

Introduction

The Chemical Weapons Convention (CWC) was opened for signature in January 1993 and entered into force in April 1997. One important disarmament aim is the world-wide destruction of all chemical weapons (CW). To this end the CWC contains detailed instructions on how to destroy CW and related production facilities, imposes precise deadlines (including many interim deadlines) for the destruction requirements.

A party to the CWC is prohibited to eliminate its CW stockpile through open-pit burning, land burial or dumping in any body of water. In this way the convention sets environmental standards for the destruction methods. In addition, the latter two methods are also unacceptable on the grounds that the destruction process must be essentially irreversible.

Tonnes of chemical munitions have been disposed of in the seas and other bodies of water across the world after the end of both World Wars. Furthermore, munitions recovered from the former battlefields and even modern CW were sea-dumped. International awareness of the potential ecological consequences of these dumping operations has meanwhile grown. Moreover, some of these once remote dumping sites are now being disturbed as a result of expanding economic activities, such as fishing, harbour expansions and the laying of deep-water cables and pipelines. The likelihood of human contact with dumped chemical munitions increases accordingly.

The CWC does not ignore the problem of CW dumped in water. However, it does not specifically encourage parties to the convention to remedy such situations. It also recognises the problem of the haphazard retrieval of such munitions, and therefore it establishes a special framework for declaring and destroying these CW whereby it allows state party discretion over decisions to invoke the destruction obligations.

This paper introduces the concept of chemical weapon under the CWC and describes the different classes of CW and their respective declaration and destruction obligations. It then analyses how the CWC deals with CW dumped at sea and in internal waters and discusses some of the legal issues that may arise if such weapons are recovered. The paper concludes with some recommendations to remove ambiguities surrounding the status of recovered dumped munitions under the CWC.

Chemical weapons in the Chemical Weapons Convention

One of the central components of the CWC is the destruction of CW and the prevention of future (re)armament with such weapons. The verification regime of the treaty is geared towards these goals. It includes on-site inspections of CW stockpiles and CW destruction facilities by teams of international inspectors of the Technical Secretariat of the Organisation for the Prohibition of Chemical Weapons (OPCW) in The Hague.

Inspectors also visit commercial industrial plants and facilities run by government agencies (including the military) that handle chemicals specified in the CWC in order to ascertain that no prohibited activities take place in them.

The parties to the CWC must continuously collect information on activities of relevance to the convention occurring on their territory and report such information to the Technical Secretariat. In order to be able to implement this vast undertaking the CWC contains an elaborate definition of CW. This definition does not encompass every type of munition or agent that national military doctrines may have considered to be a means of chemical warfare; the definition serves the objectives of the CWC [1]. Article II of the CWC defines CW as follows:

"Chemical Weapons" means the following, together or separately:

- Toxic chemicals and their precursors, except where intended for purposes not prohibited under this Convention, as long as the types and quantities are consistent with such purposes;
- Munitions and devices, specifically designed to cause death or other harm through the toxic properties of those toxic chemicals specified in subparagraph (a), which would be released as a result of the employment of such munitions and devices;
- Any equipment specifically designed for use directly in connection with the employment of munitions and devices specified in subparagraph (b) [2].

Taking the history of chemical warfare into account, the CWC identifies three periods of CW production. The first period ends in 1924 and includes World War I. The second one runs from 1925 until 1945, the year in which the Axis Powers were defeated in World War II. The third period begins on 1 January 1946 and continues until the present.

Based on these time delimitations Article II specifies two subcategories in addition to CW, namely "old chemical weapons" (OCW) and "abandoned chemical weapons" (ACW). There are two classes of OCW, namely (a) CW that were produced before 1925 [3], and (b) CW produced in the period between 1925 and 1946 that have deteriorated to such an extent that they can no longer be used as CW [4].

Abandoned chemical weapons are CW left behind by one state after 1 January 1925 on the territory of another state without the latter's consent [5]. Old chemical weapons produced before 1925 can thus never be considered as ACW. Chemical weapons produced between 1925 and 1946 can be ACW; CW produced after 1945 cannot be OCW because of the time specification.

Obligations with respect to the elimination of chemical weapons

A primary objective of the CWC is the world-wide elimination of CW stockpiles. A key requirement is the essential irreversibility of the destruction process so that the munitions and other devices can no longer be used [6]. The CWC also explicitly prohibits three methods for CW disposal: open-pit burning, dumping in any body of water, and land burial [7].

Ecological considerations obviously played a role in these exclusions. However, the CWC also contains specific provisions for dealing with CW dumped at sea and buried on land before certain dates (see below), which would be purposeless if dumping in water or land burial were permitted ways of CW disposal.

In addition, any authorisation of sea-dumping would have been in contravention of international environmental and maritime law, notably of the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the so-called London Convention) and the 1982 UN Convention on the Law of the Sea (UNCLOS) [8].

The CWC is primarily concerned about the CW that were produced after 1 January 1946, and the reporting and destruction requirements, and the verification procedures for these munitions (as well as for their production facilities and storage sites) are very detailed [9]. The reporting and destruction requirements for OCW are significantly different [10]. States parties must destroy OCW under the general destruction obligation in Article I of the CWC [11].

Old chemical weapons manufactured before 1925 are subject to inspection by the Technical Secretariat, upon which they become toxic waste (which exempts them from the CWC definition of CW). The state party in question must then destroy or otherwise dispose of this toxic waste in accordance with its national legislation [12].

The reporting and destruction requirements for OCW produced between 1925 and 1946 are more elaborate as the Technical Secretariat must determine the non-usability of these CW. A state party must to the greatest extent possible submit information to the Technical Secretariat on a level of detail similar to that for CW produced after 1945 [13].

If, following one or more inspections, the Technical Secretariat confirms their status based on the non-usability criterion, then the state party will destroy them as OCW, which offers the possibility of a more flexible destruction regime than for CW produced after

1945 [14]. If, in contrast, the Technical Secretariat cannot confirm their non-usability, then the state party must destroy these CW according to the provisions for CW manufactured after 1945 [15].

It should be noted that the CWC definition of CW consists of three parts, so that the criteria apply to these parts together or separately. This signifies that the condition of non-usability must be determined for each part, as for instance, the agent may have retained much of its toxicity despite corrosion of the shell casing [16]. Those parts that do not meet with the non-usability specification must be destroyed in accordance with the CWC provisions for CW manufactured after 1945.

Under the CWC the disposal of ACW is the responsibility of the abandoning state [17]. However, the specific destruction requirements for the abandoning state party depend on whether the ACW meet the criteria for OCW or not. These criteria are the production of the CW between 1925 and 1945 *and* the determination of their non-usability.

This has two important implications. First, as the concept of ACW applies only to CW manufactured after 1 January 1925 the disposal of chemical munitions recovered from the World War I battlefields and dumps (as toxic waste) is the responsibility of the states that recover them (e.g., Belgium, France and Italy) and not of the countries that manufactured or fired them.

Second, ACW produced after 1945 can never be considered as OCW even though their condition may have deteriorated to such an extent that they can no longer be used. They must be destroyed according to the requirements for CW manufactured after 1945. For the abandoning state party, the determination by the Technical Secretariat that ACW are OCW may significantly reduce the cost of verification and destruction.

Chemical weapons dumped at sea or in other bodies of water

In the last century dumping at sea, in deep lakes and other waters or land burial were fairly common and cheap ways of eliminating CW. Especially after both World Wars the former belligerents applied these methods on a large scale in order to discard huge quantities of chemical munitions from the battlefields, storage sites and production facilities. They were also economic disposal modes for obsolete or deteriorated CW, or chemical munitions recovered from former battlefields [18].

However, growing environmental awareness led to doubts concerning the soundness of these disposal methods. The 1958 Convention on the High Seas, which included some provisions regarding marine pollution, proved inadequate [19]. Sea-dumping, however, first became illegal in a regional setting with the entry into force of the 1972 Convention for the Prevention of Marine Pollution by Dumping From Ships and Aircraft in April 1974 [20]. Although Article 9 permits exceptions in the case of force majeure or extreme emergency, it cannot be invoked lightly [21].

A similar global regulation followed with the entry into force of the London Convention in 1975. A protocol to the convention expounds the notion of dumping and after its entry into force it will extend the prohibition to dumping in internal waters [22]. UNCLOS, which entered into force in 1994, obliges parties to take measures to prevent, reduce and control pollution of the marine environment by means of, *inter alia*, dumping [23]. As noted earlier, the CWC totally prohibits such disposal methods (in addition to open-pit burning).

Regarding past CW disposal operations, the CWC distinguishes between CW buried on land and CW dumped at sea. As many states have a legacy of CW disposal, the CWC has created certain exemptions for both categories. While practical considerations guided the formulation of the relevant provisions (e.g., incomplete historical records, or the impossibility to recover the munitions), the overriding concern is the assurance that all CW remain unusable. Consequently, the specific modalities for land-buried and sea-dumped CW differ.

A party to the CWC is not required to submit national declarations or destroy CW buried on its territory, provided that these weapons were buried on its territory before 1 January 1977 and that they remain buried. The exemption applies to OCW and CW manufactured before 1977 [24]. At the First Conference of the States Parties, held on 6–24 May 1997 following the entry into force of the CWC, the term "territory" was defined as including the land territory and all internal waters of a state party [25]. Internal waters include rivers and mouths of rivers, lakes, canals, ports and permanent harbour systems and (under specific conditions) embayments [26].

If CW are thus recovered from such internal waters, they will have to be assessed against the criteria for OCW in order to determine which section of Part IV of the Verification Annex applies. However, the clause "buried on its territory" indicates that the paragraphs in Articles III and IV of the CWC regarding land-buried CW do not apply to ACW.

The declaration and destruction obligations for ACW, which depend on their production dates, remain even in the case that such CW were buried before 1977. As explained in the previous section, the criteria for ACW do not apply to CW manufactured before 1925. Thus, the disposal of World War I CW dumped in the waterways near the frontlines would be the responsibility of the state party that recovers them.

Sea-dumped CW are also the subject of exemptions. States parties are not required to submit declarations or destroy CW that were dumped at sea before 1 January 1985 [27]. The term "sea" is understood to include the high sea, the territorial sea and archipelagic waters of a state party. The border line between the territorial sea and the land territory (with its internal waters) of a state party is determined in accordance with the relevant rules of international maritime law [28]. The territorial sea starts at baseline on the land mass, which in most cases corresponds with the low-water line on the coast or straight lines connecting two base points across estuaries, deeply indented coasts, and so on [29].

Sea-dumped CW fall under a different regime than land-buried ones. The relevant passages in the CWC do not contain clauses like "in its territorial sea" or "which remain dumped". This has some important consequences. The exemption of declaration and destruction requirements is extended to sea-dumped CW that have been recovered for whatever reason.

As an immediate consequence, the time delimitations regarding CW production to distinguish between CW and OCW are without object. Furthermore, sea-dumped CW can never be considered as ACW, even if they were dumped in the territorial sea of another state. The opposite case would have led to legal tangles, as the producer or former possessor of the sea-dumped CW is not necessarily responsible for their disposal at sea. Especially after World War II, the Allied Powers conducted or coordinated the dumping of Axis chemical munitions in the Baltic and Adriatic Seas.

If a coastal state wishes to clear a dump site, then under the CWC it is solely responsible for the financial costs and the disposal of the munitions (which might be storage on land, as there are no destruction requirements). A former possessor or a state responsible for the dumping operations may contribute financial and technical assistance on a voluntary basis, but is not obliged to do so under the CWC.

Sea-dumped CW may also be destroyed under water. This occurs as part of ordnance-clearing operations at undersea dump sites with mixed high-explosive and toxic munitions. As the CWC remains silent on the destruction of sea-dumped CW, such operations are constrained only by the relevant provisions regarding the preservation of the marine environment under international maritime law and safety considerations for the divers [30].

The First Conference of the States Parties decided that CW buried on land after 1976 or dumped at sea after 1984 fall under the strict declaration requirements for CW. In addition, the declaration could include supplementary information to facilitate the Technical Secretariat's evaluation of the submission, such as the exact date of the burial or dumping, the way in which the CW were buried or dumped, the present condition of these CW, and an assessment of the risks they might pose to the environment [31].

Following a decision by the Third Conference of the States Parties in November 1998, it was clarified that the Technical Secretariat shall inspect CW buried on land after 1976 or dumped at sea after 1984 on the basis of these declarations, provided that the CW are accessible. Challenge inspections, which according to Article IX of the CWC any state party may request in case of a serious non-compliance concern, also apply to such weapons [32].

To date there are no confirmed cases of burial or sea disposal of CW after the specified dates. The CWC (including decisions by the annual Conference of the States Parties) does not address the question of the destruction of CW buried on land after 1976 or dumped at sea after 1984, although it can be expected that, should such a case be declared by a state party or be confirmed by means of a challenge inspection, the Executive Council and the Conference of the States Parties of the OPCW will take the necessary decisions.

Discussion

The CWC does not specifically encourage states parties to recover CW that were dumped in internal waters or at sea. In the eventuality of such recoveries there are different declaration and destruction requirements.

For CW dumped at sea before 1985 there are no declaration or destruction obligations. Even if a state party decides to declare sea-dumped CW to the OPCW, there are no other responsibilities that automatically follow from this declaration. The distinctions between CW, OCW and ACW are irrelevant. In contrast, a state party must submit detailed declarations about its disposal of CW at sea after 1984.

However, in the absence of confirmed cases of such dumping activities there are as yet no specified follow-on obligations for states parties (with the exception of those relating to inspections by the Technical Secretariat). Any future OPCW decision on remediation will have to take the physical ability to recover these weapons into account.

Chemical weapons dumped in internal bodies of water fall under the provisions of land-buried CW. States parties are not required to declare or destroy any CW that were disposed of in internal waters before 1977 as long as they are not recovered. (This exemption from the declaration and destruction obligations does not apply to ACW.) If CW dumped in internal waters are recovered, they must be declared. The follow-on obligations regarding their destruction depend on the determination by the Technical Secretariat of their status as OCW or CW.

Chemical weapons dumped in internal waters after 1976 must be declared in detail. As with CW dumped at sea after 1984, there are no specific follow-on obligations regarding remediation, although it is conceivable that in the eventuality of such a declaration the Executive Council will take a decision in line with the obligations regarding land-buried CW. The physical ability to recover these weapons (e.g., from deep lakes) will also influence the decision.

It was noted that CWC prohibits three methods of CW disposal: open-pit burning, dumping in any body of water, and land burial. The prohibition is contained in the Verification Annex, Part IV (A) [33], which means that it applies to CW manufactured after 1945, CW produced between 1925 and 1945 that do not meet the non-usability criterion, and ACW.

Old chemical weapons that were produced before 1925 or between 1925 and 1946 provided they meet the non-usability criterion are considered to be toxic waste. As such, they are exempted from the definition of CW. It is at the discretion of a state party to decide how it disposes of toxic waste. Depending on its national legislation, open-pit burning, dumping and burial may be conceivable options.

The dumping at sea of toxic waste may be restricted under international environmental or maritime law, but these international agreements focus mainly on minimising the consequences of marine pollution or contain an emergency clause. Stricter regulations have not yet entered into force. In addition, some of these international agreements have attracted the ratification or accession of only a small subset of parties to the CWC.

A similar vagueness exists with respect to retrieved CW that were dumped at sea before 1985. These weapons, irrespective of their date of production or origin, are fully exempted from declaration and destruction requirements.

As a consequence, a state party may dispose of these weapons without notification of the Technical Secretariat and might thus consider open-pit burning, land burial (including dumping in internal waters) or re-dumping at sea, or even storage on land. Re-dumping at sea might be subject to international environmental and maritime law (especially if the weapons were first moved onto land, e.g., for repackaging). Dumping in internal waters is not yet subject to an international prohibition as the 1996 Protocol to the Convention on the Prevention of Marine Pollution has not yet entered into force [34].

Nevertheless, the issue raises some legal questions under the CWC. If such recovered sea-dumped CW were to be buried on land or dumped in internal waters or at sea, this would necessarily have happened after the dates specified in the CWC that determine the exemptions for land-buried or sea-dumped CW. In other words, bearing in mind that the mere act of retrieval does not generate new responsibilities for states parties, can items that were totally exempt from the declaration and destruction obligations under the CWC become the subject of CWC regulations?

In the case of a negative answer, how does this affect the decisions taken at sessions of the Conference of the States Parties with respect to CW that have been buried after 1976 or dumped at sea after 1984? In fact, a negative answer would raise the far more fundamental question whether the sea-dumped CW still fall within the purview of the General Purpose Criterion (GPC) of the CWC. It will be recalled that Article II, § 1 considers *all* toxic chemicals and their precursors, as well as the munitions designed for their employment on the battlefield as CW, unless they are intended for *purposes* that are not prohibited under the convention [35]. The negative answer would thus amount to stating that a munition loses its characterisation as chemical weapon by the mere fact of having been dumped into a sea. This clearly cannot have been the intention of the negotiators of the CWC.

In the case of a positive answer, will state parties face the detailed declaration requirements for CW disposed after the CWC-specified dates, and which follow-on responsibilities will govern their destruction?

Particularly regarding land-buried recovered sea-dumped CW, will the specific declaration and destruction requirements for OCW and CW then become applicable (especially in view of the possibility that recovered sea-dumped CW might fail the non-usability criterion)?

Furthermore, will a state party then be in a position to declare such weapons as ACW, as the fresh obligations might entail considerable costs with respect to the destruction operations and verification of CW?

If a state party decides to store the recovered sea-dumped CW, does this act make it a CW possessor (again, especially in the light of the non-usability criterion), perhaps requiring a fundamental change in its original declarations and leading to the assumption of totally new and costly destruction obligations?

If storage of retrieved sea-dumped CW does not lead to a disposal obligation, how can this outcome be compatible with the core obligations in Article I of the CWC not to acquire or stockpile CW and to destroy CW in the possession of a state party?

Recommendations

These and possibly many other questions highlight the uncertainties regarding the status of CW dumped in bodies of water. Many of the issues raised in this paper may appear academic and of secondary importance in the light of the current difficulties in implementing the CWC. Indeed, no legal problems will surface as long as these weapons remain untouched.

However, it cannot be assumed that the present situation will not change. The continuing development of economic activities affecting the sea bed will increasingly disturb dump sites and require their remediation. Furthermore, there are concerns about the impact of the deteriorating munitions on the marine environment and on human safety.

Initiatives to remedy munition disposal sites in the Baltic Sea are being set up in the context of the NATO Partnership for Peace programme, scientific programmes to assess the condition of sea-dumped CW in European waters are in progress of being coordinated internationally and may eventually lead to policy recommendations, and Italy has indicated that it wants to clear CW from the Southern Adriatic. It is not inconceivable that similar initiatives will be developed for other parts of the world.

In the light of these developments, it is recommended that the OPCW considers the status of recovered sea-dumped CW under the CWC. It is clear that the categorisation of such munitions as chemical weapons in the full sense of Article II of the CWC will stifle any initiative to remedy the marine dump sites. Hence, it may be advisable to create a separate status for these weapons, perhaps analogous to the exemption as toxic waste, but supplemented with more stringent declaration and verification conditions, especially with regard to CW that might still be usable. In this context, the OPCW may wish to treat all recovered sea-dumped CW uniformly and discard the distinction between classes of CW based on their production date. This would not "penalise" a state party for recovering sea-dumped CW, but merely require it to destroy the weapons in accordance with its national legislation and require the Technical Secretariat to certify their destruction.

Related to the issue of sea-dumped CW, the OPCW may wish to study the interconnection between the CWC and international environmental and maritime law beyond the mere definitional aspects of terms. Similarly, it may wish to explore opportunities of collaboration with the international bodies created under the relevant agreements.

Furthermore, the OPCW may wish to support initiatives at environmental remediation of CW dump sites through Article XI of the CWC. The UNCLOS, the Oslo and London Conventions and the 1996 Protocol to the London Convention contain provisions on global and regional cooperation and on scientific and technical assistance and exchanges with respect to the marine environment that may serve as examples [36]. In this way the OPCW would invest in a small, but visible way in the long-term public stakes in the CWC, while contributing to the strengthening of international norms regarding environmental protection.

Note

The positions in this paper are those of the author and do not necessarily reflect the views of SIPRI. The author wishes to thank Julian Perry Robinson, Thomas Stock and Ralf Trapp for their constructive comments on an earlier draft.

References

1. Incendiary, smoke and anti-plant agents have been, and in some cases still are, considered to be chemical weapons by some countries. In some instances, the body within the military responsible for chemical warfare also developed and/or operated these other weapon categories.

2. CWC, Article II, para. 1. Some of the core terms, such as "toxic chemical" and "precursor" are further defined in other paragraphs.
3. This period essentially covers CW manufactured during World War I and in the years immediately following the Armistice. 1925 is a symbolic date, as it is the year of the conclusion of the Geneva Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or other Gases, and of Bacteriological Methods of Warfare.
4. CWC, Article II, para. 5.
5. CWC, Article II, para. 6.
6. CWC, Verification Annex, Part IV (A), para. 12.
7. CWC, Verification Annex, Part IV (A), para. 13.
8. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the so-called London Convention), adopted on 29 December 1972 and entered into force on 30 August 1975. Article 12, para. e explicitly refers to "agents of chemical and biological warfare". For more information, see URL <http://sedac.ciesin.org/entri/register/reg-067.rrr.html>, version current on 4 July 2001. United Nations Convention on the Law of the Sea, adopted on 10 December 1982 and entered into force on 16 November 1994, URL <http://www.un.org/Depts/los/unclos/UNCLOS-TOC.htm>. The sea-dumping prohibitions are in Part XII "Protection and preservation of the marine environment". The term "dumping" is defined in Article 1.

   In addition, there are several regional agreements with stricter obligations regarding marine pollution and dumping, such as the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (the so-called Oslo Convention), adopted on 15 February 1972 and entered into force on 7 April 1974, URL <http://sedac.ciesin.org/pidb/texts/marine.pollution.dumping.ships.aircraft.1972.html>; and the Convention on the Protection of the Marine Environment of the Baltic Sea Area (the so-called Helsinki Convention), adopted on 22 March 1974 (revised convention adopted in April 1992) and entered into force on 2 May 1980, URL <http://www.oceanlaw.net/texts/helcom.htm>.
9. CWC, Article IV and Verification Annex, Part IV (A). For a detailed discussion of these obligations, see Hart, John, "Chemical weapon destruction requirements of the CWC", in Hart, John and Miller, Cynthia D. (eds.), *Chemical Weapon Destruction in Russia: Political, Legal and Technical Aspects*, SIPRI Chemical & Biological Warfare Studies, no. 17 (Oxford University Press: Oxford, 1998), pp. 47–54.
10. CWC, Article III, para. 1 (b) (i) and Article IV, para. 1.
11. CWC, Article I, 2: Each State Party undertakes to destroy chemical weapons it owns or possesses, or that are located in any place under its jurisdiction or control, in accordance with the provisions of this Convention.
12. CWC, Verification Annex, Part IV (B), para. 6.
13. CWC, Verification Annex, Part IV (B), para. 3. The information must be submitted in accordance with CWC, Verification Annex, Part IV (A), paras. 1–3.
14. CWC, Verification Annex, Part IV (B), paras. 5 and 7.
15. CWC, Verification Annex, Part IV (B), para. 5.
16. For example, an agent such as Adamsite hardly deteriorates over time. Mustard agent may also retain its toxicity for a very long period. Krutzsch, Walter and Trapp, Ralf, *A Commentary on the Chemical Weapons Convention* (Martinus Nijhoff Publishers: Dordrecht, 1994), p. 34.
17. CWC, Article I, 3.

18. For overviews of such operations, see the contributions in Stock, Thomas and Lohs, Karlheinz (eds.), *The Challenge of Old Chemical Munitions and Toxic Armament Wastes*, SIPRI Chemical & Biological Warfare Studies, no. 16 (Oxford University Press: Oxford, 1997). Technical reports about sea-dumping operations in the Baltic Sea after World War II were produced by the Baltic Marine Environment Commission, Helsinki Commission, Ad Hoc Working Group on Dumped Chemical Munition (HELCOM CHEMU) in the early 1990s. Details of US operations after World War II are contained in Brankowitz, William R., *Chemical Weapons Movement History Compilation* (Office of the Program Manager for Chemical Munitions (Demilitarization and Binary) (Provisional): Aberdeen Proving Ground, Maryland, 12 June 1987), available from URL <http://www-pmcd.apgea.army.mil/NSCMP/IP/R/cwmove/>.
19. Convention on the High Seas, adopted on 29 April 1958 and entered into force on 30 September 1962, URL <http://www.un.org/law/ilc/texts/hseas.htm>.
20. See note 8.
21. Belgium, for example, faced stiff international criticism for the way it invoked Article 9 in order to dump an accumulated stock of 225 tonnes of World War I toxic munitions in the Gulf of Biscay in 1980. Zanders, Jean Pascal, "The destruction of old chemical munitions in Belgium", in Stock and Lohs (note 18), p. 211.
22. Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, adopted on 7 November 1996, Article 1, para. 4 and Article 7, URL <http://www.fletcher.tufts.edu/multi/texts/dumping.txt>. The protocol has not yet entered into force, but will supercede the convention as between contracting parties to the protocol that are also party to the convention (Article 23). For further information on international maritime law, see the International Maritime Organization, URL <http://www.imo.org>.
23. UNCLOS (note 8), Part XII, in particular Articles 194, 210 and 216.
24. CWC, Article III, para. 2 and Article IV, para. 17. The respective paragraphs refer to the totality of Part IV of the Verification Annex (Section A covers CW and Section B OCW and ACW).
25. OPCW, First Conference of the States Parties, "Understanding with respect to the terms "buried by a State Party on its territory" and "dumped at sea", document C-I/DEC.31, 16 May 1997.
26. Convention on the Territorial Sea and the contiguous Zone, adopted on 29 April 1958 and entered into force on 10 September 1964, URL <http://www.un.org/law/ilc/texts/terrsea.htm>. The definitions are expanded in the UNCLOS (note 8), Section 2.
27. CWC, Article III, para. 2 and Article IV, para. 17.
28. OPCW document C-I/DEC.31 (note 25).
29. UNCLOS (note 8), Section 2, Articles 5 and 7.
30. This issue was debated at the Partnership for Peace Coastal Maritime Operations Seminar, organised by the Headquarters of the Commander-in-Chief East Atlantic (CINCEASTLANT) and Commander Allied Naval Forces North (COMNAVNORTH) in Riga, 17–19 October 2000.
31. OPCW, First Conference of the States Parties, "Declaration requirements for chemical weapons buried by a State Party on its territory after 1976 or dumped at sea after 1984", document C-I/DEC.30, 16 May 1997. The basic declarations must be made in accordance with Article III, para. 1(a) and the relevant provisions of Verification Annex, Part IV (A).
32. OPCW, Third Conference of the States Parties, "All aspects of the issue of chemical weapons buried by a State Party on its territory after 1976 or dumped at sea after 1984, including a possible challenge inspection, and its implications for the Technical Secretariat's responsibilities", document C-III/DEC.12, 20 November 1998.

33. See note 7.
34. See note 22 .
35. See note 2.
36. UNCLOS (note 8), Part XII, in particular Articles 197–203; Oslo Convention (note 8), Article 12; London Convention (note 8), Article 9; and Protocol to the Convention on the Prevention of Marine Pollution (note 22), Articles 13 and 14.

The Coastal Maritime Operations Seminar 2000 and the possible role of NATO in solving the problem of sea-dumped chemical weapons

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Abstract - During the last decade, cross-border environmental problems have been a priority area of cooperation between NATO and the countries of Central and Eastern Europe. Within the framework of the NATO Coastal Maritime Operation programme a seminar was organised in 2000 in Riga (Latvia) on the subject of "Environmental and safety implications of the recovery and disposal of dumped ordnance in coastal waters". The workshop was open to both military staff as well as civilian scientific personnel, and a number of national and international civilian organisations. Its main aim was to determine and recommend structures and procedures for NATO and Partner nations to deal with the problem of sea-dumped warfare. One issue that was especially stressed during the debates was the urgent need of a collaboration between the military and civilian/scientific world. Further topics concerned the need for more research in order to verify the necessity of munition removal, and the possible set-up of an inventory of dump sites. In this, the "Baltic Ordnance Pilot" project may serve as a guideline. Ideally, the military authorities could take on the role of coordinator; different options exist for NATO funding through the NATO Science Division.

Background and aim

The NATO Regional Headquarter East Atlantic (RHQ EASTLANT) at Northwood, UK (Fig. 1), has a busy and active programme of maritime Partnership for Peace (PfP) activities. The HQ contributes to the conceptual work on improving interoperability with partner nations, and it pursues a step-by-step approach to the practical aspects, for example by the organisation of seminars and workshops.

The PfP initiative, introduced by NATO in 1994, is the basis for practical security cooperation between NATO and individual Partner countries. There are now 27 members of PfP (Fig. 2). PfP is expanding and intensifying political and military cooperation throughout Europe, increasing stability, diminishing threats to peace and building confidence. PfP activities include defence planning and budgeting, military exercises and civil emergency operations.

During the last decade, cross-border environmental problems have been a priority area of cooperation between NATO and the countries of Central and Eastern Europe. In 1992 a Pilot Study was proposed within the framework of the North Atlantic Cooperation Council (NACC), entitled "Cross-border environmental problems emanating from defence-related installations and activities". In their report "NATO and Partner Countries study defence-related radioactive and chemical contamination" (NATO 1995, NATO 1996), NATO stated that the most outstanding example of cross-border contamination is the dumping of large quantities of chemical warfare into the Atlantic, the Baltic Sea, Skagerrak and possibly the Arctic Seas. In 1996 a second phase of the Pilot Study was launched.

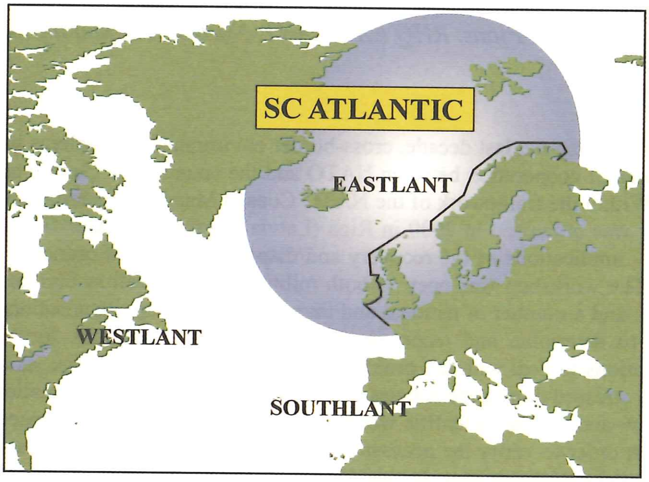

Fig. 1. *Sphere of action of NATO RHQ EASTLANT.*

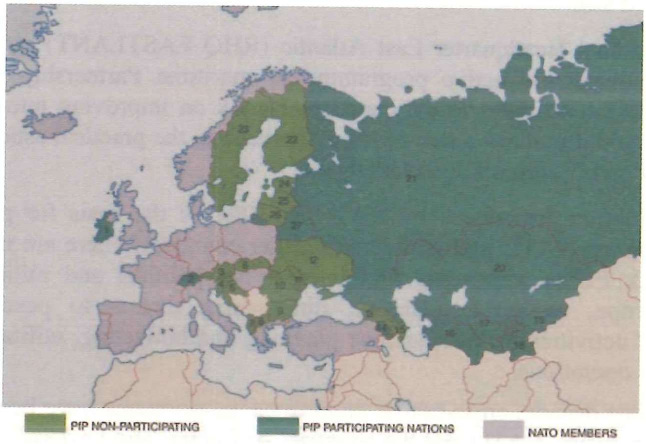

Fig. 2. *Overview of NATO member countries and Partner countries.*

Coastal Maritime Operations Seminar

The EASTLANT Coastal Maritime Operation Seminar is an annual seminar covering different subjects each year within the overall framework of Coastal Maritime Operations. In 2000 the topic was "Environmental and safety implications of the recovery and disposal of dumped ordnance in coastal waters". The PfP country Latvia hosted the event, through the Latvian Navy, in Riga from 17–19 October 2000. The seminar included specialist briefs, workshop sessions and plenary discussions.

The motivation and underlying idea of the seminar was the present-day situation in the Baltic and NW Europe. In the Baltic Sea, chemical weapons were often deposited at depths of less than 120 meters. Over the years, the warfare has become covered by several meters of sediment. Main aim of the seminar was to identify the different problem areas and to determine and recommend structures and procedures for NATO and Partner nations to deal with the problem of sea-dumped warfare. Also, as East-West cooperation has become more extensive, the need for a military-civilian forum became increasingly evident.

Workshop Participants

The workshop delegates embraced 26 NATO countries and 13 Partner countries, including both military staff as well as civilian scientific personnel and a number of national and international civilian organisations working on the issue. Civilian scientists were from Belgium (MUMM and University of Gent), The Netherlands (TNO-Prins Maurits Laboratory), Sweden (SIPRI - Stockholm International Peace Research Institute) and NATO (Scientific Division of the NATO HQ Brussels). Military delegates included naval officers from Albany, Belgium, Denmark, Estonia, France, Germany, Italy, Latvia, Lithuania, the Netherlands, Poland, Sweden and the UK.

Seminar topics

The set-up of the seminar was to present specialist briefings from both scientific and military views. The participation of civil scientists was much appreciated, not only because of their extensive knowledge of the problem but also because this allowed the discussions to go beyond the usual "military approach".

To set the scene Prof. Carvalho-Rodrigues from NATO Scientific Division highlighted the dynamics of different dangers of sea dumped ordnance. He also discussed possible ways of funding for future projects involving sea-dumped CW, which could lead to potential solutions.

Cdr Perfetti (Italian Navy) presented the results of ordnance clearing operations in the Adriatic Sea. During a military operation in the Balkan Allied Force aircrafts were forced to jettison munition into the sea. A total of 235 bombs were dropped. After accidents with local fishermen a first clearing operation was carried out in summer 1999. A second operation was carried out in spring 2000. However the further discovery of ordnance cannot be excluded.

Dr. Jacques (Belgium, MUMM) informed on the possible dangers related to sea-dumped ordnance for the marine environment (both fauna and flora). Some guidelines for seismic surveys were presented, and different release scenario's (slow leaking, sudden release, acute release) and their impact on the marine life were discussed.

Drs. van Ham (TNO-Prins Maurits Laboratory, the Netherlands) presented the results of ongoing research in The Netherlands on sea-dumped conventional ammunition. Special attention was paid to the degradation process of the shells, the dilution involved and possibilities for recovery operations.

Lt CDR Westman, Legal Advisor of the Swedish Naval Command, highlighted the legal implications when operating in coastal waters of other nations.

Dr Zanders, head of the Chemical and Biological Warfare (CBW) project of SIPRI, gave a situation report on the legal issues related to sea-dumped CW. In specific he discussed the situation in Belgium where WW1 munitions were dumped at sea in 1920 and are still found on daily bases in the fields of Flanders.

Lt CDR van der Veen (Royal Dutch Navy) reported on the Operation Allied Harvest in the Adriatic Sea in 1999. He discussed operational aspects and the problems encountered in localisation and clearance of the jettison areas and the safety measures involved.

Capt Besch (German Navy) reported on the mine clearing operations in the eastern Baltic in 1996-2000 ("Baltic Sweep" and "Open Spirit") and the recently set-up Baltic Sea Ordnance Pilot (BOP) project. Main aim of the BOP is the detailed identification of the different dump sites in the entire Baltic in view of potential recovery and removal of the dumped warfare. The project is supported by all Baltic states and is a first comprehensive effort to catalogue such complex matter; it could therefore serve as a good "blueprint" for future work in other areas.

Discussion

The seminar was divided into three main themes. The first theme involved a more political question - should NATO/PfP get involved in the recovery and clearance of sea-dumped warfare? The next theme was on a more strategic/operational level - what are the required prerequisites to be fulfilled before commencing such an operation? Finally the last theme focused on the operational/tactical approach - what are the possible concepts of how to conduct such an operation? The discussion was split up into three discussion groups. Each group reported on the internal discussion on the different themes in an open session.

As the seminar progressed, it became clear that the background information needed to consider operational details was not available or not sufficient. It became furthermore obvious that there is no scientific consensus concerning the best approach: to remove the dumped munition or leave it be. In many cases munition removal is much doubted. Several scientists point out that the environmental risks related to recovery will be much bigger than if the dump site is left alone; however detailed monitoring of each site is needed to check for the possible release of toxic materials.

Also it is stated that although the major dumping areas are well known, a lot of warfare was not dumped on the intended location and their precise whereabouts is not known. Such being the case, it was not considered relevant to continue with the last theme as planned. Instead it was decided to replace the last theme with three minor themes. Each of the three discussion groups was given a different question: (1) what are the possible reasons for

NATO/PfP to get involved in recovery and clearance operations, (2) what are the possible reasons against NATO/PfP involvement, and (3) what steps need to be taken by NATO in case an operation to clear dumped munition is to take place.

Seminar conclusions

The following list includes a number of conclusions and recommendations noted during the lively debate that followed the de-briefings of each discussion group:

- The environmental threat seems to be mainly related to chemical weapons rather than conventional weapons; however chemical and conventional warfare may often be mixed.
- More and better information is needed concerning the kind of chemical munition and the exact locations; to this end the work already underway in the BOP project can be used.
- Nations are requested to forward national data to Germany, in order to be included in the BOP, accessible to all.
- The scientists must be tasked to further investigate the severity of the problem with respect to deterioration and corrosion of dumped munition.
- Improvement is needed for the safety measures for divers and underwater equipment (request to the scientists for further investigation).
- Work cannot be done by military or civilian independently, collaboration and cooperation between the two is essential.
- An initiating body is required as well as a coordination authority; the military seems a good option for the first, NATO seems a good option for the second.
- More detailed data and information on dump sites should be freely available.
- Case studies should be conducted by scientists.
- Further development of methods to monitor chemical munition dumps is needed prior to maritime operations.
- In order to proceed nations must be consulted by NATO to estimate their response.
- A first approach to the problem of sea-dumped ordnance should be regional and if successful, expanded.

Consequences for CINCEASTLANT

The Riga seminar was successful as it both stimulated the civilian and military participants to an exchange of ideas, and also resulted in possible prospects for RHQ EASTLANT to address the issue of dumped munitions at sea. Thanks to the flexibility of the seminar set-up a thorough and meaningful discussion was achieved.

The main outcome of the seminar was that there clearly is a need for more research. This is needed in order to verify if the problem encountered requires removal of the dumped ordnance, or if such a removal in itself might cause a higher risk for the environment than letting it stay in place.

The rather broad scope of the discussion themes caused some problems in finding "suitable limits" for the discussions. Additionally, some of the discussions inevitably touched on the political aspects related to the subject. This occasionally caused some confusion and disappointment, as the results of these discussion were not so clear and therefore not immediately applicable for practical use.

Another important issue concerned further investigations needed for the exact location of dumped ordnance, since apparently the warfare was not always dumped where it was supposed to be dumped. For the Baltic area, the BOP project discussed above may form a good guideline for this purpose.

In conclusion, the main strategy to follow for SINCEASTLANT is initially to propose further scientific research which can then lead, in a further phase, to a decision involving the possible collaboration of the military in helping to solve the problem of sea-dumped munitions.

Future actions

One issue that was especially stressed during the Riga debates was the urgent need of a collaboration between the military and civilian/scientific world in future projects on the subject of dumped ordnance - ordnance that often found its way to the ocean bottom via military operations. In such a future cooperation, both scientists and military should originate from NATO and PFP Nations bordering the NW European and Baltic seas. Ideally, the military authorities could take on the role of coordinator.

Perhaps the best way to deal with this is a phase-like approach :

- A first task is to set-up an inventory of the dump sites : exact geographical position, type of war material dumped, quantities involved, ... In this, the BOP project may serve as a guideline. Ideally, the results of this study could be published.
- A second, important task concerns risk-analysis and possible standardisation. How dangerous is each site, is there need for recovery ? The outcome of this could be a practical guide.
- A third task involves the analysis of state-of-the-art recovery techniques. Different sites will call for different technical challenges. What are the risks involved, how can these risks be minimalised. Again this could result in a practical guide.
- A fourth task concerns the storage and destruction of the recovered munition. What is the dismantling capacity in the different countries; are there possibilities for international collaboration.

These different tasks should not necessarily be carried out successively - they may be carried out simultaneously, or in a different order.

Possible funding

Still, one important question remains : how can this be funded ? It is obvious that most tasks necessitate a collaboration with and input by the military. For instance, task 1 involving dump site inventory will highly depend on information held by military archives. It therefore seems logical to include NATO funding. Possible options for this are :

- NATO Science Division (NSD) (civilian) : the CCMS programme (Committee on the Challenge of Modern Society) opens different perspectives for funding :

- Advanced Research Workshop (ARW)
- Expert Visits (EV)
- Collaborative Linkage Grant (CLG) (cooperation between R&D Centres / Labs)
- NATO Research and Technology Division (RTD) (military) : the HMF Programme (Human Factors in military) offers several funding options.

In addition there is the possibility to combine NSD and RTD funding - i.e. a combined CCMS/HMF project. However it should be kept in mind that NATO funding alone may not be sufficient to support an entire project - it merely involves supplementary funding within an already existing project.

A possible option could therefore be to use NATO funding as a means of preparation for a new project (e.g. through the organisation of a workshop). During this preparatory phase the project outline can be defined and - equally important - a network may be set up. Deadlines for submission of ARW proposals are several times per year. The current director of the NATO Science Division, Dr. Carvalho Rodrigues, highly favours the input of NATO in solving the problem of sea-dumped CW.

Acknowledgements

NATO SINCEASTLANT would like to thank T. Missiaen from the Renard Centre of Marine Geology, Gent University, and F. Carvalho Rodrigues from the Scientific Division at NATO HQ Brussels for their helpful assistance in the preparation and organisation of the Riga workshop.

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