55534

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

VADIM PAKA [1] AND MICHAEL SPIRIDONOV [2]

[1] *Shirshov Institute of Oceanology, Atlantic Branch, Prospect Mira 1, 236000 Kaliningrad*

[2] *Karpinski All-Russia Geological Institute, St. Petersburg*

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.

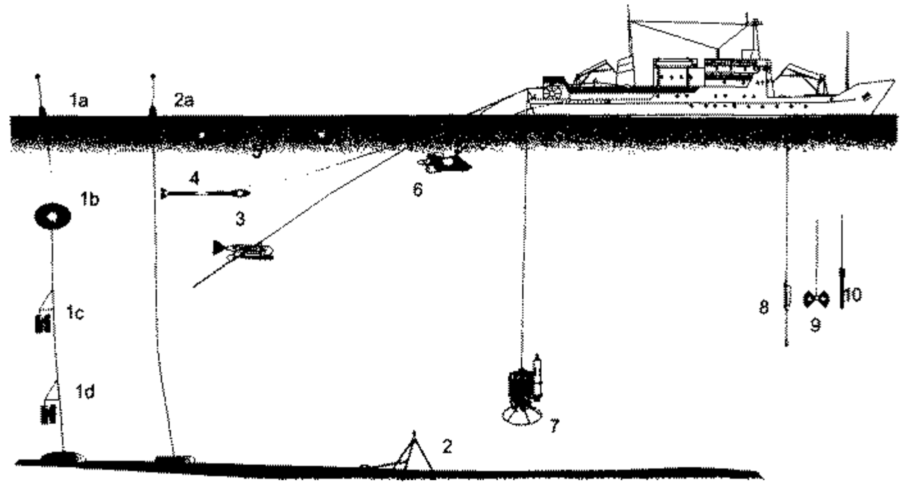

Fig. 1. Instrumentation of the R/V "Professor Shtokman". 1 - moored system consisting of a marker buoy (1a), a submerged float (1b), and current meters (1c, 1d), 2 - moored turbulence measuring probe with marker buoy (2a), 3 - towed undulating multi-parameter profiler, 4 - side-scan Sonar, 5 - differential 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.

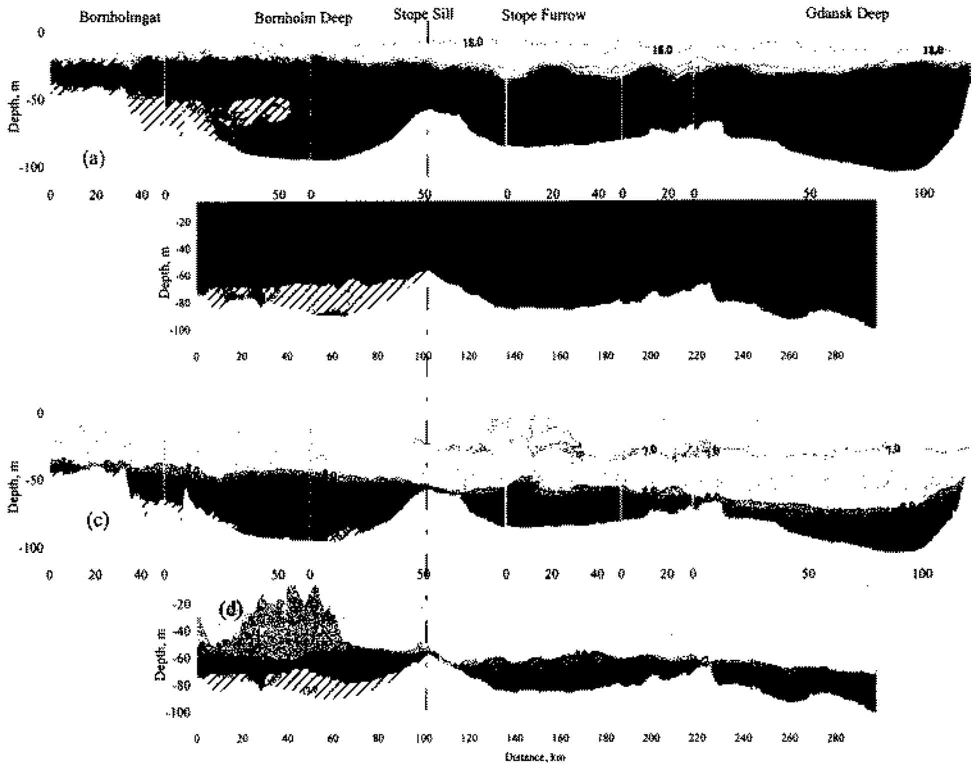

__Fig. 2.__ Distributions of temperature (a, b) and salinity (c, d) in the Southern Baltic from the Arkona Basin to the Gdansk Deep in September (a, c) and December (b, d) 1999. Positions of narrows, deeps and sills are marked by their names. Intervals of temperature 9 < T < 10 °C and salinity S > 16‰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

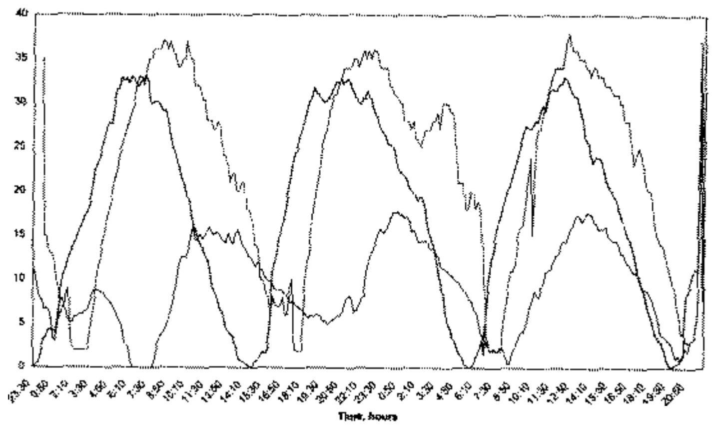

Fig. 3. Plots of measured current speed (cm/s) at depths of 20 m (highest magnitude), 40 m and 85 m (lowest magnitude) within the Bornholm dump site. Water depth 94 m.

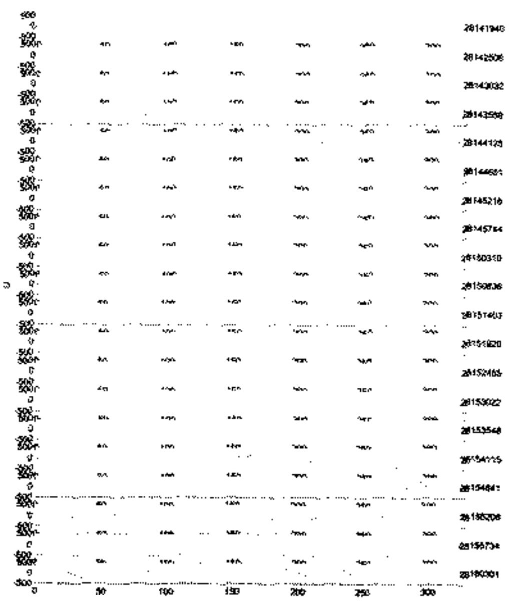

Fig. 4. Sample of the record of current velocity fluctuations made by the autonomous bottom-installed turbulence probe (see Fig. 1(2)). The magnitude has an arbitrary scaling. Each line represents one data file, named by date, hours, and minutes, to provide the ability to detect the duration of records 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

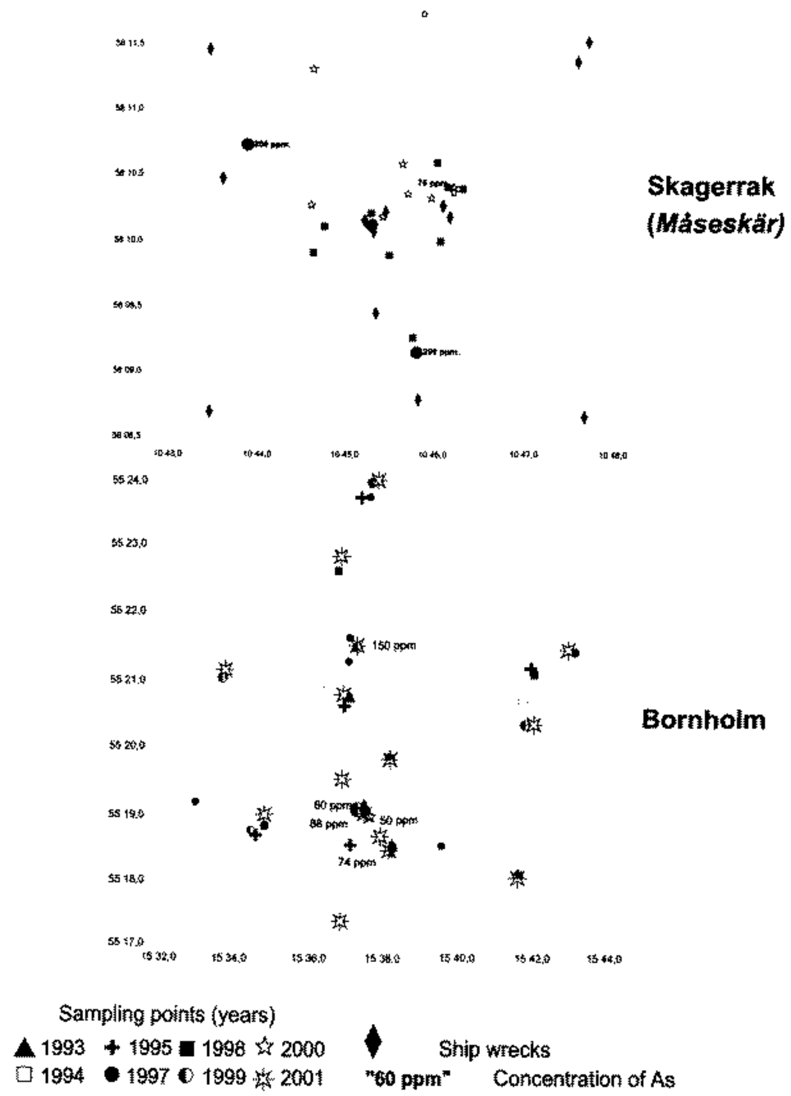

Fig. 5. Shipwreck positions and monitoring data at the Skagerrak (Måseskär) dump site (top) and at the Bornholm dump site (bottom).

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.

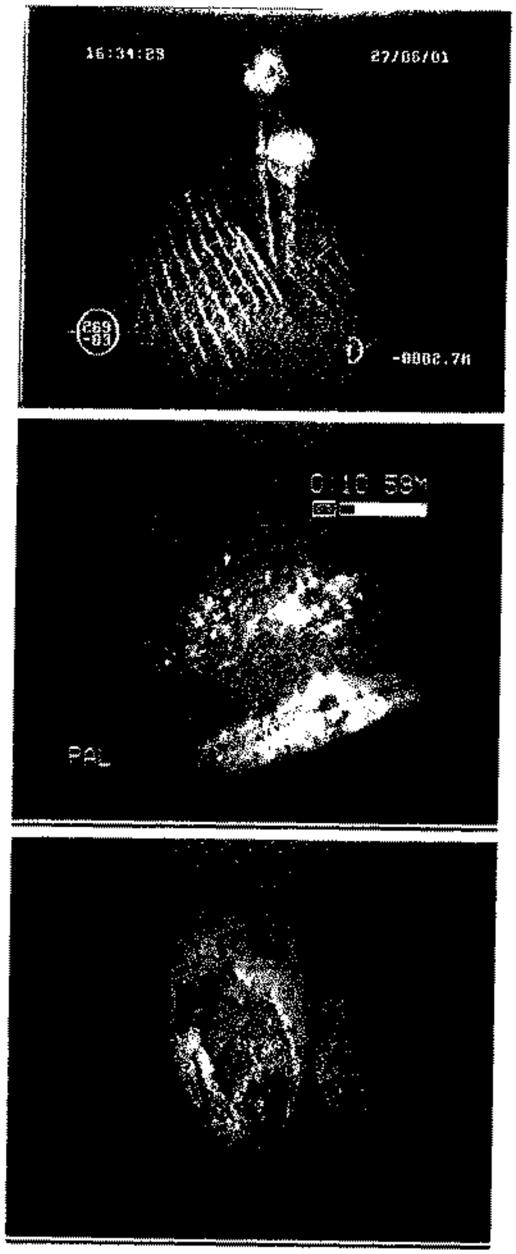

Fig. 6 . *Video-images of sunken vessels at the Bornholm dump site. Top: fishery nets. Middle: object looking like a tail of an aerial bomb. Bottom: corroded artillery missile*

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.

References

ALEXANDROV, V., AND EMELYANOV, V. 1993. *Poison-gases.* Moscow, Military publishing house, 272 p. (in Russian).

ANON. 1993. *Chemical munitions in the southern and western Baltic Sea. Compilation, assessment and recommendations.* Federal Maritime and Hydrographic Agency, Hamburg, Germany, 65 pp.

BORISOV, T. 1997. *Methods of burial of environmentally dangerous underwater objects.* Proc. III Internat. Scientific and Technological Conference "The Modern Technique and Tools for Oceanographic Researces", Moscow, pp. XVII-XXI (in Russian).

EMELYANOV, E.M. 1998. *Barrier zones in the ocean. The sediment- and ore formation, and geo-ecology.* Yantarny Skaz, Kaliningrad, 416 pp. (in Russian).

EMELYANOV, E.M., KRAVTZOV, V.A., AND PAKA, V.T. 2000. *Danger to life of areas of dumped trophy chemical munitions in the Skagerrak Sea and in the Bornholm Basin. Baltic Sea.* In: Local Agenda 21. Through Case Method Research and Teaching Towards a Sustainable Future. München, Mering, 58-64.

GARRETT, B. 1999. *Chemical weapons in the Baltic Sea: What is to be done?!* Baltic Floating University Research Bulletin, No 3, 94-98.

GORODNITSKI, A.M, AND FILIN, A.M. *Techniques and results of magnetic detection of dumped weapons in Bornholm and Skagerrak dump sites.* This volume.

HEINTZE, H.-J. 1997. *Legal problems related to old chemical munitions dumped in the Baltic Sea.* SIPRI Chemical & Biological Studies, v. 16. In: T. Stock & K. Lohs (eds), The challenge of old chemical munitions and toxic armament wastes. SIPRI Chemical & Biological Warfare Studies, Oxford University Press, 255-262.

HELCOM CHEMU. 1993a. Complex analysis of the hazard related to the captured German chemical weapon dumped in the Baltic Sea. Report submitted by Russia to the HELCOM CHEMU Working Group, 11 October 1993.

HELCOM CHEMU. 1993b. *Report on the availability of correct information on dumped chemical munition on the Swedish Continental Shelf.* Report submitted by Sweden to the HELCOM CHEMU Working Group, April 1993.

HELCOM CHEMU. 1994. *Report on chemical munitions dumped in the Baltic Sea.* Report submitted by Denmark to the HELCOM CHEMU Working Group, March 1994.

LAURIN, F. 1997. *The Baltic and North Sea dumping of chamical weapons : still a threat ?* In: T. Stock & K. Lohs (eds), The challenge of old chemical munitions and toxic armament wastes. SIPRI Chemical & Biological Warfare Studies, Oxford University Press, 263-278.

MEDEA. 1997. *Ocean dumping of chemical munitions: environmental effects in arctic areas.* US Government Report, 235 pp.

SURIKOV, B.T., AND DUURSMA, E.K. 1999. *Dumped CW agents in European seas.* In: E. Duursma, (ed), Dumped chemical weapons in the sea – options, Heineken Foundation for the Environment, Amsterdam, 5-12.

THEOBALD, N. Chemical Munitions in the Baltic Sea. This volume.