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Munitions Dumped at Sea: A Literature Review

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Executive Summary

1. Both chemical and conventional munitions have been extensively dumped at sea since World War I. The extent of dumping is worldwide, but for the purposes of this report we are concentrating primarily on those weapons that have been dumped in the waters around the UK and in the NE Atlantic.

2 The purpose of this study is to provide a "review of the relevant published studies and other relevant information on the current scientific opinion on munitions (both conventional and chemical) that have been disposed of by dumping on the sea bed".

3. In some cases, the location, and types, of both conventional and chemical munitions are well known. In other cases their locations and types are problematic for a number of reasons which include insufficient record keeping, dumping of material outside agreed official dumping areas and to an extent the movement of munitions, once dumped, to areas outside the dump locations. A comprehensive list of dumped chemical weapons (CWs) material does not exist, as the composition of material in many dumping incidents is unknown.

4. There are three basic types of danger that these sea-dumped munitions can cause:

   (i) direct physical contact with either chemical or conventional munitions resulting in threats to human health;

   (ii) contamination of marine organisms and the environment in the vicinity of dumped munitions and the consequent potential for some concentration of toxic contaminants entering the wildlife and human food chains;

   (iii) spontaneous explosions which can be both directly life threatening, but also have the potential to spread material away from the dump sites so increasing the potential for more of it to come into direct physical contact with individuals.

5. Direct physical contact with munitions can clearly come in a number of ways and include not only individuals who are involved in working in close proximity to dumped munitions, for example, fishermen, pipeline layers or those involved in construction projects such as dredging or off-shore wind farms. For example, there is literature to indicate that those using beaches are also under some threat as material following either oceanographic or man-made disturbance has been washed ashore and has the potential to cause injury.

6. The workers who are most directly involved in activities that lead them to close proximity to dumped munitions are fishermen. The overall depletion of the main fish stocks in the NE Atlantic has meant that trawler operators now fish deeper and in much wider geographical locations. There is thus the potential that fishermen will encounter material brought up in their nets. Of particular concern are encounters by fishermen with mustard gas, sometimes with severe results. The problem here is that the material can become encrusted so that the live mustard gas lies under a coating of encrusted sediment.

7. The practice for dealing with material that has been brought up in nets varies from country to country, but around the UK the practice is to send in a Naval team to deal directly with the material and to offer compensation to fishermen, if appropriate.

8. In aquatic systems, the transport, behaviour, fate and hence exposure of biota to chemical contaminants are, to a large extent governed by the physical and chemical properties of the compounds involved. For some of the warfare agents in question, these properties have been reviewed. It is convenient to distinguish between those that are water-soluble, those that contain mustard gas, and those that are arsenic based. Appendix 2 contains the chemical composition of the main materials that have been dumped (including conventional munitions). Whilst the solubility and other data (see also Table 3) are most useful, for the purposes of a comprehensive risk assessment much of the essential information is lacking. We have, for example, been unable in this study to find appropriate quality assured data to address Persistence, Bioaccumulation and Toxicological (PBT) criteria, traditionally the basis for assessing hazardous substances. It is suggested that these data should be compiled.

9. Conventional material including TNT and variants can be extremely toxic to marine organisms. There have been a number of studies that document this. There does also appear to be the potential that this material could concentrate in food chains after some degree of absorption has occurred. As far as we are aware, the toxicity of products of TNT in sea water has not been addressed in any detailed way in the current literature. However, a recent study comparing the environmental fate and transport process descriptors of explosives in saline and freshwater systems, found that, when tested in the laboratory, dissolution rates, transformation rates and absorption rates of TNT, RDX, and HMX were generally in close agreement in fresh and saline water.

10. Given this potential plethora of problems from dumped munitions it is important to examine the evidence to date of what if any examples there are of direct toxicity of CW and explosive material to marine organisms, and indeed the food chain. There was a comprehensive survey conducted by the Marine Laboratory in Aberdeen in 1995. This study found no evidence of a problem from the material, in excess of one million tonnes, that had been dumped in and around Beaufort’s Dyke.

11. The literature implies that there may have been spontaneous detonations of dumped conventional munitions in the Beaufort's Dyke, but as yet no definitive evidence exists. However, any dumped munitions which contain Shellite or Lyddite as the filling will be far more likely to spontaneously detonate than, for example, TNT-filled ordnance. Especially if the dumped munitions which contain Shellite or Lyddite as the filling are disturbed. This might arise, for example, from them being subjected to an impact due to the structure of a ship collapsing, or another munition falling, onto them. Thus, clearly, there is the possibility of spontaneous detonations of dumped conventional munitions, which might trigger further explosions. However, the literature, albeit very limited in extent, does not consider there to be any major threat from even relatively large underwater detonations occurring in the dumping sites. Further, the incident of the *SS Kielce* (which was in a collision and sank in the English Channel off Folkestone with a "full cargo of bombs and ammunition") where there was an explosion during an attempt to remove the munitions *"reinforced the decision of the Committee on Hazardous Wrecks to recommend a policy of non-interference."*

12. The overwhelming view to be found in the literature, with respect to both conventional and chemical munitions, is that the munitions dump-sites on the sea-bed should remain undisturbed.

13. Turning to future scenarios, then it is clearly evident from the literature that the current state of corrosion of casings of munitions dumped on the sea bed varies from 'very little' to 'completely degraded away', and that it is not possible to predict the condition of the munitions in a particular dumping area. There is no definitive evidence in the literature which considers that the continuing corrosion of munitions dumped on the sea-bed will give rise to any step-change in the conclusions which have been currently reached, assuming that the munitions are left undisturbed. However, most authors would argue that there should be some continued monitoring.

1. Introduction

1.1 Both chemical and conventional munitions have been extensively dumped at sea since World War I. The extent of dumping is worldwide, but for the purposes of this report we are concentrating primarily on those weapons that have been dumped in the waters round the UK and in the NE Atlantic. The purpose of this study is to provide a "review of the relevant published studies and other relevant information on the current scientific opinion on munitions (both conventional and chemical) that have been disposed of by dumping on the sea bed". Much of the literature referred to in the following sections relates specifically to munitions dumping and associated impacts of this in the Baltic Sea. This is primarily due to the high relevance of information sourced from this region (e.g. types and quantities of munitions dumped, dates and methods of dumping, subsequent human activities in the area). Additionally, the Baltic Sea effectively provides a 'worse case' scenario, due to the relatively shallow depths of the dumping sites in the Baltic: e.g. east of Bornholm at depths of approximately 90m, South of Gotland at depths of approximately 100 to 130m, and as shallow as 30m in the Little Belt region (Surikov and Duursma, 1999). These depths may be compared with the greater depths of dumping grounds in the Beaufort's Dyke area of the Irish Sea of between 100 to 200m, and up to depths of 300m in some areas (FRSR, 1996).

1.2 In some cases, the location, and types, of both conventional and chemical munitions is well known. In other cases their locations and types are problematic for a number of reasons which include insufficient record keeping, dumping of material outside agreed official dumping areas and to an extent the movement of munitions, once dumped, to areas outside the dump locations. Appendix 1 gives some examples of the locations and types of sea-dumped munitions. For example, considering some of the many relevant statements:

"*Dumping east of Bornholm in the Bornholm basin was primarily inside a circular area with a radius of 3 nautical miles. The centre of this area is specified on the Danish charts with the coordinates 55° 21'0 N and 15° 37'02 E. However, it must be assumed that the chemical munitions were spread over a considerably larger area during dumping. Several factors indicate this, e.g. the positions where fishermen have caught munitions in their nets and the circumstances of the dumpings.*" (HELCOM, 1994)

"During transport to the dumping area east of Bornholm, munitions were sometimes thrown overboard while the ships were on route. Therefore, warfare agents are assumed to be spread over a considerable area along the transport routes.

Furthermore, the actual dumping of munitions may have taken place while the vessels were either drifting or under-way. The first dumping operations took place while munitions were still packed in wooden boxes, which sometimes were observed to drift around before sinking to the bottom of the sea. It is stated, that in some cases the boxes were washed ashore on Bornholm and on the Swedish coast.

Buoys marking the dumping positions were laid out relatively late. By that time the dumping vessels were only equipped with strictly necessary navigation equipment, therefore in many cases the exact dumping positions are uncertain." (HELCOM, 1994)

"However, spreading of the chemical munitions are also done unintentionally by fishing vessels when trawling. In this way, chemical munitions can be dragged about in the trawl over the sea bed without being caught." (HELCOM, 1996)

"…spreading of dumped chemical warfare material is to some degree caused by fishermen re-dumping chemical warfare equipment which has been caught in fishing nets, possibly a long way from the position where it was dumped originally." (HELCOM, 1996)

1.3 And an extensive report produced from surveys of the Beaufort's Dyke Explosives Disposal site, which was carried out by Fisheries Research Services, Marine Laboratory, Aberdeen between November 1995 and July 1996 (1996), stated that:

"Side-scan sonar, underwater television, and pulse induction surveys confirmed that the centre of distribution of dumped munitions and munitions-related materials was located within, and immediately adjacent to, the northeast sector of the Beaufort's Dyke explosives disposal site.

Medium to high densities of dumped munitions, munitions-related materials and unidentified man-made debris were confirmed in the area adjacent to the northeast sector of the charted explosives disposal site. In this area, munitions and munitions-related materials were located a considerable distance outside the charted boundary of the site.

Low to medium densities of unidentified man-made debris were confirmed in two smaller areas to the west and southwest of the charted boundary of the explosives disposal site."

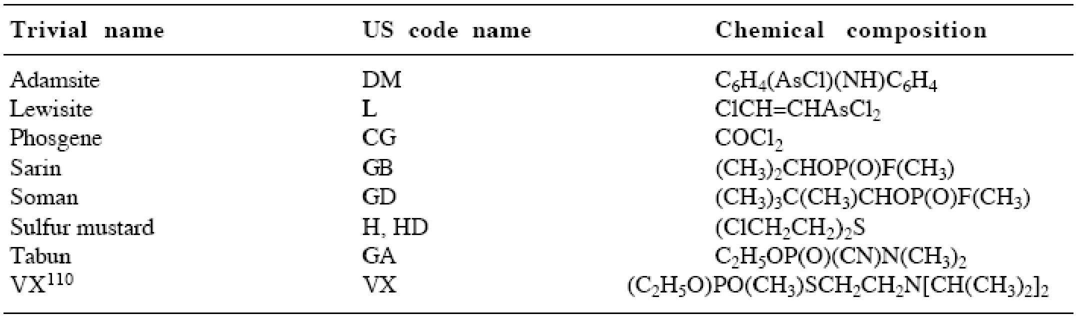
The report concluded that:

"*The results of the side-scan sonar, underwater television, and pulse induction surveys confirm that the centre of distribution of dumped munitions and munitions-related materials is located within, and immediately adjacent to, the northeast sector of the explosives disposal site. Large quantities of dumped munitions and munitions-related materials are located in the area adjacent to the northeast sector of the charted explosives disposal site. Moderate quantities of unidentified manmade debris, probably related to munitions dumping operations, are located in two smaller areas adjacent to the west and southwest boundaries of the charted explosives disposal site."*

1.4 The materials that have been dumped around the UK are a mix of captured German material and that produced by the UK. Elsewhere there is Russian, American and other material. The locations and types of material that have been dumped are indicated in Appendix 1. It is convenient for the purposes of this report to make a distinction between conventional and chemical munitions, although as will be seen later, both can have toxic effects on the environment.

1.5 As noted above, a comprehensive list of dumped chemical weapons (CWs) material does not exist, as the composition of material in many dumping incidents is unknown. A list of chemical warfare agents and their chemical compositions (Hart, 2000) is given in Table 1.

Table 1. Chemical Warfare Agents and Their Chemical Compositions (Hart, 2000).



Trivial name	**US code name**	**Chemical composition**
Adamsite	DM	$C_6H_4(AsCl)(NH)C_6H_4$
Lewisite	L	$ClCH{=}CHAsCl_2$
Phosgene	CG	$COCl_2$
Sarin	GB	$(CH_3)_2CHOP(O)F(CH_3)$
Soman	GD	$(CH_3)_3C(CH_3)CHOP(O)F(CH_3)$
Sulfur mustard	H, HD	$(ClCH_2CH_2)_2S$
Tabun	GA	$C_2H_5OP(O)(CN)N(CH_3)_2$
VX[110]	VX	$(C_2H_5O)PO(CH_3)SCH_2CH_2N[CH(CH_3)_2]_2$

These chemical weapons can easily be divided into three types. Those that are directly soluble in water and are therefore unlikely to present significant problems; those that contain high arsenic content which has the potential for concentration in the food web; and those containing mustard gas where polymerisation is possible and the material is therefore unlikely to be broken down quickly and will remain in the location where it has been dumped unless moved by oceanographic factors. For example, Hart (2000) states that:

"In principle, CW agents may (a) be essentially inert and pose little if any toxic threat to the marine environment; (b) hydrolyze readily into relatively benign hydrolysis products; or (c) pose a highly toxic, long term environmental hazard (e.g. through bioaccumulation). Various ocean processes and their physical and chemical interaction with plant and animal life complicate any attempt to analyze the behaviour of CW agents in the marine environment. Chemical changes may be caused by hydrolysis, oxidation, photolysis and thermolysis reactions. Most chemical changes of CW agents in the marine environment are caused by hydrolysis, however....."

1.6 Conventional munitions are unsurprisingly the main proportion of the material that has been dumped and they consist primarily of TNT and other similar material. The extent of the dumping and the volumes of these material are again indicated in Appendix 1.

1.7 There are three basic types of danger that these sea-dumped munitions can cause:

(i) direct physical contact with either chemical or conventional munitions resulting in threats to human health;

(ii) contamination of marine organisms and the environment in the vicinity of dumped munitions and the consequent potential for some concentration of toxic contaminants entering the wildlife and human food chains;

(iii) spontaneous explosions which can be both directly life threatening, but also have the potential to spread material away from the dump sites so increasing the potential for more of it to come into direct physical contact with individuals.

Each of these dangers is addressed in some detail in the following sections of this report. In Section 2, direct physical contacts are addressed. In Section 3, contamination of marine organisms and the possible effects on the food chain are explored and, in Section 4, the potential for spontaneous explosions is examined.

1.8 Clearly some key options that this report needs to address are whether:

(i) the munitions dump-sites on the sea-bed should remain undisturbed; or

(ii) the munitions should be recovered and treated in some way in order that the dangers outlined in previous paragraphs cannot be realised; or

(iii) to examine possible ways in which the material can be rendered completely harmless *in situ*.

Section 5 of the present report deals with these questions.

1.9 There is a potential issue that insufficient time has elapsed for the full process of corrosion to have affected the containers of the chemical weapon or explosive material. There is thus the potential that corrosion in subsequent years may lead to hitherto unrealised problems. This is examined in the Section 6 of the report, where possible future scenarios are addressed.

2. Physical Contact with Munitions

2.1 Direct physical contact with munitions can clearly come in a number of ways and include not only individuals who are involved in working in close proximity to dumped munitions, for example, fishermen, pipeline layers or those involved in construction projects such as dredging or off-shore wind farms. For example, there is material evidence to indicate that those using beaches are also under some threat as material following either oceanographic or man-made disturbance has been washed ashore and has the potential to cause injury. Most evidence comes from a survey and report covering a twelve-month period between 1 March 2002 and 28 February 2003 by the Advisory Committee On Protection of the Sea (ACOPS, 2003). Excerpts are given below from Section 4.5 covering Munitions and Pyrotechnics:

"The Royal Navy reports indicated that at least 15 items of explosives ordnance or their components had been recovered in the nets of fishing vessels operating in coastal waters around the British Isles. The items included bombs, buoyant mines or their components, depth charges and torpedo components. In all incidents the items were safely disposed of without any injuries sustained by fishermen or damage to their vessels.

Seven of 11 bombs reported were recovered in the East of England Region. Two World War II 1,000 pound (454 kg) bombs were recovered in the nets of a fishing vessel operating off the Essex coastline and in a Clyde Naval Dockyard during June 2002. Two British medium capacity bombs were trawled up by fishing vessels during July 2002. A German World War II SC 250 bomb was recovered at Portsmouth.

Two depth charges were attributed to the wreck of HMS Vulture in Loch Erribol. Another two depth-charges were reported by fishing vessels operating in Scottish waters off Dunbar and Troon.

Most hand grenades were recovered on the shores of southern and south-west England including amenity beaches at Bournemouth, Brixham, Chichester, Hayle, Newquay, Portsmouth Sidmouth, St. Austell and St. Ives.

The most frequently reported types of mines were British and German World War I and World II buoyant sea mines or their components, including sinker mooring drums, top sections and charge cases. At least three British Mark 17 buoyant mines were trawled-up in the nets of fishing vessels operating in Scottish waters. World War I buoyant mines were safely disposed of at Weston-super-Mare, Weymouth and at Dover.

Most land service mortar projectiles were recovered in the Wales and the West of England region in the vicinity of former coastal practice or gunnery ranges. Reported finds included twelve 3" projectiles and smaller numbers of 2", 4" and 6" projectiles. Several items were recovered on or near amenity beaches at Braunton, Eastbourne, Littlehampton, Newquay and Woolacombe.

Military pyrotechnics, mostly in an expired condition, were washed ashore around the entire UK coastline during the survey period. Most were current phosphorous smoke and flame generating devices launched from aircraft, ships and submarines and examples are shown in ***Plates 5 & 6****. At least 12 pyrotechnics were attributed to the US Services and 9 to the French Services.*

Rocket or rocket components were reported on 11 occasions and all were recovered in the Wales and West of England MCA Region. During April 2002 a Sea Cat Practice warhead was discovered on a beach at Mousehole and during the same month part of a Sea Wolf missile was landed at Looe by a local fishing vessel. Six barrage rockets were discovered in the vicinity of a former practice range at Borth.

A wide range of different types and calibres of shells, both naval and land service, were reported during the survey period. The smaller calibres (< 76.2mm) included high explosive naval shells, cannon shells, anti-aircraft shells and artillery shells. Twenty-three 25 pound practice and high explosive shells were collected from the former Whitford Sands range on the Gower Peninsula during the survey period. Elsewhere, eight nineteenth century Palliser type shells were discovered and safely disposed of.

The larger calibre rounds (> 76.2mm) included 3", 4", 5", 6" and 13" high explosive naval shells which were recovered at many different locations around the UK coastline including Dover, Great Yarmouth, Hurst Spit, Lymington, Portland and Shoeburyness. Out of a total of 1,339 shells reported, 1,076 were collected from aggregate yards in eastern and southern England where they had been landed by vessels engaged in marine aggregate collection operations.

The Royal Navy reports also referred to torpedo components including 3 air vessels, 2 tail sections and 2 warheads. The miscellaneous category of other explosive and non-explosive items included a target sonar buoy, a navigation buoy battery, bomb fuses, percussion detonators and a bridge demolition charge." (ACOPS, 2003).

Additional information originates from the National Press. For example:

"Beach users have suffered burns after handling devices containing phosphorous" (Dixon, 1992; Scottish Herald, 21 October, 1995) (ACOPS, 2003)

2.2 There is some literature on the material that has been washed up on beaches and the problems that this has caused and the types of materials that have been particularly problematic have included phosphorous and high explosives. There seems to be little evidence currently around the UK of mustard gas and related compounds being washed ashore and causing danger to those encountering it. This may be for similar reasons to those pointed out by HELCOM (1994), for the lack of incidences reported in the Baltic Sea region:

"With the exception of tabun, all the warfare agents given in Table 6 are much heavier than Baltic Sea water (density: 1.08 g/cm3). Therefore, warfare agents dumped in the Helsinki Convention Area do not show a tendency to rise to the surface and drift away."

"The possibility that chemical munitions or lumps of viscous mustard gas can be washed ashore is extremely unlikely. All of the dumped chemical warfare agents have a density of more than 1.

The only exception is tabun, which has a density close to 1. 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. Likewise, lumps of viscous mustard gas, which have a density of about 1.3 - 1.5 g/cm^3*, will not be shifted far by the currents. Except for the cases referred to below, there has not been any confirmed reports of bombs or bomb remains having been washed ashore on Danish,* *Swedish, Polish or German territories, since the dumped warfare objects were settled on the seabed. Again, except for the cases referred to below, rumours about mustard gas finds on beaches, did not stand up to later investigations.*

The only confirmed finds of chemical munitions onshore are the following:

It is reported that five bombs were found along the Polish coast between 1952 and 1954, but it is not known whether they were conventional or chemical munitions. Similarly, their origin is uncertain - possibly they have been dumped en route to the dumping areas.

In 1954, a chemical bomb was found at Selliner Strand on the island of Rügen. The possibility that water currents could have transported this bomb to Rügen from a depth of around 100 m in the Bornholm Basin can be ruled out. It is more likely that the bomb was thrown overboard near Rügen while being transported from Wolgast.

On the 18th of February 1992, a 250 kg bomb containing mustard gas was found at Dueodde beach on Bornholm. Judging from the bomb's condition, Danish experts came to the conclusion that it had not been in the sea for a longer period of time and that it had not been washed ashore.

The possibility is also ruled out that the bomb had been buried for a longer period of time in the sand and had only just been uncovered by the tide. Thus, the only possible explanation is that the bomb has been placed at the beach by purpose.

Supporting the conclusion - that warfare agent residues from the dumping areas in the central part of the Baltic Sea area cannot be washed ashore by currents - is the fact that the seabed currents in the area are easterly and weak, and that material released from the seabed will thus move into the Baltic Sea. In addition, the dumped material needs to be moved upwards from a depth of up to 100 metres in order to be washed ashore." (HELCOM, 1994)

2.3 There is some evidence to indicate that washed-up munitions are more numerous following disturbance, thus laying pipelines through the Beaufort's Dyke may have resulted in a number of incidents that were documented at the time. For example, the ACOPS (2003) survey reported that:

"Apart from large bombs and shells, munitions and non-military pyrotechnics have been dispersed from their original dumping or loss positions by water movements. Subsequently, many items have either been found on the shoreline or recovered during the exploitation of marine resources.

For example, since 1990 at least 5,000 incendiary-type devices with a phosphorous content have been washed up on the Isle of Man and other areas of the Irish Sea coastline, particularly south-west Scotland and the Antrim area of Northern Ireland (The Scotsman, 5 September, 10 October & 25 October 1995; Belfast Telegraph, 6 October 1995). The non-military incendiary devices may have been disturbed on the seabed during seismic work and a pipe-laying operation (Daily Telegraph, January 9 1996). The competent authorities continue to issue warnings alerting beach users to the danger of handling the devices, some of which have ignited and given off noxious fumes (Plate 1). During March 2003 a further 30 devices were recovered on beaches on the island of Arran. The above figures quoted in newspaper articles have not been verified by the competent authorities."

"Anti-tank and anti-invasion mines were recovered from two beaches in Norfolk. Two World War II German Parachute mines and a German Ground Mine were recovered in the Thames Estuary. Two reports referred to recovery of mines in the vicinity of oil and gas installations. During July 2002 a US Mk 52 Drill Mine and a German GG Mine were located in BP's Amethyst and West Sole Gas Fields." (ACOPS, 2003)

An article from Harrison in the 'Diver' magazine, described how:

"In 1995 the Beaufort Dyke hit the headlines after 4000 phosphorous incendiary bombs were washed up on Mull, Oban, Arran and other parts of Scotland's west coast. A four-year-old boy, Gordon Baillie from Campbeltown, suffered burns to his hand and legs when a bomb he picked up on the beach ignited. The bombs had become dislodged by British gas engineers who were laying a pipeline close to the dyke, environmentalists claimed. Government ministers were quick to point out that no link could be proven between pipe-laying and the appearance of the bombs. Shortly afterwards, however, they were proved wrong. Sonar and video scans by the Scottish Office's marine laboratory in Aberdeen proved "beyond reasonable doubt" that the bombs had been disturbed by British Gas ploughing operations. A series of articles in, among others, The Independent, The Times and New Scientist, showed that bombs had been dumped short of the intended site and had lain 3 miles offshore, in as little as 50m of water." (Harrison, 1998)

Further evidence is outlined by Davies (1996):

"The saga of the munitions dump in Beaufort's Dyke, Irish Sea (See Mar. Poll. Bull. 30 (12), p 768) looks set to continue with further data now available about the spread of material and contaminants around the dump site. The Scottish Office Agriculture and Fisheries Department carried out a video and seabed sampling survey earlier in the year which has shown that munitions material does lie a considerable distance outside the designated dump site. The position of this material in relation to the recently laid gas pipeline provides strong 'circumstantial' evidence that the pipeline operations had been responsible for the disturbance of containers of phosphorous flares. The flares were then washed up on nearby shores over the following months in considerable quantities."

There is evidence to indicate that, following disturbance, explosives and case material has been encountered on beaches. However, it should be emphasised that man-made disturbance does not constitute the only cause of material being washed ashore.

2.4 In particular, there seems evidence to indicate that following corrosion certain types of munitions are able to float and that these can wash ashore, while there are also indications that oceanographic factors can lead to quite substantial movements of large munitions. A report by the OSPAR Commission (2004) details how:

"Phosphorus devices also present long term problems. Advice to date has been that if left undisturbed on the seabed they pose no risk. If disturbed, as was the case recently in the Irish Sea's Beaufort's Dyke dumpsite during pipe laying, these positively

buoyant devices may float to the surface and represent a real risk to the seafarers and to the general public should they be washed ashore. Without records being maintained on encounters with dumped munitions and chemical weapons it is not possible to monitor the risk posed by such munitions and weapons."

And:

"During the 1990s reports of large numbers of phosphorous devices stranded on Scottish and Irish coasts were commonplace. While these devices may have been dislodged as a result of pipe laying activities, once they escape from their cases will, as a result of their positive buoyancy float to the surface. On the surface these devices are at the mercy of wind and currents and represent a real risk to the seafarers and to the general public should they be washed ashore. One of the concerns relating to phosphorous devices is that the containers they were dumped in may now be in an advanced state of decay."

2.5 Most munitions recovered in the marine environment are subsequently disposed of by Royal Navy Explosive Ordnance Disposal (EOD) Teams which are part of the Superintendent of Diving (Fleet Diving Squadron) currently based at Horsea Island. The United Kingdom is divided into three command areas each with its own EOD units. EOD units can respond to any requests for assistance in any part of the UK within a few hours. EOD units generally assume that the items recovered are armed, and the explosives in a sensitive state following deterioration with time, especially when they have been out of water. In some instances mines have been immersed in sea-water for more than 50 years have been found to be in perfect working order and capable of functioning as designed.

2.6 The current practice of involving the military at an early stage to address any problems seems to be working well. However, although there is some evidence to indicate that there is some slackening off in the level of incidents that are occurring, nevertheless, the need for Naval involvement in the destruction of such material is likely to extend for a considerable period of time. In the ACOPS (2003) report:

"Analysis of Royal Navy statistics indicated further significant reductions in reported finds of six of the eight types of munitions and pyrotechnics. The only exceptions were land service mortar projectiles and hand grenades, and all types of shells. Buoyant mines and torpedoes, or their components, continue to be trawled up in the nets of fishing vessels operating around the UK coastline. The advice and procedures issued by the authorities to fishermen and others in response to such incidents appear to be followed thereby minimising the risks of injuries or fatalities.

Few civilian pyrotechnics, such as date-expired distress signals, were recovered on beaches because large numbers continue to be brought ashore by mariners for correct disposal by the competent authorities."

"Overall, explosives ordnance of World War II origin still accounts for a significant proportion of reported finds especially in the MCA's East of England Region. The evidence suggests that substantial quantities still remain to be discovered and hence the services of RN Diving Teams will continue to be required for many years to come."

2.7 The workers who are most directly involved in activities that lead them to close proximity to explosive material are fishermen. The overall depletion of the main fish stocks in the NE Atlantic has meant that trawler operators now fish deeper and in much wider geographical locations. There is thus the potential that fishermen will encounter material brought up in their nets. Examples include the deaths of three Dutch fishermen on April 6th this year who were killed when the trawler Maarten Jacob hauled a bomb on board which then exploded (Lloyds List 6.4.05). An article in April 15th 2005 edition of Fishing News describes the incident:

"An explosion on board the Dutch beamer Maarten Jacob of Ouddorp OD 1 (Skipper Krijn vd Klooster) killed three of her crew last Wednesday (6 April) as she fished 100 miles west of Ijmuiden. Five of the crew were on deck when a huge explosion occurred as the cod end of the port beam trawl was released above the bin. It was believed to have been caused by an unexploded World War II bomb or shell. Two of the crew were blown overboard by the explosion, while a third was found fatally injured aboard. The two other crewmen on deck were uninjured. A Lynx helicopter lowered a doctor on board, but he could only certify the deaths. A hole had been blown through the bin and deck and into the fish hold, but the boat was still seaworthy enough to proceed to Ijmuiden under her own power. The dead were transported to a hospital in Haarlem. The victims were the skipper's son Jaap vd Klooster (27), Hans Meijer (58) and Jos van Belzen (40). The mines are thought to be lying about 40 miles off the coast of Lowestoft, close to the median line with Netherlands waters in a depth of 40m. Yarmouth Coastguard has issued a warning to fishermen regarding unexploded ordnance on the seabed in the following areas: 52 22.148N 002 55.346E, 52 25.076N 002 53.240E and 52 17.037N 002 43.113E. There is no immediate risk, but it asks if any ordnance is raised in the nets to lower it back gently into the water and mark the site and contact the Coastguard."

2.8 The incidents described below are for illustrative purposes only and do not provide a basis for assessing the frequency of such events. Details of each incident were generally confirmed with local authorities and other reporting organisations, including the MoD (Dixon, T.R. and Dixon, T.J., 1985; Dixon, T.R., 1992).

2.9 Incidents of munitions on boats include:

1 September 1982-31 August 1983. First ACOPS survey of packaged dangerous goods/munitions. Approximately half of the 75 mines reported were British or German World War II buoyant types recovered in the nets of fishing vessels and subsequently landed at ports. Likewise, 15 British and German torpedoes were recovered by fishing vessels and landed in ports at Burghead, Girvan, Greenock and Tarbert.

April 1986 and March 1989. The ***Susana D****, a 28m long beam trawler was damaged when a mine caught in its nets exploded 8 km south of Beach Head (Fishing News, 11 April 1986). The same vessel was again damaged after detonating another mine in its trawl gear off Shoreham on 5 March 1989 (Lloyd's List, 11 March 1989).*

August 1986. One crewman was injured, and the dredger ***Arco Tees*** *damaged 16 km off the Norfolk coastline when the suction head of the vessel detonated a suspected bomb or mine (Daily Telegraph, 5 August 1986).*

October 1988. The fishing vessel ***Niblick*** *operating off Lowestoft was slightly damaged following an explosion when hauling in nets. There were no injuries to the crew (Lloyd's List, 3 October 1988).*

June 1989. The fishing vessel ***Ha'burn*** *netted a mine off the Isle of Arran. The mine was towed a safe distance from land for a controlled explosion. As the vessel sailed away an explosive charge attached to the mine by an EOD team detonated prematurely. Shrapnel hit the Ha'burn which later sank and the crew were rescued (Lloyd's List, 3 July 1989; Financial Times, 1 July 1989).*

January 1990. There was a controlled explosion after a 500 kg German bomb was hauled in by a dredger operating in Poole Harbour (Daily Telegraph, 10 January 1990).

19 August 1990. A trawler recovered a WWII sea-mine off Weymouth.

31 December 1991. The fishing vessel ***Shelandra*** *netted 23 kg of gun cotton in blocks, which were later brought ashore for disposal at Ramsgate.*

1 October 1991-30 September 1992. During the second survey undertaken by ACOPS 12 German GC mines were recovered by fishing vessels in the Thames Estuary and English Channel. British buoyant mines, including 16 practice or exercise types, were similarly reported throughout the UK survey area and landed (or brought inshore) for disposal at Methil, Port Seaton, North Shields, Blackwater Estuary, Whitstable, Ramsgate, Mersea, Lee-on-Solent, Poole, Portland, Brixham, Plymouth and Swansea. Similarly, torpedoes (or components) were landed by fishing vessels at Gosport, Wynes Bay and Peterhead.

2.10 Interactions with chemical munitions involving phosphorous include:

22-27 July 1983. Twenty-six military smoke and flame markers (originally containing some phosphorous and calcium phosphide) were washed ashore without warning on beaches in South Devon and Cornwall. The Emergency Services were required to carry out a search and recovery operation. All persons who had been in contact with the devices were advised to seek precautionary medical examination.

August 1987. The fishing vessel ***Emma Radich*** *operating off Aldborough trawled in a case of phosphorous which later ignited on deck. There were no injuries to the crew.*

February 1989. There was an alert at Studland Bay in Dorset after children inadvertently collected small particles of phosphorous, with seashells, from a local beach. The particles later ignited in a minibus. A sunbather received minor burns in the same location during the previous year (Sunday Telegraph, 12 February 1989).

October and November 1990. Moyle District Council (Northern Ireland) responded to a major incident after approximately 300 gelled gasoline incendiary devices were found stranded on beaches at Cushendall between 20 October and 18 November 1990. Each was in the form of a canister, 5 cm long by 1.4 cm in diameter, and filled with cellulose acetate, butynate and petrol, with a white phosphorous igniter. Similar devices, used as anti-tank bombs, were issued by the authorities to some units of the Home Guard during World War II. They were later collected and disposed of by dumping in deep water in the Beaufort Dyke. Another 34 devices of the same type were washed ashore between 1 and 3 June 1992.

November 1990. Six workmen required precautionary medical examination after discovering a cache of 37 phosphorous grenades in half pint bottles at Croyde in North Devon. One later ignited when thrown onto rocks (Daily Telegraph, 9 November 1990).

April 1992. Pieces of white phosphorous were recovered from a beach on the Mull of Kintyre.

30 August 1992. A 17 year old girl suffered burns to her body after inadvertently picking up a piece of white phosphorous from a beach at Margate. The phosphorous ignited after it had dried out in the pocket of her coat. Both her mother and sister sustained minor burns as they attempted to deal with the emergency.

30 August 1992. Pieces of white phosphorous were recovered from an amenity beach at Cleethorpes.

2.11 The practice for dealing with material that has been brought up in nets varies from country to country, but around the UK the practice is to send in a Naval team to deal directly with the material and to offer compensation to fishermen, if appropriate. For example:

*"**1.4.12** In the event of trawlers, dredgers or other vessels unintentionally recovering discarded explosives, there is an established procedure in place whereby mariners inform the Naval Authorities, through HM Coastguard, Ship's Agents or Fishery Offices. The procedure is communicated to fishermen and other mariners in the Annual Summary of Admiralty Notices to Mariners (NP247) and the Mariners Handbook (NP100) published by the UK Hydrographic Office (UKHO). In particular, detailed advice about handling discarded explosives is contained in Annual Notice to Mariners Number 6. For example, instructions are given to fishermen operating from ports in the United Kingdom explaining how to dispose of mines and other explosive weapons encountered at sea, or recovered in trawls."* (ACOPS, 2003)

2.12 High explosives and other chemical munitions can be encountered by fishermen in this way. However, in the case of chemical munitions we have been unable to find instances of these encounters in British waters. The OSPAR Commission (2004) discusses the lack of reports in the UK amongst other countries as follows:

"The remaining seven Contracting parties (Ireland, Belgium, France, UK, Portugal, Spain and Norway) indicated that there was 'no information' available on reported incidents (i.e. date, location, details etc.) It is unclear whether this reflects the fact that there have been no incidents reported in these countries or if such information is either unavailable or unrecorded. Thus, whilst there are formal procedures in place for reporting encounters, these procedures do not go as far as maintaining easily accessible central records of historic incidents."

and Hart (2000) added:

"Procedures for reporting and collecting data on such incidents from around the world could probably be improved. It is standard procedure for fishermen who recover conventional or chemical munitions to cut their nets. Denmark offers financial reimbursement to fishermen for lost nets. The number of reported incidents rose sharply in 1991 to a total of 103 incidents. Then, however, the number dropped to 58 in 1992. Between 1976-90, before the remuneration program took effect, the total reported incidents varied from 5 to 48. The numbers may be skewed upwards due to the policy of remuneration. Conversely, not offering financial restitution for lost nets may have resulted in under reporting of recovery of CW."

In this context, it is noteworthy that the Maritime and Coastguard Agency is now establishing a database to record incidents and encounters with munitions at sea or when ashore around the UK (CG3 Coastguard and Operational Instructions).

2.13 There are a number of instances however, of fishermen coming into contact with this material elsewhere, particularly in the Baltic. For example, OSPAR (2004) reported that:

"In the period 1995-2000 a total of 11.3 tonnes of conventional munitions have been encountered by fishermen and reported to the authorities in the German state of Lower Saxony. An average of 10 conventional explosives have been located annually by Dutch fishermen over the last decade, and destroyed. Swedish and Danish fishermen have recovered quantities of chemical munitions from the Baltic over the past several decades."

While HELCOM (1994) reiterated that:

"Discoveries of warfare agents during fishery outside the dumping areas, happen from time to time. The problem is recognised especially in the area east of Bornholm. Fishermen operating here do repeatedly find bombs, shells and fragments thereof and lumps of mustard gas in their bottom trawl nets."

Of particular concern are encounters by fishermen with mustard gas, sometimes with severe results. The problem here is that the material can become encrusted so that the live mustard gas lies under a coating of encrusted sediment. For example:

“Germany has reported 13 cases. Only the incidents in which crews were injured are known -so far with no major fatalities. All 13 incidents occurred east of Bornholm in the area marked "Foul chemical munitions" and "Anchoring and Fishing Dangerous" or in the immediate vicinity. Sweden has reported 4 incidents with mustard gas from this area since 1980 -one involving a fishing vessel from Estonia.

Due to the fact that in the Gotland Basin the composition of the munitions is similar to that in the Bornholm Basin, a similar assessment of the risks to fisheries applies, but at a smaller scale.

Latvia has reported about fishermen's contact with chemical munitions. The contacts have taken place in the 50s up to the 70s, and in some cases later. The places of discovery are within the dumping area south-east of Gotland. Most findings were in the 50s, and in some instances the contacts have caused heavy consequences for fishermen.

Sweden has reported 4 fishing vessel incidents involving dumped chemical warfare agents southeast of Gotland since 1980. Two incidents involved mustard gas and the others Clark I and chloroacetophenone. Likewise Lithuanian fishermen occasionally have had contact with chemical weapons in the area. One episode from 1986 is reported (56 ° 20'N and 19 ° 48'E), where fishermen after contact with a mustard gas bomb were hospitalized.

In the Polish exclusive economic zone there have been 16 identified findings of outdated ammunition and weapons. Chemical munitions have occurred in one of those areas. Judged from the coordinates given (54 ° 37'0 N and 15 ° 39'0 E), this area is on the route which the ships used to the dumping area south-east of Gotland.”(HELCOM, 1994)

In his chapter for the book ‘Sea Dumped Chemical Weapons: Aspects Problems and Solutions’, Andrulewicz (1996) reported that:

“Cases of catching viscous mustard gas or net contamination during bottom trawling were recorded until the end of the seventies (1979). Locations of these cases were reported mainly for the western part of the Polish coast which is in good agreement with the available information on dumping locations and dumping routes.”

Personal accounts of these incidents exist in the press, as in this article by Doyle for Reuters News Service (2004):

“It was terrifying. The pain was unbearable and my hands blistered all over,” said Danish fisherman Walther Holm Thorsen, who was 15 when he threw a cracked grey canister back into the Baltic Sea after it was snared in the net of his trawler.

One of the first post-war victims of the Nazis in the 1969 accident, he said the pain came in the middle of the night, hours after he and another crew member had rinsed the oily substance off the fish. They had no idea it was mustard gas.

Thorsen spent three months in hospital, and his hands badly scarred despite skin grafts. 'Working as a fisherman now is hard – my hands often feel like they're freezing' he said. Horten, Norway Jan 26 2004"

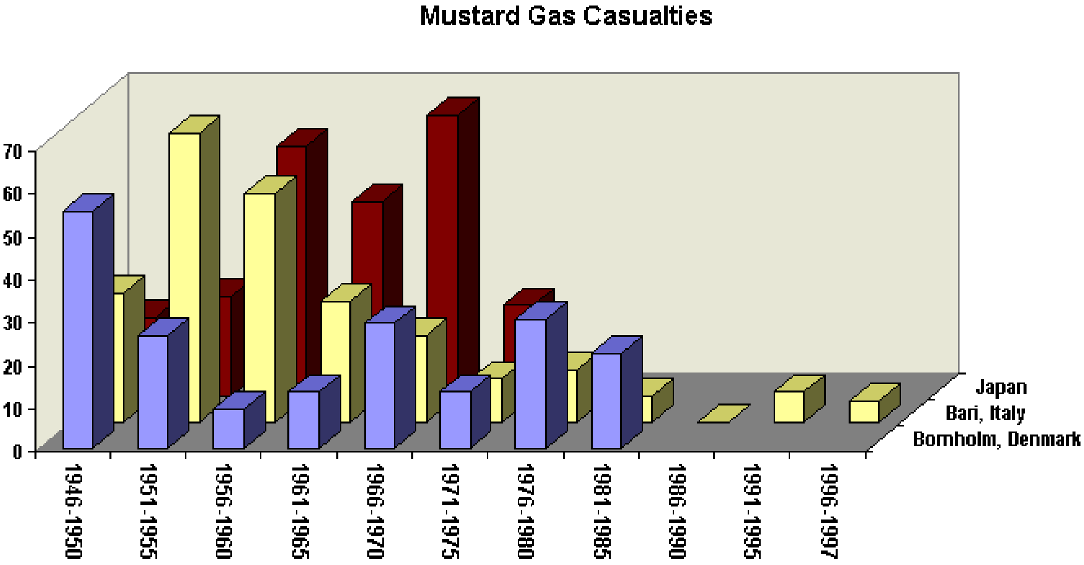
The following quote is from a Lithuanian website:

"We had 10 cases of people finding bombs this year," said Begr Rasmussen, head of the Fishermen's Association of Bornholm, the Danish island close to one of the main dumping grounds. Denmark, which offers special incentives for reporting munitions to the military for retrieval, has recorded more than 400 such incidents in the last two decades." (Lietuvos.net)

While the website for Mitretek Systems (a Canadian non-profit scientific research and engineering corporation) has detailed information on dumping of chemical weapons on the sea bed, including statistics on reported human encounters with mustard gas:

"Accidents due to ocean dumping of chemical weapons have been reported in the Baltic Sea, the Adriatic, and in the Pacific Ocean and Japanese coastal waters. Most reports came from fishermen who had inadvertently snared plastic lumps of mustard gas in their nets. When exposed to sea water, mustard forms a thick outer "crust" over a core of mustard which allows the mustard to be brought to the surface where it can injure unsuspecting fishermen. These accidents began occurring shortly after the material was dumped and have continued throughout the intervening years (see Figure (1) below). Note that in each location exposure continued through the date of the report (1980 in Japan, 1985 in Denmark) with the most recent reports coming from Italy in 1997." (Mitretek Systems).

Figure 1. Mustard Gas Casualties reported from Japan, Italy and Denmark between 1946 and 1997. Compiled by Mitretek Systems (2004) from Sivo & Lubuono, (pers. comm.); Theobald & Ruhl (1994) and Kurata (1980).



Glasby (1997) has commented that one of the three:

> *"…..main threats of chemical warfare agents which have been dumped in the sea are……to fisherman trawling lumps of viscous mustard gas from the sea floor with their nets. Although the largest amount of chemical agents were dumped in the Bornholm Basin and this is clearly marked on nautical charts, the area continues to be fished. Fishermen still recover bombs, shells and lumps of mustard in their nets. Since 75% of the fishermen there are Danish, they have been the most affected. In the period between 1976 and 1992, 439 reports of recovery of chemical warfare agents were made equivalent to a catch rate of approximately 0.02%. Under Danish law, catches contaminated by chemical agents must be destroyed…….All injuries to fishermen have occurred when liquid or solid mustard gas have escaped from rusted munitions and come into contact with the skin. The mustard can penetrate clothing or rubber gloves and causes severe blistering of the skin and irritates the eyes and throat. It is considered doubtful that fish contaminated by chemical agents could reach the consumer."*

2.14 In addition to fishermen who are clearly likely to encounter material, there are other workers who for completeness should be mentioned. Activities such as dredging and pipe or cable laying can result in workers operating in close proximity to the material. This can be particularly problematic where the full geographical extent of the dump is unknown. ACOPS (2003) reported:

> *"Significant damage to the suction dredgers/sand carriers Vesalius and Britannia Beaver caused by detonation of explosives ordnance during dredging operations (Lloyds List , July 6 1996 & September 1996)."*

2.15 More recently the extension of off-shore wind farms offers the potential for physical contact with munitions and therefore potential danger, particularly during pile driving activities to set turbines.

2.16 Clearly some sensible actions can be taken to minimise the problems of direct encounters between workmen and munitions, in particular detailed maps of known locations of munitions can serve as an appropriate warning to fishing, pipeline and other operators. It is correspondingly somewhat concerning that all the main organisations that have reported on the location of these materials have indicated that they have real difficulty in specifying exactly where this material occurs. For example OSPAR (2004) states that:

"The full extent of this dumping will never be known due mainly to inadequate documentation of operations at the time of dumping and the subsequent loss or destruction of records that may have been taken. Remediation of marine chemical weapons and munitions dumpsites is technically challenging because of the nature of the material and the uncertainty surrounding the quantities, type, locations and the present conditions of stability of these materials."

While Hart (2000) maintained that:

"The full scope and details of past dumping of CW will never be fully known. Some operations were inadequately documented. Information on other operations has been lost or destroyed.[15] *Examples of ships crews failing to scuttle ships laden with CW at designated coordinates due to bad weather and other reasons, have been documented. Questions associated with dumped CW have still not been as fully researched as they ought to be due to certain military and political inhibitions combined with a broader lack of attention."*

3. Contamination of Marine Life

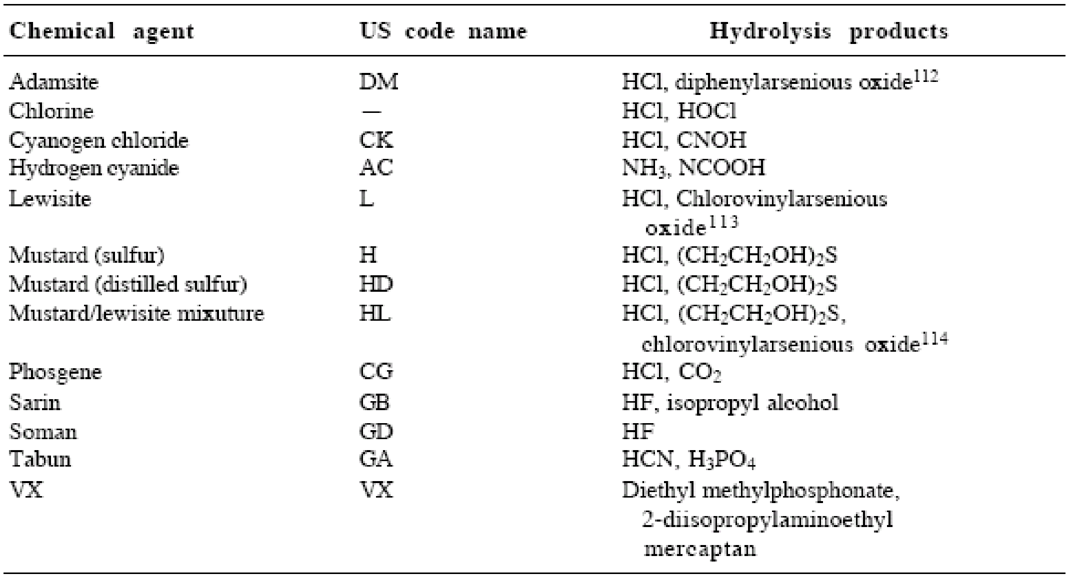
3.1 *Prima facie* the dumping of both conventional and chemical munitions in the sea reflects a situation in which dangers to marine organisms and the potential danger to the food chain have been ignored. However, as many commentators have indicated, alternatives to this dumping were largely unavailable, particularly in the periods following both World War I and II when the majority of this material was dumped. In Surikov's chapter in Kaffka's (1996) book, he details that Admiral Tributs, the former commander of the Baltic fleet:

> *"………. also repeatedly stressed that, at that time, neither victors nor defeated had adequate technologies to safely destroy CW in their armouries. This was the reason why political leaders of the Soviet Union, the USA and the UK made the fundamental decision to bury CW in the deeps of the Atlantic Ocean."* (Surikov, 1996)

3.2 In dealing with the potential contamination of the marine ecosystem from this material, it is appropriate to consider both chemical and conventional material.

3.3 Chemical munitions are of a variety of types, which are listed in Hart (2000):

Table 2. A List of Chemical Warfare Agents and Some Possible Hydrolysis Products. (Hart (2000) quote from *Military Chemistry and Chemical Compounds, Field Manual FM 3–9*, Department of the Army, Oct. 1975.)



Chemical agent	US code name	Hydrolysis products
Adamsite	DM	HCl, diphenylarsenious oxide[112]
Chlorine	—	HCl, HOCl
Cyanogen chloride	CK	HCl, CNOH
Hydrogen cyanide	AC	NH_3, NCOOH
Lewisite	L	HCl, Chlorovinylarsenious oxide[113]
Mustard (sulfur)	H	HCl, $(CH_2CH_2OH)_2S$
Mustard (distilled sulfur)	HD	HCl, $(CH_2CH_2OH)_2S$
Mustard/lewisite mixuture	HL	HCl, $(CH_2CH_2OH)_2S$, chlorovinylarsenious oxide[114]
Phosgene	CG	HCl, CO_2
Sarin	GB	HF, isopropyl alcohol
Soman	GD	HF
Tabun	GA	HCN, H_3PO_4
VX	VX	Diethyl methylphosphonate, 2-diisopropylaminoethyl mercaptan

Hart explained:

"CW agents may be divided according to their principal physiological effects, namely: blister (vesicant), blood, choking, incapacitating, nerve, tear gas, and vomiting agents. Chemical structures of selected agents and their United States military designators are given in the text below and are also listed in Annex 2 (Note: see Table 2 above)*. As its name implies, blister agents cause skin blisters and can severely irritate the eyes, throat, and lungs. Potentially life threatening infections in the trachea and lungs can result. Lewisite (L), nitrogen mustards (HN-1, HN-2, HN-3), sulfur mustard (H, HD), and phosgene oxime (CX) are examples of blister agents. They are all relatively non-lethal and were meant instead to cause mass casualties.*[48] *Those exposed may also suffer from longterm health problems.*

Blood agents, such as arsine (SA), cyanogen chloride (CK), and hydrogen cyanide (AC), inhibit cytochrome oxidase, an enzyme needed to allow oxygen to be transferred from the blood to the body's tissue.

Choking agents, such as chlorine, diphosgene (DP), phosgene (CG), and PFIB, interfere with breathing. Phosgene and diphosgene interfere with transfer of oxygen via the lung's alveoli sacks. Symptoms of phosgene poisoning do not become apparent for several hours. In addition the chances for survival are a function of physical exertion. The more a victim exerts himself physically after being exposed, the more likely it is he will die. Complete rest and oxygen treatment are recommended.

Incapacitating agents are designed to induce physical disability or mental disorientation. LSD (a form of lysergic acid) and BZ (3-quinuclidinyl benzilate) are two examples. The United States Government investigated potential military uses of LSD. It also weaponized BZ, which can cause constipation, headaches, hallucinations, and slowing of mental thought processes.

The principal nerve agents, Sarin (GB), Soman (GD), Tabun (GA) and V-agents, are all organophosphorus compounds which inhibit an enzyme responsible for breaking down acetylcholine, a neurotransmitter. Nerve agents may be inhaled or absorbed through the skin. Symptoms include drooling, dilated pinhead pupils, headache, involuntary defecation, and a runny nose. Death is caused by cardiac arrest or respiratory failure. Extensive sea dumping of nerve agents have been carried out.

Tear gases, such as chloroacetephenone (CN) and O-chlorobenzalmalonitrile (CS), cause irritation of the skin and uncontrolled tearing. Although they are designed to be used as nonlethal, riot control agents, their employment can result in death or injuries if improperly used in enclosed areas for extended periods of time. This is especially true if those affected are pre-adolescents, elderly or are in poor physical health. Tear gases must be used within specified guidelines to ensure that targeted individuals do not experience unacceptably high levels of toxic exposure. As far as the author is aware, tear gases have not been dumped in appreciable quantities with the possible exception of adamsite, an arsenical agent originally developed for use on the battlefield. It proved unsatisfactory as a lethal agent, but is also too dangerous for riot control purposes. (Adamsite is considered further below).

Although vomiting agents, such as adamsite (DM), diphenylchloroarsine (DA), and diphenylcyanoarsine (DC), can be used for riot control purposes, all three agents are now considered rather unsatisfactory in this regard. Diphenylchloroarsine and diphenylcyanoarsine, for example, contain arsenic. These two agents, which are in the form of a powder at ambient temperatures, were used as 'mask breakers' during WW

I. The particles were able to penetrate the filters used at the time and could induce a soldier to break the seal of his mask allowing a more toxic agent such as phosgene to take effect. Diphenylchloroarsine and diphenylcyanoarsine were also mixed with sulfur mustard to lower the freezing temperature of the mustard." (Hart, 2000)

3.4 In aquatic systems, the transport, behaviour, fate and hence exposure of biota to chemical contaminants are, to a large extent governed by the physical and chemical properties of the compounds involved. For some of the warfare agents in question, these properties have been reviewed (HELCOM, 1994) and are listed in Table 3. The HELCOM document concluded that:

"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 warfare agents were often not used in their pure form, but mixed with other substances, the melting points are mostly slightly lower than those given in Table….

Vapour pressure is included in the Table as the measure showing how easily the warfare agents tend to vaporize - the higher the vapour pressure, the greater the concentration of the substance in the air, the quicker the substance volatizes.

Aqueous solubility is one of the most important parameters for the behaviour of warfare agents in the marine environment. Chemical degradation and dispersion in the sea (drifting, dilution) occur orders of magnitude faster when warfare agents are in the dissolved state.

The density of warfare agents determines whether the substances sink to the sea bed or rise to the surface of the water and accumulate there. With the exception of tabun, all the warfare agents given in Table… are much heavier than Baltic Sea water (density: 1.08 g/cm^3). Therefore, warfare agents dumped in the Helsinki Convention Area do not show a tendency to rise to the surface and drift away." (see also Section 2.2)

The document also addressed other factors:

The behaviour of chemical substances in the marine environment depends both on the chemical and physico-chemical properties of the substances and on environmental factors such as temperature, salinity and the pH value of the water. As the pH value of sea water is rather constant - Baltic Sea water is slightly alkaline (pH 8) - salinity and temperature are the main environmental parameters that influence chemical reactions here. The solubility of the compounds and the speed of reactions both increase with a rise in temperature. With an increase in temperature of 10°C, the speed of reactions generally doubles. Water temperatures in the Baltic Sea vary between 0° and 20°C, i.e. reactions occur 4 times faster at 20°C than at 0°C. However, in the water above the seabed in the Baltic Sea the temperature variation is less, typically between 2° - 12°C.

Dissolution of the chemical warfare agents into the sea is considered as the crucial first step in the degradation of the compunds. Besides a rise in temperature, current in particular speeds up the process of dissolution. As Table… shows, the solubility of the various chemical warfare agents varies from good (tabun) to very poor (Adamsite, viscous mustard gas). However, it should be noted that, poor solubility retards the process of degradation.

The behaviour of warfare agents in the marine environment is additionally influenced by the physical properties of the agents. For instance, a warfare agent in viscous or highly viscous form or in lump form can be caught in nets; this cannot happen to substances in liquid or powder form. This is one reason why most accidents with warfare agents so far have involved viscous mustard gas. Because of the admixture of thickeners, viscous mustard gas is the only warfare agent occurring in large lumps that are mechanically relatively stable. Other warfare agents are also resistant to sea water - e.g. Clark and Adamsite. All warfare agents react with sea water, but reaction rates can vary enormously depending on the chemical structure of the different agents. Through reaction with water - hydrolysis – new compounds are formed which have different properties from those of the warfare agents. Such reaction products are usually no longer toxic or are less toxic and generally dissolve better in water. Investigations on behaviour of warfare agents under Baltic Sea conditions exist only for a few substances. For this reason, their behaviour can often only be described qualitatively; details of the rates at which the processes occur are mostly missing.”

Table 3. Physical and Chemical Properties of Those Agents Dumped in the Largest Quantities (adapted from HELCOM, 1994).

Trivial Name	**Chemical Name**	**Melting point [°C]**	**Boiling point [°C]**	**Vapour Pressure [mm Hg] 20°C**	**Density [g/cm3]**	**Solubility in Water [g/l]**
CAP	Chloroacetophenone [CAS: 532-27-4]	54-56	244	0.013	1.32	1
Clark I	Dipenylchlorarsine [CAS: 712-48-1]	38-44	307-333	0.0016	1.442	2
Clark II	Dipenylcyanorarsine [CAS: 23525-22-6]	30-35	290-346	0.00047	1.45	2
Adamsite [Agent DM, Sternite]	Diphenylaminechlorarsine, 10-chloro-5,10-dihydrophenarsazine [CAS: 578-94-9]	195	410	$2x10^{-13}$	1.65	0.002
Phosgene	Carbonyl dichloride [CAS: 75-44-5]	-128	7.6	1178	3.4	9
Diphosgene [Agent DP]	Trichloromethyl chloroformate [CAS: 503-38-8]	-57	127	10.3	1.65	
Mustard Gas HD, [Yperite,Lost]	Bis-(dichloroethyl)-sulphide [CAS: 505-60-2]	14	228	0.72	1.27	0.8
‘Winter Mustard’	Bis-(dichloroethyl)-sulphide [63%] and 2-Chlorovinyl dichlorarsine [37%] [CAS: 505-60-2 and CAS: 541-25-3]	-14	<190		1.66	<1
N-Mustard [N-Lost, HN-1]	N-ethyl-2,2-dichlorodiethylamine [CAS: 538-07-8]	-4	235	0.011	1.24	0.16
Lewisite I [Agent L]	2-Chlorovinyl dichlorarsine [CAS: 541-25-3]	-18	190	0.35	1.89	0.5
Tabun [Agent GA]	Ethyl N,N-dimethylphosphoramidocyanidate [CAS: 77-81-6]	-50	246	0.07	1.07	120

3.5 It is convenient to distinguish between those that are water-soluble, those that contain mustard gas, and those that are arsenic based. Appendix 2 contains the chemical composition of the main materials that have been dumped (including conventional munitions). Whilst the solubility and other data (see also Table 3) are most useful, for the purposes of a comprehensive risk assessment much of the essential information is lacking. We have, for example, been unable in this study to find appropriate quality assured data to address Persistence, Bioaccumulation and Toxicological (PBT) criteria (traditionally the basis for assessing hazardous substances, for more details see Appendix 3) documented for these materials in available sources. This is especially noteworthy for the ecotoxicology. It is suggested that these data should be compiled. Despite these shortcomings, available information on the individual compounds is addressed in the following paragraphs using the distinction between water soluble, those which contain mustard gas, and those that are arsenic based.

3.6 A number of chemical munitions have relatively high solubility in water and the products of their hydrolysis are not particularly toxic. It is nevertheless clear that there is quite substantial ignorance about the toxicity of this material in water and the likely concentrations that can potentially occur. The material that is accepted by most authors to be largely unproblematic due to its solubility includes Phosgene, Sarin, Soman, Tabun, Cyclone B and Chloroacetephenone (HELCOM, 1994; 1996; Hart, 2000).

Hart (2000) gives details on the behaviour of some of this material in sea water, for example:

“*Phosgene freezes at 8 degrees C. The hydrolysis products of phosgene are carbon dioxide (CO_2) and hydrochloric acid (HCl). It does not present an environmental threat.*

Sarin will be completely hydrolyzed within a week or so. All of its hydrolysis products are relatively benign.

The melting point of pure sarin is -57 degrees C. Its boiling point is 147 degrees C. The hydrolysis products of sarin are fluoride (HF), methylphosphonic acid, and 2-propanol. Sarin in sea water hydrolyzes within a period of several days.

The melting point of pure tabun is -49 degrees C. Its boiling point is 246 degrees C. The hydrolysis products of tabun are cyanide (HCN), dimethylphosphoriamidic acid, dimethylamine, ethanol, and phosphoric acid. Tabun in sea water hydrolyzes within a week or so.”

HELCOM (1994) also gives the following details of CW behaviour in seawater:

*“**Chloroacetephenone** hydrolyses only very slowly, if at all, in water, but its chemical structure does indicate that it can be biodegraded. After dehalogenation (removal of the chlorine atom) non-toxic products develop that can easily be fully degraded in sea water.”*

*“**Phosgene** is a very reactive compound which in sea water is broken down into carbon dioxide and hydrochloric acid. In slightly alkaline sea water, hydrochloric acid is neutralized. The reaction occurs rapidly - even at 0°C: an 1% watery phosgene solution is completely decomposed after only 20 seconds.”*

*“**Tabun** dissolves well and is of relatively little resistance. At a temperature of 7°C, its half-life in water is about 5 hours. During hydrolysis non-toxic esters of phosphoric acid and hydrogen cyanide are formed. Toxic hydrogen cyanide is converted relatively easily into non-toxic formic acid or its sodium salt.*

***Cyclone B** consists of salts of hydrogen cyanide which dissolve well. Toxic hydrogen cyanide is converted relatively easily into non-toxic formic acid or its sodium salt.”*

Anecdotal evidence on the rapid degeneration/hydrolysis of these particular CW agents is given in HELCOM (1996):

“In autumn 1971 and spring 1972, the West German Army raised 28 bombs and 15 shells, which contained phosgene and tabun, from the southern Little Belt. The recovered munitions had sunk about 50 cm into the mud. An examination revealed, that most had been corroded and no longer contained warfare agents. No traces of warfare agents were found in sediment and water samples taken in the immediate vicinity.”

3.7 The components of mustard gas do present problems for the environment as they do not degrade quickly. For example:

*“**Mustard gas**. Hydrolysis of mustard gas in sea water occurs in two stages. Thiodiglycol and hydrochloric acid are formed; the former is non-toxic and the latter is neutralized by sea water.*

While mustard gas has a half-life of minutes when it hydrolyses in pure water, hydrolysis in sea water occurs more slowly, especially if water temperatures are low; then half-life is measured in hours. This time scale applies only to dissolved mustard gas, however. Because mustard gas is relatively insoluble, the slower dissolving process becomes the determining factor. The dissolving process itself depends on many parameters such as salinity, temperature, current speed and the extent to which munitions are covered. Degradation of solid mustard gas can thus take weeks or years.” (HELCOM, 1994)

Types of mustard gas that were developed in Germany towards the end of World War II are particularly problematic. In a discussion of the Baltic Sea, the following excerpts give some indication of the reasons:

“Scientists argued chemical agents would dissolve harmlessly upon contact with water. But Professor Paka believes their studies have ignored one chillingly unique feature of the sunken arsenal. Nazi scientists commissioned a special new formula of mustard gas for the first winter of their troubled Russian campaign amid concerns it would not withstand the freezing temperature. The “winter mustard” they delivered contained 37 per cent arsenic, creating a viscous substance that Professor Paka maintains is insoluble. Officials estimate 20 per cent of Germany's entire poisonous gas production is down there, including almost all the winter gas.” (Lietuvos.net)

*"**Sulphur mustard. Behaviour in sea water** - The principal hydrolysis products of sulfur mustard are hydrochloric acid (HCl) and thiodiglycol (2,2'-thiobis[ethanol]). When sulfur mustard comes in contact with cold water a tarry substance forms around the exterior while the interior remains viscous over a period of many decades, if not longer. The exterior consists mainly of precipitates derived from thickening agents. Although dissolved sulfur mustard hydrolyzes within a matter of hours, the rate of dissolution in cold sea water is much slower. The chemical composition of the tarry exterior is not well understood partly because it varies from case to case. Various polymer materials, such as alloprene and poly[methyl methacrylate] (PMMA), for example, were sometimes combined with sulfur mustard to lower its freezing temperature. Solvents such as chlorobenzene, have also been combined with sulfur mustard. Clumps of mustard may remain even after the munition bodies have largely corroded away."* (Hart, 2000)

"Diphenylchloroarsine and diphenylcyanoarsine, for example, contain arsenic……..Diphenylchloroarsine and diphenylcyanoarsine were also mixed with sulfur mustard to lower the freezing temperature of the mustard." (Hart, 2000)

The main problem here is not the reaction with marine organisms, and therefore the potential for direct harm, but that it is inert and is therefore remaining *in situ* and constitutes a continuing danger for those encountering it. For example:

***"Viscous mustard gas** is mustard gas to which thickeners have been added. It has a completely different appearance from ordinary mustard gas and reacts differently in physical terms as well.*

Its colour ranges from reddish brown/brown green to black and has the consistency of thick paste - something like bee-wax. It is viscous and very sticky. About 20% of the mustard gas produced was processed into viscous mustard gas. Water-insoluble thickening agents such as polystyrene and montan wax have a crucial effect on its behaviour in the marine environment as they prevent the mustard gas from reacting with the sea water. Hydrolysis is possible only after the mustard gas has diffused out of the viscous mustard gas.

The thickening agents remain and form the basis of a developing crust on which fine sand and mud particles can also be deposited. This further hinders diffusion of any remaining active parts of mustard gas. Warfare agent which are contained in lumps of viscous mustard gas can thus be preserved for many years - the bigger the lump of mustard gas, the longer it will be conserved.[25]

Crushing by mechanical means in the sea is made more difficult because the lumps are very elastic and are protected by a leather-like crust.

It must, therefore, be assumed that a very long time is needed before viscous mustard gas is broken down into harmless substances. Depending on oceanographic conditions, waves or bottom current can transport lumps of *viscous mustard gas, which are heavier than sea water, across the seabed."* (HELCOM, 1994)

3.8 The third type of material is where there is a substantial component of arsenic and this includes Lewisite and other materials e.g. Adamsite, Clark I and Clark II. There is no doubt that there is a potential for arsenic-based material to accumulate in the food chain and there have been reports of concentrations of arsenic occurring, particularly from Russian sources. Glasby (1997) has explained that:

"Clark I and II and adamsite hydrolyse to form compounds that contain arsenic which would persist in sea water. Assuming that the Clark I and II and adamsite were dumped in the Baltic in the proportions that they were manufactured in Germany (approx. 8% of the total) and the weighted average amount of arsenic in them is approximately 27%, it can be calculated that the maximum amount of arsenic that may have been released into Baltic sea water from these weapons is approximately 280t. The natural concentration of arsenic in Baltic sea water is approximately 1ppb. It can therefore be calculated that the maximum amount of arsenic that could be released into Baltic sea water is just over 1% of the total amount of naturally occurring arsenic in the Baltic sea water at any one time. Local enrichment of arsenic in the sediments would be possible. However, bioaccumulation of arsenic in marine organisms or enrichment in adjacent sediments above background level (100ppm) have not been detected so far. There have also been no reports of bioaccumulation of toxic agents in marine organisms in the Baltic or of poisoning of fish due to the presence of chemical warfare agents.

In spite of the relatively optimistic picture painted by western scientists, Russian opinion appears much more negative…..

In May 1990, a warning signal was given when a massive amount of poisoned crabs, mussels and over 6 million jellyfish were washed ashore I the White Sea off northern Russia. At first, this was thought to be the effect of mustard gas but was later attributed to sulphide-containing industrial waste water as well as highly toxic propellant for strategic sea-launched rockets. However, it is now known that 50-60 railway wagons full of lewisite aerial bombs were dumped in the Russian North Sea." (Glasby, 1997)

HELCOM (1994) also goes into some detail regarding warfare agents containing arsenic:

"Due to their physico-chemical properties, the possibility cannot be ruled out that Clark and Adamsite can accumulate in biota. This has not been investigated though. However, it has to be taken into consideration that warfare agents containing arsenic, even after complete degradation of the substances, the arsenic still persists as an inorganic arsenic compound. Such inorganic arsenic compounds are less acutely toxic than the warfare agents. Taking into account the mass reduction of the warfare agents, while they degrade (200g of Clark contains

75g of arsenic) and the decrease in the acute toxicity of inorganic arsenic compounds, partial detoxification can be expected following complete degradation. Inorganic arsenic compounds undergo further reaction in algae and fish to form non-toxic organic arsenic compounds.

In a series with fresh water organisms parallel to those with mustard gas no toxic effects were found neither with Adamsite or with chloroacetophenone, probably due to their low solubility….Those compounds which show a slow degradability (Clark I and II, Adamsite…) have only a very little water solubility, so that only very low concentrations are reached, which according to the present knowledge cause no ecological effects.

However, one has to bear in mind that insufficient data is available for the arsenic containing warfare agents, as well as chlorinated additives. These compounds are often lipid soluble, and therefore, possibly bioaccumulative."

A HELCOM report added:

"The organic arsenic compounds possess properties which imply that they could be transferred via marine food to consumers. However, in specific analyses of fish the amounts of arsenic that are absorbed, are so small that they are irrelevant with regard to acute toxicity. Inorganic arsenic compounds do not have the properties of warfare agents, but they are regarded as carcinogenic in humans. The formation of organic arsenic compounds in algae and fish could, however, also be a link between marine life and human beings." (HELCOM, 1994)

Research of dumped chemical weapons in Gotland, Bornholm and the Skagerrak, carried out by Paka & Spiridonov (2002) found that:

"The Bornholm and Måseskär dump sites are characterised by high dispersion and sharp anomalies of As levels, reaching up to 150-200mg/kg.

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 centimetres below the bottom/water interface. This implies a powerful source of As was present either on the seabed surface or was buried greater than the redoxcline."

Paka & Spiridonov (2002) also claim that they:

"…have numerous observations of leakage of some chemical, 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 sign of leakage were specific changes of micro-biota."

Further quotes from Russian literature include:

"....high levels of sparingly soluble Clark, adamsite or viscous mustard gas can occur in the sediments in the immediate vicinity of dumped munitions and reports on the detrimental effects in the marine environment due to warfare agents have been recorded." (Duursma & Surikov, 1999)

"According to scientific reports, yperite (sulphur-mustard) *lying on the sea bottom maintains high toxicity for 400 years. Dumped lewisite after hydrolysis will produce the toxic arsenic compounds. Adamsite, chloracetophenone, diphenylchloroarsine and other poisons are very stable to hydrolysis. Nitrous yperite, chloroarsin and some others with hydrolysis will produce secondary highly toxic substances. The poisons will be accumulating in fish and biota. Thus, thousands of chemical weapons on the Baltic sea bottom are a real danger for the Baltic region."* (Surikov, 1996 from Kaffka, 1996)

3.9 Given this potential plethora of problems for chemical munitions it is important to examine the evidence to date of what if any examples there are of direct toxicity of CW and explosive material to marine organisms, and indeed the food chain. There was a comprehensive survey conducted by the Marine Laboratory in Aberdeen in 1995. This study found no evidence of problems from the material in excess of one million tonnes that had been dumped around Beaufort's Dyke. For example the report concluded that:

"Screening of surface seabed sediment samples collected from within and immediately adjacent to, the Beaufort's Dyke explosives disposal site confirmed that the samples did not contain the chemical warfare agents phosgene, mustard gas, or contain elemental phosphorus." (FRSR, 1996)

And:

"The results of the explosive and propellant residue and heavy metal analyses indicate that munitions dumping operations after both World Wars have not resulted in chemical contamination of the surface seabed sediments or the edible flesh of commercially exploited fish and shellfish species." (FRSR, 1996)

3.10 With respect to the Baltic Sea, a HELCOM (1994) report stated that:

> *"At the dumping area south of the entrance to Little Belt sediment and water samples were taken in 1971/72 by German authorities….. No traces of warfare agent were found in the sediment and water samples taken in the immediate vicinity.*
>
> *In connection with video recordings of the seabed in the dumping area east of Bornholm, samples of the seabed sediment were taken in November 1992. Two samples close to one another were taken from the middle of the dumping field. The Civil Defence Analytical-Chemical Laboratory, Denmark found mustard gas in one of the samples and the more stable 1,4-dithiane in both samples. 1,4-dithiane is a by-product of mustard gas production. National Environmental Research Institute, Denmark analyzed the samples for arsenic; and detected an increased content (185 and 210 mg As/kg dry weight) compared to samples taken from other parts of the Baltic Sea. No other traces of chemical warfare agents or chemical compounds related to such agents were found in the sediment samples.*
>
> *In 1992, the Norddeutscher Rundfunk (North German Radio Station) had 18 sediment samples analyzed. They had been collected at 6 different positions, 5 of them in the Bornholm dumping area. In one sample, a concentration of 10 mg of Clark I per kg of sediment (10 ppm) was found; nothing was found in the other samples from the same area. Likewise, no other warfare agents were found in any other sample. The arsenic concentrations - even in the sample containing Clark - did not exceed the values usually observed in the Baltic Sea area of up to 100 mg per kg of sediment.*
>
> *Investigations by the German Hydrographic Institute in 1987 showed that the arsenic content of Baltic Sea water, including near-bottom water, does not exceed 1 µg/l (0,001 ppm). Concentrations in the dumping areas were not higher than those measured elsewhere.*
>
> *In the summer of 1992 investigations were carried out 20 nautical miles west of the lighthouse Måseskär on the Swedish west coast (Skagerrak), where German mine sweepers were sunk after World War II……Biological investigations were carried out by using cages containing crabs and mussels. The cages were placed to leeward of the bottom current in the immediate vicinity of the five wrecks and on a reference station. Sediment samples were collected on six locations in the vicinity of the wrecks.*
>
> *When the cages were retrieved the specimens were quite normal and no mortality was noted. The crabs which had been placed furthest away from the wrecks showed a somewhat lower activity of the enzyme acetylcholinesterase (AChE), an enzyme which is inhibited by the presence of organic phosphorous compounds (such as in tabun), compared to crabs in the immediate vicinity of the wreck. Although an influence cannot be excluded, the difference is not statistically significant though.*
>
> *The sediment samples were analyzed for mustard gas and the degradation*

product thiodiglycol. The detection limit was as low as 0.1 ppt (equals 1 to 10^{-12}). At this level of detection the analysis of the sediment has demonstrated very low concentrations of mustard gas at least one kilometre from the wrecks. It has not been possible to detect the presence of nerve gas.

In 1989, the research institute of the Norwegian Ministry of Defence undertook an extensive investigation of the ships loaded with munitions that had been sunk in the Skagerrak. Most of the bombs found in the wrecks or nearby still seemed to be intact, but others were already perforated by corrosion. Water and sediment samples were taken in the immediate vicinity of the bombs and analyzed. No mustard gas, nor tabun or mustard gas decomposition products were found in any sample, although also in this case very low levels for detection limits were achieved (ng/kg and µg/kg range).”

3.11 By contrast, there have been some indications in the Russian literature, although it is not well documented, of significant mortality occurring to starfish in the White Sea. In a book edited by Duursma (1999), Duursma and Surikov, describe how:

“The ecological catastrophe on the Letnii Coast of the White Sea’s Dvina Gulf in May 1990, where 4-20 million starfish Asterias rubens died, was probably due to CW agent intoxication. On 06/10/90, a girl who was playing with starfish died. Following another catastrophe in 1979, in which a mass death of bottom-dwelling fish was noted, official data confirmed that 700 aircraft bombs and over 5 tons of mustard gas-lewisite mixture in 31 iron barrels were dumped in the vicinity. There are at least ten hypotheses as to the cause of this disaster, and an official report by the Arkhangelsk Fishery Complex indicates that repeated tests showed traces of yperite (S-mustard) in samples of starfish, herring, mussels, seaweed, whitefish, flounder and navag in the period May 23 1990 to June 7 1990; later, however, all samples were negative.

Some CW agents, such as S-mustard and lewisite, have a higher solubility in lipids than in water, and can accumulate in cells from dissolved state in sea water. This does not mean that these products necessarily accumulate in the food chain. The determining factor is the ratio between their concentrations in water and in lipids, although intake may also occur from food.”

The White Sea is a source where substantial pollution has occurred from industrial operations and hence the clear causal connection to chemical munitions has not been made. Nevertheless it is concerning.

3.12 Although the evidence is mixed, when looking at the scale of the NE Atlantic there is some potential for optimism in that the Aberdeen survey, which was reasonably comprehensive and did not find notable concentrations in the food chain nor indeed significant disturbances to marine life in the area. The different depths and oceanographic regimes associated with the dumps in the Russians studies and those around Beaufort’s Dyke may explain the difference. For example, in the Baltic Sea, east of Bornholm there are depths of approximately 90m, South of Gotland depths of approximately 100 to 130m, and depths as shallow as 30m in the Little Belt region (Surikov and Duursma, 1999). These depths may be compared with the greater depths of dumping grounds in the Beaufort's Dyke area of the Irish Sea of between 100 to 200m, and up to depths of 300m in some areas (FRSR, 1996).

3.13 Conventional material including TNT and variants can be extremely toxic to marine organisms. There have been a number of studies that document this, the details of which are quoted below.

"The chronic toxicity of sediment-associated 2,4,6-trinitrotoluene (TNT) to the marine polychaete Neanthes arenaceodentata and the estuarine amphipod Leptocheirus plumulosus was evaluated. Test organisms were exposed to sediments spiked with radiolabeled TNT for 28 d, after which time the endpoints of mortality, growth, and reproduction (L. plumulosus only) were assayed and compared against the TNT tissue concentrations as well as the TNT sediment concentrations. Survival was significantly reduced at a tissue concentration of 61 mu g TNT/g wet wt tissue in N. arenaceodentata and at 6.3 mu g TNT/g wet wt tissue in L. plumulosus……..Reproduction was significantly reduced at a tissue concentration of 6.3 mu g TNT/g wet wt tissue in L. plumulosus. The results of this study demonstrate that both N. arenaceodentata and L. plumulosus are sensitive to the presence of sediment-associated TNT and that more information is needed about the toxicity of TNT to benthic fauna to facilitate risk assessment and management of TNT-contaminated sites." (Green et al., 1999)

"The toxicity of nitroaromatic (2,4-diaminonitrotoluene [2,4-DANT] and 1,3,5-trinitrobenzene [TNB]) and C-14-labeled cyclonitramine compounds (hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX] and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine [HMX]) to the marine polychaete Neanthes arenaceodentata and the estuarine amphipod Leptocheirus plumulosus following 10-or 28-d exposures to spiked sediments was investigated. Oganismal-level effects on survival, growth, and reproduction and cellular-level effects on apoptosis (programmed cell death) were evaluated………Survival was significantly affected by nitroaromatics at nominal sediment concentrations as low as 200 mug/g, with L. plumulosus being more sensitive than N. arenaceodentata. Growth was significantly decreased at sublethal concentrations of 2,4-DANT for N. arenaceodentata. Reproduction, measured only with L. plumulosus, was significantly decreased only in the highest RDX treatment and also in the lower TNB treatment." (Lotufo et al., 2001)

"A toxicity database for ordnance compounds was generated using eight compounds of concern and marine toxicity tests with five species from different phyla. Toxicity tests and endpoints included fertilization success and embryological development with the sea urchin Arbacia punctulata; zoospore

germination, germling length, and cell number with the green macroalga Ulva fasciata; survival and reproductive success of the polychaete Dinophilus gyrociliatus; larvae hatching and survival with the redfish Sciaenops ocellatus; and survival of juveniles of the opossum shrimp Americamysis bahia (formerly Mysidopsis bahia). The studied ordnance compounds were 2,4- and 2,6-dinitrotoluene, 2,4,6-trinitrotoluene, 1,3-dinitrobenzene, 1,3,5-trinitrobenzene, 2,4,6-trinitrophenyl-methylnitramine (tetryl), 2,4,6-trinitrophenol (picric acid), and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). The most sensitive toxicity test endpoints overall were the macroalga zoospore germination and the polychaete reproduction tests. The most toxic ordnance compounds overall were tetryl and 1,3,5-trinitrobenzene. These were also the most degradable compounds, often being reduced to very low or below-detection levels at the end of the test exposure. Among the dinitro- and trinitrotoluenes and benzenes, toxicity tended to increase with the level of nitrogenation. Picric acid and RDX were the least toxic chemicals tested overall." (Nipper et al., 2001)

3.14 There does also appear to be the potential that this material could concentrate in food chains after some degree of absorption has occurred. As far as we are aware, the toxicity of products of TNT has not been addressed in any detailed way in the current literature. However, a recent study by Brannon et al. (2005), comparing the environmental fate and transport process descriptors of explosives in saline and freshwater systems, found that, when tested in the laboratory, dissolution rates, transformation rates and absorption rates of TNT, RDX, and HMX were generally in close agreement in fresh and saline water. They hence concluded that:

"*the (existing) freshwater database for explosives fate and transport process descriptors is adequate for prediction of explosive fate and transport in marine environments."*

3.15 Thus, considering the relevant literature:

"Little is currently known regarding the toxicokinetics of TNT in fish. In the present study, the bioconcentration and distribution of trinitrotoluene (TNT) and TNT biotransformation products was investigated in juvenile channel catfish by exposing catfish to 14 C-labeled TNT in water. Uptake experiments showed relatively fast rates .... for TNT from the water; however, bioconcentration factors for TNT were low .... due to rapid biotransformation and potential elimination of TNT. Accumulation of extractable radioactivity (TNT and all extractable biotransformation products) was much greater .... than that for parent compound. TNT (parent compound) bioconcentrated to the greatest extent in the gills of the fish, while total radioactivity bioconcentrated to the greatest extent in the viscera. Residual portions of the fish that contained muscle and skin had lower concentrations of TNT than the whole fish, indicating that ingestion of

fish filets would result in decreased exposure to human consumers." (Ownby et al., 2005)

And:
"The potential of TNT to accumulate in aquatic organisms was assessed by determining bioconcentration factors for TNT and TNT biotransformation products using two benthic invertebrates (Chironomus tentans and Lumbriculus variegatus), and by determining the bioaccumulation factor of TNT and TNT biotransformation products due to TNT exposure via feeding for channel catfish (Ictalurus punctatus). In all three species, TNT was rapidly biotransformed resulting in minimal accumulation. .... As indicated by this small bioaccumulation factor, TNT accumulation in channel catfish through trophic transfer would be negligible compared to aqueous exposure (previously reported BCF of 0.79 ml g(-1)). TNT extractable biotransformation products accumulated to a greater degree than parent TNT for all three species. .... Because the bioaccumulation of TNT is very low compared to the bioaccumulation of its biotransformation products, further research including identifying and determining the relative toxicities of these biotransformation products is necessary to fully evaluate the environmental risk posed by exposure to TNT." (Belden et al., 2005)

And:
"To identify useful biomarkers of TNT-exposure for forthcoming fish monitoring studies at ammunition dumping sites, rainbow trout (Oncorhynchus mykiss) were intraperitoneal (i.p.) injected with TNT in peanut oil at doses of 0, 100, 200 or 400 mg TNT/kg body weight and sampled 72 h later. The study covered blood parameters, and hepatic antioxidant and detoxifying enzymes. .... In addition to increased methemoglobin, the increased glutathione and glutathione dependent enzyme activities indicate that TNT oxidises macromolecules and activates antioxidant defence systems which may be useful as general biomarkers of TNT-exposure........... A dose-dependent increase in TNT, 2-amino-4,6-dinitrotoluene (2-ADNT) and 4-amino-2,6-dinitrotoluene (4-ADNT) was found in the hydrolysed bile of the TNT-treated fish. These results indicate that the fish are able to detoxify and excrete TNT and suggest that the detection of TNT, 2-ADNT and 4-ADNT in bile may be suitable as a direct marker of exposure to TNT." (Ek et al., 2005).

3.16 Thus, the evidence to date does not indicate that there have been significant ecological effects generated from TNT-based munitions. One explanation for this may be that the containers in which the TNT is located are typically made of strengthened steel and are unlikely to have corroded much in the time since they were dumped. Accordingly there may be a problem over a rather longer time scale as corrosion continues. This aspect is discussed in the Section 6. Some examples of authors considering this aspect are:

"…current knowledge of the corrosion status of the munitions, the behaviour of persistent warfare agents in marine environment, and the biological effect of such agents are incomplete." (Waleij, 2001)

"Technical analyses conducted thus far suggest that dumped CW pose little immediate threat to the environment or human health with the exception of fishermen raising chemical munitions in their nets and the possibility of elevated levels of arsenic in localized areas surrounding dump sites. It is possible that additional problems may become apparent in the future." (Hart, 2000).

3.17 As noted above, it will be explored later, but it is perhaps worth pointing out that the Aberdeen study occurred in 1995, some 50 years after the main World War II dumping occurred, and this may only give a partial picture as corrosion may continue and generate problems subsequently. Many commentators would argue that there should be some continued monitoring:

For example HELCOM (1994) stated that:

"Only poorly soluble and poorly degradable warfare agents can persist locally in the sediment at elevated concentrations over a long period of time. Investigations on the chemical processes and ecological effects of warfare agents under Baltic Sea conditions exist only for a few substances. These processes and effects can often only be described qualitatively."

And recommended that:

"Further investigations on these processes and effects, especially on poorly soluble compounds such as viscous mustard gas and arsenic compounds, should be undertaken."

HELCOM (1994) also stated that:

"Due to 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 so far have shown that intact munitions and completely corroded casings not containing warfare agents are found. It is important to examine whether the chemical munitions are embedded in the sediment or are lying on the sediment surface and what is their state of corrosion."

And recommended that:

"… further investigations on these issues should be carried out in selected parts of the dumping areas."

Hart (2000) also has reiterated that:

"There is a continuing need for additional research relating to sea-dumped CW. Extensive toxicity studies have been conducted on non-marine species only. Obtaining reliable toxicity numbers by extrapolating data from other species is difficult, while applying such numbers to marine species even more so. Toxicity studies on the effects of CW agents on marine organisms ought to clarify the nature of the threat and might also provide unexpected results. The behavior of arsenic in the marine environment is not very well understood either. How arsenic shifts out of organic compounds into inorganic compounds (where arsenic is normally found) is not clearly understood."

Later, Waleij (2001) noted that:

"Several international conferences have been held since the HELCOM working group was disbanded. The consensus is that some kind of environmental monitoring of the dumpsites ought to take place and that research in the behaviour of persistent chemical warfare agents in the marine environment must be carried out too."

4. Underwater Explosions, and their Consequences

4.1 Whether the dumped conventional munitions do periodically undergo spontaneous detonation, and the consequences that such an event may have, are two intriguing questions.

4.2 Unfortunately, the existing literature is rather limited on these aspects.

4.3 An article in the 'Diver' by Harrison (1998) reported that:

"In the Autumn of 1966, merchant vessels reported hearing underwater explosions in the vicinity of Beaufort's Dyke. Suspicions were further aroused in 1995 when a British Geological Survey reported seismic traces of eight unexplained explosions in the area."

4.4. However, note in relation to Section 5 below, the article goes on to state:

"Nobody is suggesting that munitions be raised to the surface."

4.5 The BBC News web-site (2004), in an article by Kirby, has written:

"Mr Fellows, who has worked for 40 years in bomb and mine clearance .... told the programme .... "There are sporadic explosions two or three times a month, I should think, in the Irish Sea, popping off all the time.""

4.6 Davies (1996) has written:

"The renewed interest in the area has also prompted the British Geological Survey to look again at some of their data, in particular records of ground tremors. The network of seismograph readings are mainly used for earthquake detection but other large scale events such as explosions can also be detected. It has been found that a number (25) of unexplained 'events' have occurred in the area of Beaufort's Dyke since 1982. These have been interpreted as underwater explosions of the munitions in the dumpsite. Although at present there have not been any consequences from these explosions, concern about the longer term impacts of such a munitions dump are increasing."

4.7 On behalf of the MoD, the British Geological Survey (BGS) issued a recent report in 2005 and reported that:

"The BGS seismic database contains 47 underwater explosions in the Beaufort's Dyke area for the period 1992 to 2004, including three events identified during this work (Figure 5, Table 1). The majority of explosions are located within the charted disposal site area. However, a number of explosions are located to the northeast of this area. Some events are located outside the main dyke area, which matches the observations made by the Fisheries Research Services (Marine Laboratory, 1996).

Table 1 Underwater explosions in the Beaufort's Dyke area between 1992 and 2004. The three explosions identified during this work are highlighted. The comment "confirmed explosion" means that a deliberate explosion was confirmed as such by the responsible agency. However, it is not standard practice to seek an explanation for every event identified as unnatural source and, therefore, events without this comment could have been deliberate explosions as well."

(Note: there are 34 events recorded in Table 1 without any comment as to being a confirmed explosion. The greatest magnitude of any of these events was of a local magnitude (ML) of "ML 2.3". From the BGS report, this is approximately equivalent to a charge weight of 500 kg.)

4.8 Of relevance is 'HMS Royal Oak' which currently lies as a major submerged wartime shipwreck in Scapa Flow. The vessel was sunk as a result of enemy action early in World War II. 'HMS Royal Oak' was fully ammunitioned and fuelled at the time of sinking. As a large Capital Ship of this period the ammunition that was embarked at the time was considerable. Thus, although, 'HMS Royal Oak' does not, of course, constitute in any way a dump site, lessons may be learnt from the state of her munitions. A report on 'HMS Royal Oak': Munition and Explosives Risk Assessment' was prepared by the MoD in 1999.

4.9 This MoD report commented:

"Of all the ordnance present it is thought that the Lyddite (picric acid) and Shellite (70/40 picric acid/dinitriphenol) shell fillings would pose the highest risk to any work undertaken on the wreck. Picric acid is known to have an ageing problem through which metal picrates form, e.g. iron picrate. Such metal picrates are extremely sensitive energetic materials which can be initiated very easily. It is believed that there are considerable quantities of shells filled with these explosives, a common World War I filling, in particular, the 15 inch and 6 inch shells which are believed to be Shellite and Lyddite filled. No evidence has been found to suggest that these shells were filled with any other composition.

Picric acid fillings pose a greater hazard that TNT fillings because picric acid is more sensitive, is less stable and unlike TNT can produce highly sensitive decomposition products.

Due to the fact that there is a high likelihood that there will be extremely unstable materials in some or possibly all of the picric acid containing shells, initiation of which could result in a major explosion of a magazine, it is recommended that the wreck should not be disturbed in any way that could introduce shock into the vessel or alternatively cause movement of any of the stores or other debris which could impact onto a store.

It is feasible that if the shells have corroded allowing ingress of water, which is very possible, the water will de-sensitise the energetic materials and in the case of picric acid fillings dissolve them as these are of relatively high solubility in water."

4.10 A relevant main conclusion from the report was:

"The risk posed by the ordnance whilst in the current quiescent state on the seabed is considered to be very low although there is some risk of initiation, though almost non-quantifiable, if the vessel were to be disturbed say through collapse due to long term weakening/corrosion of fixings, fittings or hull structure."

4.11 Courtney-Green (1990) in his MSc Project report from the Royal Military College Shrivenham (RMCS) stated:

"Ammunition filled with normal military explosives, such as TNT, or TNT/RDX mixtures, is unlikely to detonate on the seabed. The unchanging 1^oC *temperature provides a remarkable benign environment for such explosives. Eventual direct contact between the explosives and the surrounding seawater will not induce chemical change in the explosive. The eventual break-up of the shell casing will produce stresses in the explosive, particularly when the fuze cavity of a plugged shell is breached, but this is unlikely to be of significant magnitude to initiate the explosive. The unplanned detonations described by Norton were due to the high impact sensitiveness of the explosive fillings; modern high explosive fillings would not react in this way."*

4.12 Underwood, attending the '1991 Ammunition Technical Officers' Course' at the RMCS, agreed and wrote in his course project report on the effects of a marine environment on the degradation of sea-dumped ammunition:

"3.8 .... the risk of detonation is minimal, given that the ammunition is correctly prepared for dumping. With any ammunition in any environment there is some chance of unwanted detonations, however small that chance may be."

4.13 Turning to any effects from the spontaneous detonation of a conventional munition, then Underwood (1991) has stated:

> *3.9 <u>Damage by Underwater Explosions</u>. In an underwater explosion the energy is dissipated as an initial shock wave followed milliseconds later by the bubble effects. Of the total energy liberated by the explosion about 33% is available to cause damage in the shock wave and a further 30% to cause damage by the bubble pulse. Whilst this would indicate that damage by the shock wave is likely to be more extensive, the kinetic energy of the bubble can cause significant damage to shipping by crushing the ship's hull. It is necessary to ensure that explosives dumping grounds are kept free of all shipping in order to minimise the risk of an accident due to an underwater detonation. It is unlikely that the effects of a detonation on the bed of the Porcupine Abyssal Plain would be significant at the surface.*
>
> *3.10 <u>Environmental Damage</u>. The Stultz study for the Oceanographer of the US Navy in 1972 (15) examined the environmental impact of sea-dumping operations in two areas. At both sites Stultz concentrated on the damage done by munitions which had been detonated. The results of his study showed that there had been no significant damage to the marine life in these areas, except that all the fish were killed. However there had been repopulation of the fish and no permanent depletions had occurred. It was also found that pollution levels were not significantly higher than in other areas."*

4.14 Courtney-Green (1990) in his MSc Project report from the RMCS stated:

> *"2.66 <u>Explosive Safety</u>*
>
> *a. It has been suggested by, Westing amongst others, that dumping high explosive ammunition would result in sporadic detonations long after the event. If this were true it would not necessarily be of great concern, since it is assumed that explosives would be dumped only in the Explosives Dumping Ground, the existence of which precludes the use of the area in perpetuity for such activities as the laying of submarine cables, or mineral exploitation. It has been shown that even very large underwater detonations have little immediate effect on the marine environment other than fish mortality in the region of the overpressure, and have no irrecoverable long-term effects (Sherman, Stultz, Young GA)."*

4.15 Underwood (1991) concluded overall:

> *"The deterioration of conventional ammunition on the abyssal plains of the North Atlantic is slow enough to suggest that sea-dumping of correctly prepared conventional ammunition will not cause a major environmental disaster."*

4.16 Also of relevance is a ship, the SS Kielce, of Polish origin, built in 1944, which was on charter to the US forces, sailing from Southampton to Bremerhaven, when it was in collision and sank in the English Channel off Folkestone. The ship was of 1896 gross tonnage, 250 ft long, 41 ft berth and drawing just over 20 ft. It had a "full cargo of bombs and ammunition", although no cargo manifest has ever been traced. The wreck was chartered at 51°02'20" N, 01° 13'33" E, and was lying in approximately 90 ft (about 27m) of water.

4.17 A report from the Maritime and Coastguard Agency (2000) explained that:

"*In 1966 the Folkestone Salvage Company was given a contract to clear the wreck, to give 50 ft clearance at MLWST, and part of the contract called for the dispersal of the explosive stores. During their preliminary work to clear collapsed hull plating, the Salvage Company fired two cutting charges on the hull without serious effect. On firing the third, however, at 1159 hours BST on 22 July 1967, a large explosion occurred which "brought panic to Folkestone's town and chaos to the beaches".*

At the time the Press and the local Police, were made aware of significant damage to various properties. Chimneys were damaged, slates dislodged and ceilings were cracked, but no case of personal injury was reported."

And:

"Two members of the staff of the Folkestone Salvage Company were in a small boat some 400 yds from the wreck when the explosion occurred, and they reported "a small ripple and some spray" - certainly not a large plume of water. However, there were a few reports of a "tidal wave" hitting the Folkestone beaches, resulting in a small number of successful claims for property damage on these beaches, although it has been computed that the amplitude of the resulting sea wave caused by the explosion would not have been greater than about 2 ft."

And:

"........ a magnitude of 4½ ± ½ was allocated to the explosion. A magnitude of 4½ indicates a yield of 2000 tons of TNT, when fully contained in water or in a dense rock. The Kielce explosion was not fully contained although, as indicated above, a small proportion of the total energy release was propagated acoustically. Hence, although the total energy released may have been higher than expected from 2000 tons of TNT, the proportion of the energy propagated through the water and the sea-bed will have been equivalent to that released by that weight of explosive "fully contained"."

4.18 The report stated:

> "*The explosion of the munitions aboard the wreck of the KEILCE in 1967, reinforced the decision of the Committee on Hazardous Wrecks to recommend a policy of non-interference. The mass detonation of the cargo occurred after explosive cutting charges were fired during an attempt to clear the wreck.*"

4.19 Thus, the above literature implies that there may have been spontaneous detonations of dumped conventional munitions in the Beaufort's Dyke, but as yet no definitive evidence exists. However, clearly, any dumped munitions which contain Shellite or Lyddite as the filling will be far more likely to spontaneously detonate than, for example, TNT-filled ordnance. Especially if the dumped munitions which contain Shellite or Lyddite as the filling are disturbed. This might arise, for example, from them being subjected to an impact due to the structure of a ship collapsing, or another munition falling, onto them. However, the literature, albeit very limited in extent, does not consider there to be any major threat from even relatively large underwater detonations occurring in the dumping sites. Further, the incident of the *SS Kielce "reinforced the decision of the Committee on Hazardous Wrecks to recommend a policy of non-interference."*

5. Leave Undisturbed or Attempt to Recover ?

5.1 Obviously, a key question raised in the literature is whether one should leave the munitions dump-sites on the sea-bed undisturbed; or attempt to recover the munitions from such sites and treat them in some way to render them completely harmless; or examine possible ways in which the material can be rendered completely harmless *in situ*.

5.2 The answer to this question from reviewing the literature is overwhelming in stating that munitions dump-sites on the sea-bed should remain undisturbed. This clear statement of ‘leave them alone’ is found with respect to both conventional and chemical munitions.

5.3. Thus, it is possible to list many statements from many authors which conclude the sea-dumped munitions sites should be left undisturbed, and some examples are given below to illustrate the typical statements and some of the varied sources to be found in the more recent literature.

5.4 Stub (1995) has directed a NATO based Committee on Challenges of Modern Society (CCMS) which has considered chemical munitions which were dumped in the Baltic Sea after World War II. They concluded:

“Chemical munitions dumped at sea do not pose an acute threat either to human beings or to the marine environment.”

and:

“The general conclusion which has been drawn from risk-assessment of sea-dumped chemical munitions is that they represent no acute danger either to human beings or to the marine environment.”

5.5 Andrulewicz (1996) in an article titled ‘War Gases and Ammunition in the Polish Economic Zone of the Baltic’ stated that:

“Human risk from conventional weapon is only likely when wrecks with ammunition or the ammunition itself are disturbed on the sea floor.”

5.6 In paper presented at the same conference as above (i.e. a NATO Workshop on ‘Sea-Dumped Chemical Munitions’ held in Kaliningrad, Russia in 1995) Lisichkin (1997) again discussed the Baltic Sea and stated:

“In summary, the lifting of chemical weapons is not to be carried out. A key argument for me consists in my personal experience participating in several projects connected with sea, fleet, chemistry, and complex technical equipment (although not in the high cost of the work and its considerable duration). This experience points unambiguously to a colossal risk, which the realisation of the idea of lifting chemical weapons involves.”

5.7 Glasby (1997), in discussing the large quantities of chemical munitions that were dumped, in the Baltic Sea after World War II states:

“There are three possible ways of dealing with this legacy:

1. *collection of the shells and disposing of them on land, possibly after incineration of the chemical agents;*
2. *collection of the shells, setting them in concrete and dumping them in the deep Atlantic; or*
3. *leaving them where they are.*

Of these, the latter appears to be the only realistic option.”

5.8 Fonnum (1997) who has also considered the ships that were filled with chemical munitions and were sunk off the Norwegian coast after World War II stated:

“It would be hazardous to try to recover the ships or munitions today. The wrecks could break up, releasing all their contents at once and creating a major disaster. If the munitions are left undisturbed in the scuttled ships the chemicals will be released slowly, probably over several years.”

5.9 Laurin (1997) who has also reported on the dumping of chemical munitions in the Baltic and North Seas has commented:

“Numerous technical problems would need to be solved to bring the munitions to the surface, and the cost of safely locating and raising them would be great. Governmental funds might more profitably be used to: (a) conduct research on the effect of these chemicals and the products released by their decay on the marine environment; (b) chart the dumping sites; and (c) establish a programme of compensation and education about the danger posed by these weapons for fishermen and other affected individuals.”

5.10 As commented above, an article in the ‘Diver’ (Harrison, 1998) stated that:

> *“Nobody is suggesting that munitions be raised to the surface.”*

5.11 Hart (2000) at a Conference held at The Royal Society has written:

> *“Shortly before the end of World War II, the German government dumped 69 000 tabun-filled (GA) artillery shells at a depth of between 20-30 meters in an area called ‘Little Belt’ located between the Danish islands of Als and Fys. In 1959-1960, the Federal German Republic raised two ships containing the GA shells and repackaged the munitions before redisposing of them in the Bay of Biscay at a depth of 2 km. As far as the author is aware, this is the only operation in which any significant quantity of dumped chemical weapons was recovered for redisposal.”*

And concluded:

> *“CW destruction activities have thus far been conducted only on land, not at sea. Specialized salvage, analytical and destruction equipment would have to be developed for use on the high seas before any significant offshore remediation efforts could be seriously contemplated. Some CW-dumped munitions were sealed into concrete or steel containers and may be located in poorly accessible areas within the interior of the scuttled ship. Raising the ship or ships may not be feasible. CW munitions could disintegrate if raised causing short term, high level CW exposure to the environment. The throughput of any destruction operation would be low, perhaps a couple of dozen per day. One would have to consider whether remediation or destruction efforts could or should be carried out at sea over a period of months or years. Removal of CW to shore, on the other hand, would increase the number and scope of problems (legal, political and technical). Furthermore, any remediation effort would have to include procedures for dealing with conventional explosives, either conventional munitions or as part of the CW munitions themselves (ie, burster charges, fuze mechanisms and propellants). It would be risky to bring thousands of fuzed munitions directly on board a ship. One or more would certainly explode. A possible alternative could be to handle all munitions on an underwater platform removed from the ship and at a depth low enough to be unaffected by surface wave action.”*

5.12 Plunkett (2003) has considered chemical warfare agent sea-dumping off Australia and stated:

"Retrieval of the dumped chemical warfare agent would seem to pose an unnecessary risk, both a risk inherent in handling the material and a risk associated with the dangerous waste dumped with the chemical warfare agent (known to include ammunition and most likely to also include chemicals). Further, it would seem to be impractical to individually locate thousands of scattered bombs and artillery shells, many now presumably buried by sediment and other waste."

5.13 Also, the Helsinki Commission Working Group on Chemical Munitions (HELCOM, 2003) has only recently re-stated yet again its long-held view:

"There is no new information that could weigh against the general HELCOM recommendation that attempts should not be made to recover the chemical munitions dumped in the Baltic."

5.14 Weaver (2003) in a radio broadcast reported that:

"The Helsinki Commission is an intergovernmental group that supervises the Baltic Sea environment. The commission has published guidelines on how fishing boats can avoid risky areas. These also advise fishing crews what to do if they pull up weapons. Included is medical advice and information on how to clean boats after such an incident.

But, the commission says the weapons do not harm the Baltic Sea in any measurable way. It says current information suggests there is no risk to plants or animals in the sea. And, it says there is no evidence that poisons have gotten into seafood for humans.

The commission says the best way to deal with the weapons is to leave them alone. It says time will destroy what remains. It argues that attempts to remove or contain them are riskier than leaving them under the sea where they may be buried under sand.

But not all scientists agree. Some say the situation is too risky to leave alone. Vadim Paka is the Director of the Institute of Oceanography in Kaliningrad, Russia. He says any highly poisonous substance in the Baltic Sea system is dangerous. Mister Paka says the situation requires more study. He says failing to do so could lead to tragedy.

Other waters around the world also hold weapons. But some people say the Baltic Sea may be at greater risk. It is only fifty metres deep on average. And it is a major shipping area with many people living along its coasts."

5.15 This report was commented on in an article on the Lietuvos.net web-site:

> *"Vadim Paka, Director of the Oceanography Institute in the Russian enclave of Kaliningrad, said surveys showed that "even deep waters are not safe for toxic materials because bottom currents can be turbulent and move the poisons around".*
>
> *He said his team of marine scientists found mustard gas residues in the soil last year and arsenic up to 100 times higher than normal levels.*
>
> *"I don't think we face a catastrophe" he said. "But any persistent highly toxic agent in the ecosystem is dangerous."*
>
> *Others, including military experts, insist that it is best to let the weapons degrade in the water, allowing time and bacteria to break them down. Clearing the dumps, they argue, is very costly and risky because the munitions could explode or break up, causing additional damage.*
>
> *"After numerous studies, the government concluded that it's safest to leave the munitions alone", Svend Auken, Denmark's former minister of environment, said.*
>
> *.. "It's an illusion to think we can clear up this mess," said Jean-Pierre Henriet, a geophysicist who has tracked dumps of mustard gas weapons in deep waters off the Belgian coast.*
>
> *"This is a worldwide problem", he said, "and there's no easy way to destroy these munitions in bulk, it's best done slowly, one by one." Farmers and fishermen still find them across northern Europe.*
>
> *With stacks of such weapons from two world wars still waiting to be destroyed, he added, "it makes no sense to collect more from the sea.""*

5.16 Hart (2000) has also commented on the above idea from the Institute of Oceanography, Kaliningrad:

> *"What specific actions would be taken, such as the selection of a destruction technology and its implementation, is unclear. The view that CW dumped in the Baltic should be remediated is not generally shared by scientists working for Scandanavian defense establishments. Nor is this view shared by all Russian government officials. Boris Alekseev, head of the Russian Ministry of Defense's Environmental Security Directorate, for example, has cautioned against hastiness to remediate."*

5.17 Considering seas around the UK where the UK have dumped munitions in the past, then a report giving an 'Overview of Past Dumping at Sea of Chemical Weapons and Munitions in the OSPAR Maritime Area' by the Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention') stated in 2004:

> *"It is a widely held view that recovery of dumped munitions is not technically feasible at present. There are also serious concerns over the safety of personnel who may be involved in any such operations."*

5.18 Thus, the overwhelming view to be found in the literature, with respect to both conventional and chemical munitions, is that the munitions dump-sites on the sea-bed should remain undisturbed.

6. Future Scenarios

6.1 In the literature there has been some consideration of future scenarios.

6.2 For example, the evidence to date indicates that there have not been significant ecological effects generated from TNT-based munitions. One explanation for that may be that the containers in which the TNT is located are typically made of strengthened steel and are unlikely to have corroded much in the time since they were dumped. Accordingly there may be a problem over a rather longer time scale as corrosion continues. For example:

"…current knowledge of the corrosion status of the munitions, the behaviour of persistent warfare agents in marine environment, and the biological effect of such agents are incomplete." (Waleij, 2001)

"Technical analyses conducted thus far suggest that dumped CW pose little immediate threat to the environment or human health with the exception of fishermen raising chemical munitions in their nets and the possibility of elevated levels of arsenic in localized areas surrounding dump sites. It is possible that additional problems may become apparent in the future." (Hart, 2000).

6.3 A National Report of the Russian Federation (1993) has raised the concern that the corrosion of containers of chemical weapons could possibly result in a substantial release of chemical weapon agents over a relatively long time scale with corresponding contamination problems for the ecosystem. Thus:

"The time of initiation and termination of unsealing was estimated for various types of ammunitions and encasements. The total period of unsealing can last for 10 to 400 years from the moment of CW dumping. By now, in the regions of CW dumping could be completely unsealed cans, some grenades, about 90% of drums; the unsealing of barrels and aircraft bombs charged with mustard gas and arsenic-containing substances is being initiated. The surface of CW shells is probably covered with products of corrosion and a layer of sediments about 20cm of thickness. These predictions are to be tested at the spot."

"According to the theoretical estimates, bulk amounts of CWA can penetrate into the Baltic waters within relatively short time intervals. That is why it is necessary to undertake a systematic analysis of a possible impact of "volley" release of CWA on the ecological systems of some Baltic regions."

6.4 Thus, the question arises as to whether one might expect a sudden increase in the rate of severe corrosion of the cases of sea-dumped munitions due to corrosion of the cases, containers, etc. ?

6.5 Courtney-Green (1990) in his MSc Project report from the RMCS stated that:

"In the form in which it is practiced by the UK, deep sea dumping appears to have no adverse environmental impact on the ocean or on marine life. A large calibre shell would decay by corrosion over a period of approximately 300 years, and its high explosive filling would dissolve slowly in seawater for a period in the order of 10,000 years."

6.6 Underwood, attending the '1991 Ammunition Technical Officers' Course' at the RMCS, agreed and wrote in his course project report on the effects of a marine environment on the degradation of sea-dumped ammunition:

"The low temperature and very slow current velocity on the abyssal plains are likely to reduce the rate of corrosion, as will the lack of biological activity. The corrosion rate on the continental shelf is likely to be higher than on the abyssal plains. On the abyssal plain a generally accepted figure for the corrosion rate of a low alloy steel is about 0.15mm/year (17), however this will be higher for the continental shelf."

And:

"The deterioration of conventional ammunition on the abyssal plains of the North Atlantic is slow enough to suggest that sea-dumping of correctly prepared conventional ammunition will not cause a major environmental disaster."

6.7 In 1991, Leewis commented that, for containers rather than relatively thick shell cases:

"Evidence, e.g. by the bombs fished up at intervals by Baltic fishermen, shows that many containers are now deteriorating and breaking up."

6.8 And Tornes et al. (2002) in a report from the Norwegian Defence Research Establishment stated:

"The investigation showed that some of the ammunition was pierced through by corrosion. The contents have therefore probably leaked out, which indicates that the release of chemical ammunition to the sea will go on for a long time. The ammunition seen on the seabed has quite thin walls, and many of the shells were pierced through by corrosion. Trying to bring the shells to the surface would most likely not be successful because they will fall into pieces by the movement and the content will leak out."

6.9 And in 2004 (HELCOM, 2004) stated:

"As many as 25 incidents of chemical munitions caught by fishermen in the Baltic Sea were reported during last year, according to the annual statistics submitted by Denmark to HELCOM. Most of the netted chemical munitions were completely corroded and represented lumps of mustard gas, sneeze gas and tear gas. As lead country for dumped chemical munitions, Denmark prepared this 2003 report based on information received as of 31 August 2004."

6.10 Plunkett (2003) has considered chemical warfare agent sea-dumping off Australia and stated:

"The corrosion of ammunition shells is a complex phenomenon. A Russian study (reported in Stock 1996) concluded sea current was the important determinant of corrosion rate. Other reports argue sea conditions are very complex and combinations of external factors can create different scenarios. We do know the 1 ton cylinder retrieved off Cape Moreton had developed a number of small "pinholes" which allowed leakage of the mustard. It was also reported some of the cylinders were already partially rusted when dumped (66). Bulk cylinders were typically made from relatively thin steel when compared with artillery ammunition, filled with thickened or unthickened mustard gas. Heavy walled artillery projectiles are likely to remain intact longer than other cylinders (Major Keith Parker pers. comm.)."

6.11 Stub (1995) has directed a NATO based Committee on Challenges of Modern Society (CCMS) which has considered chemical munitions which were dumped in the Baltic Sea after World War II. They concluded:

“As long as chemical munitions remain on the seabed they pose no threat to humans

The only real danger facing fishermen in the Bornholm basin is from the dumped chemical munitions in the Baltic Sea. There is a risk that chemical munitions or lumps of viscous mustard gas may be caught in bottom trawls and hauled on board, where it can contaminate the crew. Similarly, if thin-walled or leaking containers of liquid or gaseous chemical munitions are unintentionally lifted, chemicals may be suddenly released and endanger personnel and equipment.

…Likewise, the CW munition loadings sunk on cargo ships in the Skagerrak are not a threat to shipping or fisheries. Thin-walled CW bombs should already be empty as a result of corrosion, and the contents of chemical shells are being slowly released into sea water through leaks at the filling screws. The problems posed by the dumped CW munitions will be further reduced over time. The munitions continue to corrode and released CW agents are diluted and degraded in the sea water.”

6.12 What emerges from the above is clearly stated in a report from The 16th Meeting of the Helsinki Commission Working Group on Chemical Munitions (HELCOM) reported:

“ ....the state of corrosion ranged from intact munitions to completely corroded casings not containing warfare agents.”

6.13 And in another HELCOM (2002) report is it stated:

“Due to the many factors involved, theoretical considerations and calculations cannot be used to predict the condition of the munitions in a particular dumping area.”

6.14 The effect of corrosion on the cases of munitions dumped at sea around the UK has been seen by phosphorous charges, from phosphorus bombs, floating onto beaches, from the Beaufort’s Dyke area, back in 1995. As reported by Edwards (1995):

“In the past month, more than 4500 incendiary bombs from the Second World War have been washed up on beaches around the west coast of Scotland. They are made of phosphorus, benzene and cellulose, and were designed to ignite on contact with air. Four-year-old Gordon Baillie picked one up while playing in his uncle’s garden near Campbeltown on the Mull of Kintyre. It burnt his hand and leg, and made his clothes smoke.”

The article went on to state:

> *"But why should obsolete munitions suddenly start emerging from the dump ? The most likely answer is an undersea gas pipeline linking Scotland and Northern Ireland. .... Its (British Gas) contractors began ploughing a 60-centimetre deep trench for the pipeline in the seabed just three days before the phosphorus bombs started to come ashore. ....According to the scientists in Aberdeen, it is now "beyond reasonable doubt" that the phosphorus bombs were dislodged by the ploughing operation."*

6.15 Thus, it is clearly evident that the current state of corrosion of casings of munitions dumped on the sea bed varies from 'very little' to 'completely degraded away', and that it is not possible to predict the condition of the munitions in a particular dumping area. There is no definitive evidence in the literature which considers that the continuing corrosion of munitions dumped on the sea-bed will give rise to any step-change in the conclusions which have been currently reached, assuming that the munitions are left undisturbed.

7. Conclusions

7.1 Both chemical and conventional munitions have been extensively dumped at sea since World War I. The extent of dumping is worldwide, but for the purposes of this report we have concentrated primarily on those weapons that have been dumped in the waters round the UK and in the NE Atlantic. The purpose of this study has been to provide a "review of the relevant published studies and other relevant information on the current scientific opinion on munitions (both conventional and chemical) that have been disposed of by dumping on the sea bed".

7.2 It is not possible to be definitive about the extent or composition of the munitions dumped in the waters around the UK and in the NE Atlantic. This is primarily for two reasons. One, the location and type of material has not always been documented and two, dumping of material has been found to have occurred away from specified sites and oceanographic action has resulted in the movement of munitions away from dump sites.

7.3 One main way in which human beings can be damaged by munitions is by direct physical contact. There are numerous examples of workers involved in the fishing industry being hurt by munitions that have been trawled in fishing nets and there is other evidence of problems in other industries such as dredging. Some material has been washed aground on beaches and has resulted in harm to individuals who have come into contact with it. The current practice around the UK is to use a Navy team to deal with munitions encountered in these various ways. This seems to be working well and needs to continue.

7.4 Clearly all types of munitions present potential problems in direct contact. However, chemical weapons that contain mustard gas are particularly problematic as mustard gas does not degrade in sea water and raw mustard gas can, and has, come into contact with individuals.

7.5 The possibility of both chemical and conventional munitions entering the food chain has been examined. It is convenient to distinguish between those that are water soluble, those that contain mustard gas and those that are arsenic-based. Water soluble material does not seem to present significant problems. Mustard gas is very slow to dissolve in sea water and therefore does not appear to have any immediate effect on the food chain. Arsenic-based material is likely to have the potential for concentration within the food chain, but there is no evidence to indicate that this has occurred, although some Russian studies claim there is the potential for this in the future.

7.6 Although there are a plethora of potential problems and some concerning instances of contamination of marine life by chemical weapons, this has largely occurred in the shallow waters of the Baltic and the White Sea. By contrast, a study in 1995 by the Marine Laboratory in Aberdeen of the Beaufort Dyke region found no evidence for contamination of marine life by the dumped munitions.

7.7 The literature implies that there may have been spontaneous detonations of dumped conventional munitions in the Beaufort's Dyke, but as yet no definitive evidence exists. However, clearly, any dumped munitions which contain Shellite or Lyddite as the filling will be far more likely to spontaneously detonate than, for example, TNT-filled ordnance. Especially if the dumped munitions which contain Shellite or Lyddite as the filling are disturbed. This might arise, for example, from them being subjected to an impact due to the structure of a ship collapsing, or another munition falling, onto them. Thus, clearly, there is the possibility of spontaneous detonations of dumped conventional munitions, which might trigger further explosions. However, the literature, albeit very limited in extent, does not consider there to be any major threat from even relatively large underwater detonations occurring in the dumping sites. Further, the incident of the *SS Kielce* (which was in a collision and sank in the English Channel off Folkestone with a "full cargo of bombs and ammunition") where there was an explosion during an attempt to remove the munitions *"reinforced the decision of the Committee on Hazardous Wrecks to recommend a policy of non-interference."*

7.8 The overwhelming view to be found in the literature, with respect to both conventional and chemical munitions, is that the munitions dump-sites on the sea-bed should remain undisturbed.

7.9 Turning to future scenarios, then it is clearly evident that the current state of corrosion of casings of munitions dumped on the sea bed varies from 'very little' to 'completely degraded away', and that it is not possible to predict the condition of the munitions in a particular dumping area. There is no definitive evidence in the literature which considers that the continuing corrosion of munitions dumped on the sea-bed will give rise to any step-change in the conclusions which have been currently reached, assuming that the munitions are left undisturbed. However, most authors would argue that there should be some continued monitoring.

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Bibliography

4ecotips environment website, ‘Coastal Pollution on the Brink of Disaster’, updated 22nd November 2004.

Advisory Committee on Protection of the Sea (ACOPS), ‘Coastal Survey of Packaged Chemical and other Hazardous Items 2002/2003’, Maritime and Coastguard Agency Research Project No. 488, London, October 2003.

Agriculture and Fisheries Dept for Scotland, ‘ICI Nobels Explosives Company Ltd: Disposal of Waste Materials arising from the Production of Explosives’, Department of Agriculture and Fisheries for Scotland, 1990.

Andersson, A-C, Eriksson, J, Nygren, Y, Hagglund, L and Forsman, M, ‘Risk-Assessment of Dumped Ammunition in Aquatic Environment’ Abstract, PB2000-101476, ISSN 1104-9154, Defence Research Establishment, Sweden, December 1998.

Andersson, A-C, Eriksson, J, Hagglund, L, Nygren Y, Johansson, T and Forsman, M, ‘Simulation of TNT Leakage in Sea Environment’, Abstract, PB2003-100496, ISSN 1650-1942, Swedish Defence Research Agency, December 2001.

Andrulewicz, E, ‘War Gases and Ammunition in the Polish Economic Zone of the Baltic Sea’, in ‘*Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 9-15.

Anon, ‘Mustard Gas in the Baltic Sea’ *Marine Pollution Bulletin,* **15,** 1969, pp 17-18.

Anon, ‘World War II Poisons’, *Marine Pollution Bulletin*, **7,** 1976, p 179.

Anon., ‘An Account of the Environmental, Health and Security Situation in Connection with the Dumped Poison Gas Ammunition in the Waters Surrounding Denmark’, Miljøstyrelsen, Copenhagen, 1985.

Anon., ‘VI Military Defence’ *from the ‘Coastal Guide’ organisation web-site, http://www.coastalguide.org/code/defmili.html*, updated 13th November 1999.

Anon., ‘Dumped Munitions Resurface’, News, *Marine Pollution Bulletin,* **30,** No.12, December 1995, p 768.

Batten, JJ, Moore, BT and Smith BS, ‘Marine Corrosion: Case Histories in Failure Analysis from Defence’, *Proceedings of the 30th Annual Conference: CASS 90: corrosion - air, sea, soil,* Paper 16, Australasian Corrosion Association Inc. Conference, Auckland, New Zealand, November 1990.

Belden, JB, Ownby, DR, Lotufo, GR, and Lydy, MJ, ‘Accumulation of Trinitrotoluene (TNT) in Aquatic Organisms: Part 2 - Bioconcentration in Aquatic Invertebrates and Potential for Trophic Transfer to Channel Catfish (*Ictalurus punctatus*).’, *Chemosphere* **58**, 2005, pp 1161-1168.

Berglind, R and Liljedahl, B, ‘Compounds in Dumped and Unexploded Ordnance - Possible Environmental Hazards’, Abstract, PB2000-101463, ISSN 1104-9154, Defence Research Establishment Sweden, October 1998.

BBC News Online UK, 'Mines and Hand Grenades Washed Ashore', *http://news.bbc.co.uk/1/low/uk/1536893.stm,*11th September 2001.

BBC News Web-site, Alex Kirby, 'UK's Undersea 'Ticking Time-bombs', *http://news.bbc.co.uk/1/hi/sci/tech/4032629.stm,* 26th November 2004.

Bowles, R, 'Press Brief by MoD - re: Allegations in Scottish Press on Sea Dumping of Chemical Weapons (CW)', D News Pol 2, D/D SEF Pol/4/9/3, March 2002.

Brannon, JM, Price, CB, Yost, SL, Hayes, C and Porter, B, 'Comparison of Environmental Fate and Transport Process Descriptors of Explosives in Saline and Freshwater Systems', *Marine Pollution Bulletin,* **50**, 2005, pp 247-251.

British Geological Survey, 'Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004', CR/05/064, 2005.

Carr, RS, Nipper, M, Biedenbach, JM, Hooten, RL, Miller, K and Saepoff, S, 'Sediment Toxicity Identification Evaluation (TIE) Studies at Marine Sites Suspected of Ordnance Contamination', *Archives of Environmental Contamination and Toxicology,* **41,** No.3, October 2001, pp 298-307.

Carter LJ, 'Nerve Gas Disposal: How the AEC Refused to Take Army off the Hook', *Science*, New series, **169**, No. 3952, 25th September 1970, pp 1296-1298.

CHEMU, 'Complex Analysis of the Hazard Related to the Captured German Chemical Weapon Dumped in the Baltic Sea', CHEMU 2/2/1/Rev.1 (27 September 1993): as amended 11 October 1993 - submitted by Russia.

Chepesiuk, R, 'A Sea of Trouble?', *The Bulletin of the Atomic Scientists,* **53,** No. 5, September/October 1997, pp 40-44.

Clark, RB, Frid, C and Attrill, M, *'Marine Pollution'* (Fourth Edition), Clarendon Press, Oxford, 1997, ISBN 0 19 850069 6, pp 122 - 124 and pp. 152-155.

Courtney-Green, PR, 'Options for the Demilitarization of Explosive Ordnance', MSc Thesis, Royal Military College of Science, Shrivenham, November 1990.

Cumming, AS and Paul, NC, 'Environmental Issues of Energetic Materials: A U.K. Perspective' *Waste Management,* **17,** No. 2/3, 1997, pp 129-133.

Davenport, R, Johnson, LR, Schaeffer, DJ and Balbach, H, 'Phototoxicology: 1. Light-Enhanced Toxicity of TNT and Some Related Compounds to *Daphnia magna* and *Lytechinus variagatus* Embryos', *Ecotoxicology and Environmental Safety,* **27**, 1994, pp 14-22.

Davies, G, 'Munitions Dump Explodes into Headlines Again', News, *Marine Pollution Bulletin,* **30,** No. 3, March 1996, pp 250-251.

Dixon,TR, 'Coastal Survey of Packaged Chemical and Other Hazardous Items', PECD Reference Number 7/8/188. Submitted to CUE Marine Division, Department of the Environment. Advisory Committee on Protection of the Sea. 1992.

Dixon, TR and Dixon, TJ, 'Munitions in British Coastal Waters', *Marine Pollution Bulletin*, **10**, 1979, pp 352 – 357.

Dixon, TR and Dixon, TJ, ‘A Report on a Survey of Packaged Dangerous Goods, Munitions and Pyrotechnics Recovered on the Beaches and in the Nearshore Waters of the British Isles (1 September 1982-31 August 1983). Stage 6. Marine Litter Research Programme’, Advisory Committee on Protection of the Sea/Keep Britain Tidy Group, 1985.

Doyle, A, Reuters News Service Report, January 2004

Duursma, EK (Ed.), ‘Dumped Chemical Weapons in the Sea – Options’. Published under the auspices of the Dr.A.H.Heineken Foundations for the Environment, 2e Weteringplantsoen 5, 1017 ZD Amsterdam, Netherlands, 1999, ISBN: 90-9012717-8, June 1999.

Duursma, EK and Surikov, BT, in ‘Dumped Chemical Weapons in the Sea – Options’, Ed. EK. Duursma. Published under the auspices of the Dr.A.H.Heineken Foundations for the Environment, 2e Weteringplantsoen 5, 1017 ZD Amsterdam, Netherlands, 1999, ISBN: 90-9012717-8, June 1999.

Ek, H, Dave, G, Sturve, J, Almroth, BC, Stephensen, E, Forlin, L, and Birgersson, G, ‘Tentative Biomarkers for 2,4,6-trinitrotoluene (TNT) in Fish (*Oncorhynchus mykiss*).’ *Aquatic Toxicology* **72**, 2005, pp 221-230.

Edwards, R, ‘Danger from the Deep’, *New Scientist,* **148,** 18th November 1995, pp 16-17.

Ek, H, Dave, G, Birgersson, G and Forlin, L, ‘Acute Effects of 2,4,6-Trinitrotoluene (TNT) on Haematology Parameters and Hepatic EROD-Activity in Rainbow Trout (Oncorhynchus Mykiss)’ *Aquatic Ecosystem Health & Management,* **6 (4),** 2003, pp 415-421.

Farrington, JW, Davis, AC, Tripp, BW, Phelps, DK and Galloway, WB, ‘“Mussel Watch” - Measurements of Chemical Pollutants in Bivalves as One Indicator of Coastal Environmental Quality’, *New Approaches to Monitoring Aquatic Ecosystems, ASTM STP 940,* Ed. TP Boyle, American Society for Testing and Materials, Philadelphia, 1987, pp 125-139.

Fedorov, LA, ‘Pre-Convention Liquidation of Soviet Chemical Weapons’ in *‘Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’,* Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 17 – 27.

Fisheries Research Services Report (FRSR) No. 15/96, Marine Laboratory, Aberdeen. ‘Surveys of the Beaufort’s Dyke Explosives Disposal Site’, November 1995-July 1996, Final Report, November 1996.

Fisheries Research Services, ‘Case Study: Munitions Dumping at Beaufort’s Dyke’, *htttp://www.frs-scotland.gov.uk*, 8th April 2004.

Fokin, AV and Babievsky, KK, ‘Chemical “Echo” of the Wars’ , in ‘*Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 29-33.

Fonnum, F, 'Investigation of the Ships filled with Chemical Munitions which were Sunk off the Norwegian Coast after World War II', in *The Challenge of Old Chemical Munitions and Toxic Armament Wastes*, Ed. T Stock, and K Lohs, Sipri Chemical & Biological Warfare Studies, Volume 16, Stockholm International Peace Research Institute/Oxford University Press, 1997, pp 279 – 290.

Frondorf, MJ, 'Special Study on the Sea Disposal of Chemical Munitions by the United States', in *'Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions'*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 35-40.

Glasby, GP, 'Disposal of Chemical Weapons in the Baltic Sea', in *The Science of the Total Environment*, **206**, 1997, pp 267-273.

Granbom PO, 'Investigation of a Dumping Area in the Skagerrak, 1992', in *'Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions'*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 41-48.

Green, A, Moore, D and Farrar, D, 'Chronic Toxicity of 2, 4, 6-trinitrotoluene to a Marine Polychaete and an Estuarine Amphipod.' *Environmental Toxicology and Chemistry,* **18,** 1999, pp 1783-1790.

Haas, R, Tsivunchyk, O, Steinbach, K, Low, Ev, Scheibner, K and Hofrichter, M. 'Conversion of Adamsite (Phenarsarzin Chloride) by Fungal Manganese Peroxidase', *Appl Microbiol Biotechnol,* **63**, October 2003, pp 564-566.

Haber, R, and Hedtmann, J, 'Unexploded Ordnance Devices: Detection, Recovery and Disposal', in *'Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions'*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 73-86.

Hansard,15 November 1995.

Hansard, 'Munitions Dumping (South-west Scotland)', 22 November 1995.

Hansard, 'Beaufort's Dyke', 28 November 1996.

Hansard, 'Beaufort Trench (Mustard Gas)', 23 April 2002

Harrison, P, 'Where the Real Nasties Lurk', *Diver,* May 1998.

Hart, J, 'A Review of Sea-Dumped Chemical Weapons', presented at *'The Environment and the Common Fisheries Policy, Threats to and Constraints on Sustainability'*, (Greenwich Forum), The Royal Society, 27 January 2000.

Heintze, H-J, 'Legal Problems Related to Old Chemical Munitions Dumped in the Baltic Sea' *'The Challenge of Old Chemical Munitions and Toxic Armament Wastes',* Sipri Chemical & Biological Warfare Studies, Volume 16, Ed. T Stock and K Lohs, Oxford University Press, 1997, pp 255-290.

HELCOM CHEMU, 'Report on Sea Dumping of Chemical Weapons by the United Kingdom in the Skaggerrak Waters Post World War Two'. Ad Hoc Group on Dumped Chemical Munitions, 2nd Meeting, Vilnius, Lithuania, September 1993.

HELCOM, 'Vessels Sunk in Skagerrak as Part of UK CW Disposals', Appendix 1 in: Baltic Marine Environment Protection Commission, Helsinki Commission, UK, 'Report on sea dumping of chemical weapons by the United Kingdom in the Skagerrak waters post World War II', HELCOM CHEMU 2/2/5, 28th September 1993.

HELCOM, 'Report on Chemical Munitions Dumped in the Baltic Sea', Report to the 16th Meeting of the Helsinki Commission 8-11th March 1994 from the Ad Hoc Working Group on Dumped Chemical Munitions, HELCOM CHEMU, January 1994.

HELCOM, 'Final Report of the ad hoc Working Group on Dumped Chemical Munition', HELCOM CHEMU) to the 16th Meeting of the Helsinki Commission.

HELCOM, Baltic Sea Environment Proceedings No. 64A, 'Third Periodic Assessment of the State of the Marine Environment of the Baltic Sea Area 1989 – 1993', Executive Summary, 1996.

HELCOM, Baltic Sea Environment Proceedings No. 64B, Chapter 8, 'Special Problems: Dumping of Chemical Munition', 1996, pp 198 - 202.

HELCOM, 'Environment of the Baltic Sea Area 1994 – 1998', Baltic Sea Environment Proceedings No. 82A, 2001, p13.

HELCOM, 'Environment of the Baltic Sea Area 1994 – 1998', Baltic Sea Environment Proceedings No. 82A, Chapter 8, 2002, pp 149 – 152 and 182 - 184.

HELCOM, 'Environment of the Baltic Sea Area 1999 – 2002', Baltic Sea Environment Proceedings No. 87, 2003, p 35.

HELCOM, '25 Incidents of Chemical Munitions Caught by Fisherman in the Baltic Sea Reported in 2003', Baltic Marine Environmental Protection Commission of HELCOM, 14th September 2004.

HMSO, 'Text Book of Ammunition', The Naval & Military Press Ltd, ISBN 1843425610, 1936.

Hoffsommer, JC and Rosen, JM, 'Analysis of Explosives in Sea Water', *Bulletin of Environmental Contamination & Toxicology,* **7,** No. 2/3, 1972, pp 177-181.

Irion, G, 'Schwermetallbelastung in Oberflächensedimenten der westlichen Ostsee', Natur wissenschaften, 71, 1984, pp 536 -538.

Kaffka, AV (Ed.), *'Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions'*, Kluwer Academic Publishers, Dordrecht, ISBN 0-7923-4090-61996, January 1995.

Knightley, P, 'Dumps of Death', *Sunday Times Magazine*, 5th April 1992.

Konkov, VN, 'The Technological Problems with Sea-Dumped Chemical Weapons from the Standpoint of Defence Conversion Industries', in '*Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions'*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 87-91.

Korotenko, KA, 'Chemical Warfare Munitions Dumped in the Baltic Sea: Modeling of Pollutant Transport Due to Possible Leakage', *Oceanology,* **43,** No. 1, 2003, pp 21-34.

Laurin, F, 'The Baltic and North Sea Dumping of Chemical Weapons: Still a Threat?' in *The Challenge of Old Chemical Munitions and Toxic Armament Wastes*, Ed. Stock, T and Lohs, K, Sipri Chemical & Biological Warfare Studies, Volume 16, Stockholm International Peace Research Institute/Oxford University Press, 1997, pp 263 - 278.

Leewis, RJ, 'Environmental Impact of Shipwrecks in the North Sea. II. Negative Aspects: Hazardous Substances in Shipwrecks',*Wat. Sci. Tech.,* **24,** 10, 1991, pp 299-300.

Lietuvos.net, 'Chemical Weapon Dumping in the Baltic Sea', Lithuanian Website at: *lietuvos.net/zinios/gas_ww2.htm*.

Lisichkin, GV, 'Chemical Weapons on the Seabed', in *'Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions'*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 121-127.

Lotufo, GR, Farrar, JD, Innouye, LS, Bridges, TS and Ringelberg, DB, 'Toxicity of Sediment-associated Nitroaromatic and Cyclonitramine Compounds to Benthic Invertebrates', *Environmental Toxicology and Chemistry,* **20,** 2001, pp 1762-1771.

Malyshev, LP, 'Technological Questions of Safe Elimination of CW Dumps on the Baltic Sea Bed' in *Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 93–104.

Manley, RG, 'Chemical Weapon Agent and Historic Chemical Munitions Disposal: The British Experience', in *The Challenge of Old Chemical Munitions and Toxic Armament Wastes*, Ed. T Stock and K Lohs, Sipri Chemical & Biological Warfare Studies, Volume 16, Stockholm International Peace Research Institute/Oxford University Press, 1997, pp 231 – 240.

Maritime and Coastguard Agency, 'Report on the Wreck of the SS Richard Montgomery', Southampton, November, 2000.

Martens, H, Fonnum, F and Hobraten S, 'NATO and Partner Countries Study Defence-Related Radioactive and Chemical Contamination' NATO review 9601-3, **44,** No. 1, January 1996, pp 11-16.

Melzian, BD, Zoffmann, C and Spies, RB, 'Chlorinated Hydrocarbons in Lower Continental Slope Fish Collected near the Farallon Islands, California', *Marine Pollution Bulletin,* **18,** No.7, 1987, pp 388-393.

Ministry of Defence, 'Sea Dumping of Munitions', undated document.

Ministry of Defence, 'HMS Royal Oak Munition and Explosives Risk Assessment', ES352/97/59, April 1999.

Mitretek Systems, 'Ocean Dumping of Chemical Weapons', at the Website: *http://www.mitretek.org/home.nsf/homelandsecurity/OceanDumpChemWeap*, unknown date.

National Report of the Russian Federation, 'Complex Analysis of the Hazard Related to the Captured German Chemical Weapon Dumped in the Baltic Sea', Moscow, 1993.

Nipper, M, Carr, RS, Biedenbach, JM, Hooten, RL, Miller, K and Saepoff, S, 'Development of Marine Toxicity Data for Ordnance Compounds', *Archives of Environmental Contamination and Toxicology,* **41,** 2001, pp 308-319.

Nottingham, J, 'The Dangers of Chemical and Biological Warfare (CBW)' *Ecologist*, **2**, 1972 pp 4-6.

O'Connor, TP, Kester, DR, Burt, WV, Capuzzo, JM, Park, PK and Duedall, IW, 'Waste Disposal in the Deep Ocean: an Overview', *Wastes in the Ocean Vol. 5: Deep Sea Waste Disposal,* Environmental Science and Technology, John Wiley & Sons, pp 3-30.

OSPAR Commission, 'OSPAR Framework for Reporting Encounters with Marine Dumped Chemical Weapons and Munitions', 2003, ISBN 1-904426-26-3

OSPAR Commission, the 2004 update on 'Convention-wide Practices and Procedures in Relation to Dumped Chemical Weapons and Munitions', 2004, ISBN 1-904426-53-0.

OSPAR Commission, 'Overview of Past Dumping at Sea of Chemical Weapons and Munitions in the OSPAR Maritime Area', 2004 (Revised), ISBN 1-904426-54-9.

OSPAR, 'Convention for the Protection of the Marine Environment of the North-east Atlantic'. Meeting of the Working Group on the Environmental Impact of Human Activities (EIHA), Summary Record', London (Secretariat), 16th-18th November 2004.

Ownby, DR, Belden, JB, Lotufo, GR and Lydy, MJ, 'Accumulation of Trinitrotoluene (TNT) in Aquatic Organisms: Part 1 - Bioconcentration and Distribution in Channel Catfish (*Ictalurus punctatus*)', *Chemosphere* **58**, 2005, pp 1153-1159.

Paka, V and Spiridonov, M, 'Research of Dumped Chemical Weapons made by R/V "Professor Shtokman" in the Gotland, Bornholm and Skagerrak Dump Sites', Eds. T Missiaen, and JP Henriet, *Chemical Munition Dump Sites in Coastal Environments*, 2002, pp. 27-42.

Pearce, KW and Vincent, JD, 'Investigation into the Effects of Deep Sea Pressures on Waste Materials and Disposal Containers', AERE Report AERE - M 1254, 1963.

Perera, J, 'Chemical Munitions in the Commonwealth of Independent States and the Surrounding Seas', *'The Challenge of Old Chemical Munitions and Toxic Armament Wastes',* Sipri Chemical & Biological Warfare Studies, Volume 16, Ed. T Stock and K Lohs, Oxford University Press, 1997 pp 121-137.

Perera, J and Thomas, A, 'Fishing Boats Dodge Mustard Gas in the Baltic', *New Scientist* 10 October 1987, p. 24.

Plotnikov, VG, Zamyslov, RA, Surikov, BT, Dobrov, IV and Kayurin OYu, ' Application of Anti-Filtering Coatings for Localisation of Toxic Warfare Chemicals in the Baltic Sea Area', in '*Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions'*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 105-107.

Pluck, JA, 'Munitions Dumped in the Atlantic by the UK', MoD memorandum D/Env Pol/51/2/62 to the Foreign and Commonwealth Office. May 1996.

Plunkett, G, ‘Chemical Warfare Agent Sea Dumping off Australia’, Department of Defence, Canberra, Australia, Updated 2003, ISBN 0 642 29587 5.

Reynders, F, ‘The Coastal Maritime Operations Seminar 2000 and the Possible Role of NATO in Solving the Problem of Sea-Dumped Chemical Weapons’. The NATO Coastal Maritime Operations Seminar 2000, pp 157-163.

Riley, JD and Ramster, JW, ‘Woodhead Seabed Drifter Recoveries and the Influence of Human, Tidal and Wind Factors’, *J. Cons. int. Explor. Mer.,* **34**, No. 3, Copenhagen, October 1972, pp 389-415.

Robinson, IS, ‘Tidal Vorticity and Residual Circulation’ *Deep-Sea Research,* **28A,** No.3, 1981, pp 195-212.

Sandstrom, J and Forsman, M, ‘Biological Degradation of Explosives’, Abstract, PB 96-121108, ISSN 1104-9154, National Defence Research Establishment, Dept of NBC Defence, Sweden, August 1995.

Searle, WF and Moody, DH, ‘Explosive Remnants of War at Sea: Technical Aspects of Disposal’, in *‘Explosive Remnants of War, Mitigating the Environmental Effects’* Ed. AH Westing, Sipri, Taylor & Francis, London, 1985, pp 61-69.

Seltzer, RJ, ‘Ocean Pollutants Pose Potential Danger to Man’, *Chemical and Engineering News*, **53,** No.8, 1975, pp 19-20.

Sipri, *‘World Armaments and Disarmament: Sipri Yearbook 1983’*, Preface and Contents, Taylor & Francis, London, 1983.

Soilleux, R, ‘The Safe Disposal of Chemical Munitions in the Field’, *Explosives Engineering*, November 2002, pp 20-23.

Spiess, PN and Sanders, SM, ‘Survey of Chase Disposal Area (NITNATOW)’ , Sponsored by Oceanographer of the Navy through Office of Naval Research, SIO Reference 71-33, 28th December 1971.

Stock, T, ‘Sea-Dumped Chemical Weapons and the Chemical Weapons Convention’, in ‘*Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 49 – 66.

Stock, T and Lohs, K (Eds) , ‘ *The Challenge of Old Chemical Munitions and Toxic Armament Wastes,* Sipri Chemical & Biological Warfare Studies, Volume 16’ Stockholm International Peace Research Institute/Oxford University Press, 1997, ISBN 0-19-829190-6.

Stock, T and Lohs, K, ‘ Old Chemical Munitions and Warfare Agents: Detoxification and Degradation’, *‘The Challenge of Old Chemical Munitions and Toxic Armament Wastes’* Sipri Chemical & Biological Warfare Studies, Volume 16, Ed. T Stock and K Lohs, Oxford University Press, 1997, pp 35-52.

Stub, S, ‘Cross-Border Environmental Problems Emanating from Defence-Related Installations and Activities’, NATO/CCMS/NACC Pilot Study, Summary Final Report, Phase 1 1993-1995, Report No. 206, NATO, April 1995.

Surikov, BT, ‘How to Save the Baltics from Ecological Disaster’, in *‘Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 67-70.

Surikov, BT and Duursma, EK, in ‘Dumped CW Agents in European Seas’ in *‘Dumped Chemical Weapons in the Sea – Options’*, Ed. EK. Duursma. Published under the auspices of the Dr.A.H.Heineken Foundations for the Environment, 2e Weteringplantsoen 5, 1017 ZD Amsterdam, Netherlands, 1999, ISBN: 90-9012717-8, June 1999, pp 5-10.

Sutton, MA, Dragosits, U, Tang, YS and Fowler, D, ‘Ammonia Emissions from Non-Agricultural Sources in the UK’, *Atmospheric Environment,* **34,** 2000, pp 855-869.

Thorhaug, A, Blake N and Schroeder, PB ‘The Effect of Heated Effluents from Power Plants on Seagrass (Thalassia) Communities Quantitatively Comparing Estuaries in the Subtropics to the Tropics’, *Marine Pollution Bulletin*, **9**, 1978, pp 181-187.

Tørnes, JAa, Voie ØA, Ljønes M, Opstad AaM, Bjerkeseth LH and Hussain F, ‘Investigation and Risk Assessment of Ships Loaded With Chemical Ammunition Scuttled In Skagerrak’, FFI/RAPPORT-2002/04951 Norwegian Defence Research Establishment, 2002.

Townsend, M, ‘The Deadly Cocktail Dumped on our Shores’, *The Observer,* 19th December 2004.

Trapp, R*, ‘The Detoxification and Natural Degradation of Chemical Warfare Agents’*, Sipri Chemical & Warfare Studies, Volume 3, Sipri/Taylor & Francis, London 1985, ISBN 0-85066-309-1.

Underwood, MJ, ‘The Effect of the Marine Environment on the Degradation of Sea-Dumped Ammunition’, The Royal Military College of Science, 1991 Ammunition Technical Officers Course (Diploma in Explosives Ordnance Technology).

VanDeveer, SD, ‘ Protecting Europe’s Seas: Lessons from the Last 25 Years’, *Environment,* **42,** No. 6, July/August 2000, pp 11-26.

van Ham, NHA, ‘Recycling and Disposal of Munitions and Explosives’, *Waste Management,* **17**, No. 2/3, 1997, pp 147-150.

Volk, F, ‘Reaction Products of Chemical Agents by Thermodynamic Calculations’, in *‘Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 129-143.

Waleij. A, ‘Dumped Chemical Munition in Skagerrak and the Baltic Sea - an update’, Abstract, ISSN 1650-1942, Swedish Defence Research Agency, August 2001.

Weaver, C, ‘Environment Report - Old Chemical Weapons in the Baltic Sea’, VOA Special English Environment Report,Broadcast 11th July 2003 *http://www/manythings.org/voa/03/030711er_t.htm*

White, GF, Snape, JR and Nicklin, S, ‘ Bacterial Biodegradation of Nitrate Ester Explosives’, in *‘Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 145-156.

Witkiewicz, Z and Szarski, K, ‘The History of Chemical Weapons in Poland’ *‘The Challenge of Old Chemical Munitions and Toxic Armament Wastes’,* Sipri Chemical & Biological Warfare Studies, Volume 16, Ed. T Stock and K Lohs, Oxford University Press, 1997 pp 112-120.

Woodcock, A, ‘Washed Up Missile Parts Found Near N-Plant’, *“PA” NEWS*, 9th February 2004.

Yufit, SS, Miskevich, IV and Shtemberg, ON, ‘Chemical Weapons Dumping and White Sea Contamination’, in *‘Sea-Dumped Chemical Weapons: Aspects, Problems and Solutions’*, Ed. AV Kaffka, Kluwer Academic Publishers, Dordrecht, 1996, pp 157-166.

Zanders, JP, ‘ The Destruction of Old Chemical Munitions in Belgium’, *‘The Challenge of Old Chemical Munitions and Toxic Armament Wastes*’, Sipri Chemical & Biological Warfare Studies, Volume 16, Ed. T Stock and K Lohs, Oxford University Press, 1997, pp 197-230.

Zanders, JP, ‘Dealing with Chemical Weapons Dumped in Bodies of Water’, Sea-Dumped CW and the Chemical Weapons Convention, pp 145-156.

Zhao, J-S, Greer, CW, Thiboutot, S, Ampleman, G and Hawari, J, ‘Biodegradation of the Nitramine Explosives Hexahydro-1,3,5-Trinitro-1,3,5-Triazine and Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine in Cold Marine Sediment under Anaerobic and Oligotrophic Conditions’ *Can. J. Microbiol.* **50**, March 2004, pp 91-96.

Appendix 1: Typical Locations and Types of Sea-Dumped Conventional and Chemical Munitions

A1.1 There is a large body of literature on the topic of the locations and types of munitions that have been dumped in seas around the globe. A few examples are given here so that the reader can gain an appreciation of the typical locations and types of munitions dumped in the seas around the UK, and dumped by the UK. (But see disclaimer, paragraph A1.12)

A1.2 Sea-dumping in the Baltic Sea and Skagerrak sites has been extensively discussed in the literature. Indeed, the relatively small size and shallow depth of the Baltic Sea has led to a substantial body of literature on sea-dumped munitions in the Baltic Sea. Figures A1 and A2 show some of the reported North and Baltic Seas, and the Skagerrak, sites.

A1.3 The UK, USA, Russia and France undertook dumping of confiscated German chemical munitions into the Baltic Sea and Skagerrak between 1945 and 1947. (Note: the UK disposed of captured chemical munitions into the Skagerrak only.)

A1.4 The approximate amounts and types of munitions dumped in these Helsinki Commission waters are shown in Figure A3.

A1.5 Research by OSPAR members has shown that there are many locations of sea-dumped munitions throughout the Convention Area; munitions range from conventional munitions, phosphorous devices to mustard gases. Dumping operations included dumping overboard from vessels and by sinking ships containing chemical weapons and munitions. Figure A2 shows the typical locations of these reported dump-sites.

Figure A1: Baltic Sea and Skagerrak Sites of Chemical Munitions Dumping after World War II

(**O**: Sites of Chemical Munitions Dumps. See paragraph A1.12 for ‘Disclaimer’. Laurin (1997).)

Figure A2: Location of Munitions Sites in OSPAR-Regulated Waters

(Red: Conventional Munitions; Yellow: Chemical Munitions; Nos. 75 and 76: Unknown.
Sites with chemical munitions may also contain conventional munitions.
See paragraph A1.12 for ‘Disclaimer’. OSPAR (2004), ISBN 1-904426-54-9.)

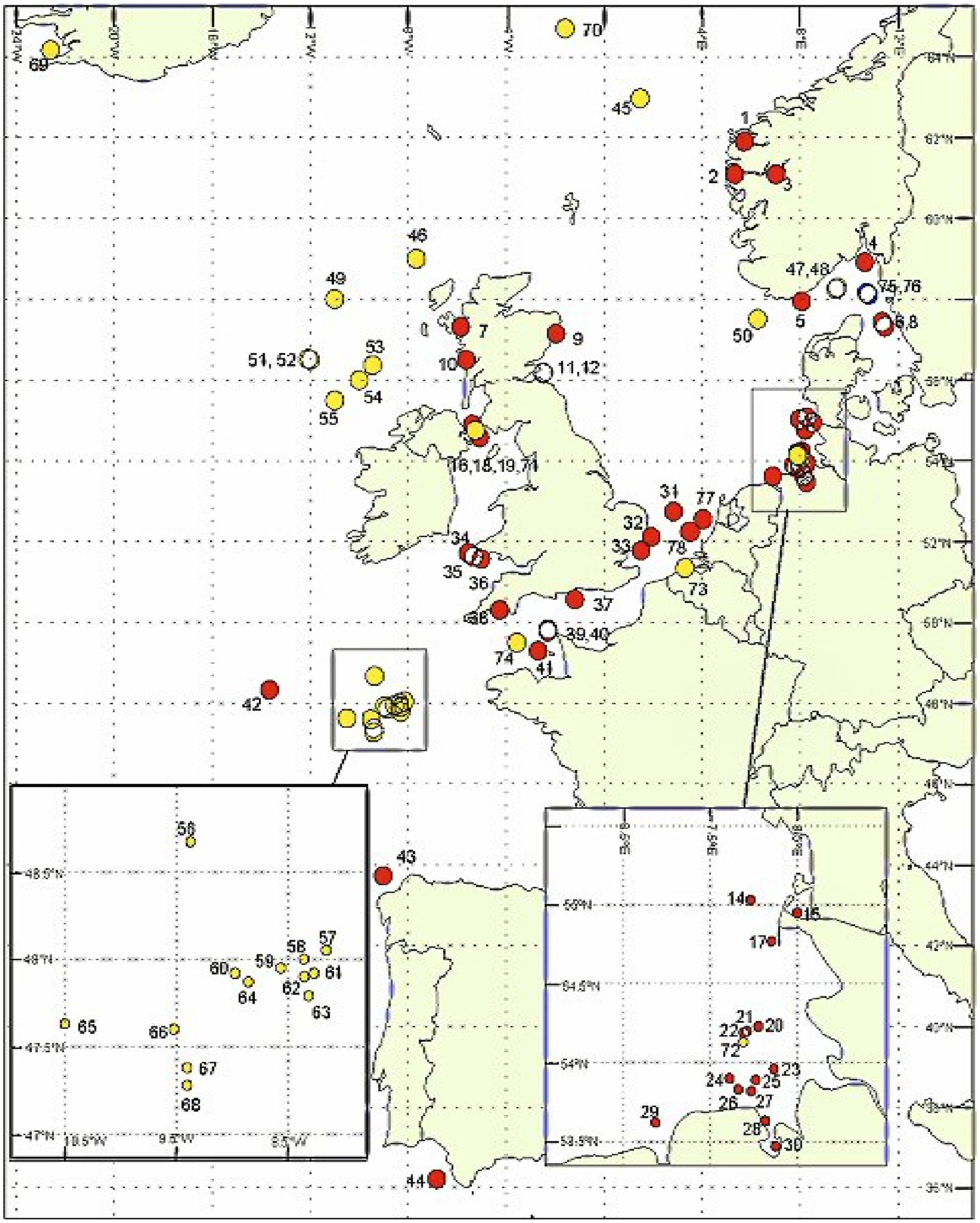
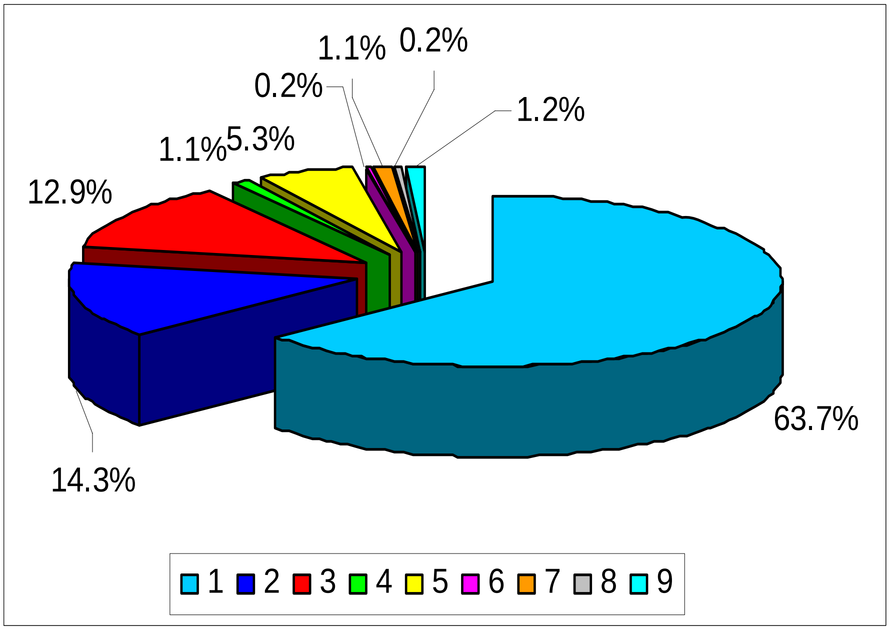
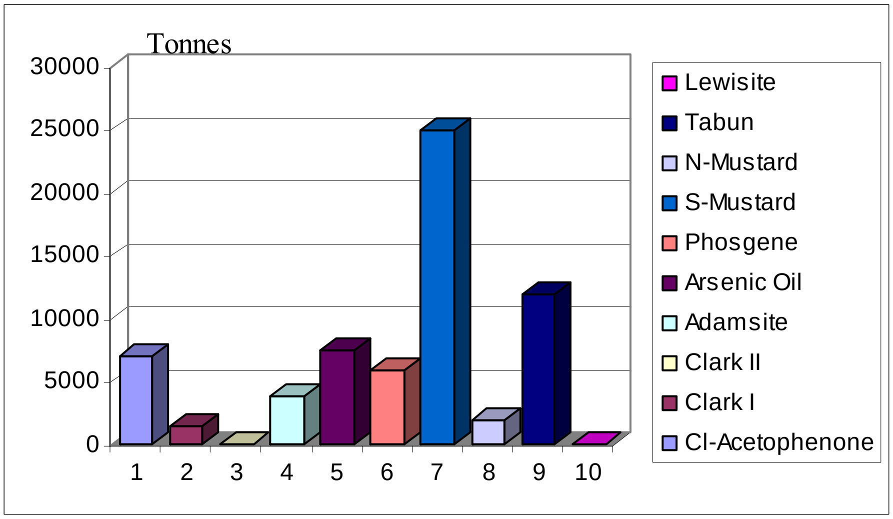


Figure A3: Estimated Amounts and Types of Munitions Sea-Dumped in the Helsinki Commission Waters after World War II (Duursma and Surikov, 1999)

(Disclaimer: Although the below shows what is believed to be the best possible information from the original source, the data shown do not constitute an exhaustive description of the munitions that may have been dumped.)

(Key for upper figure: 1 = Artillery Shells; 2 = Aircraft Bombs; 3 = Gas Pots; 4 = Boxes of Explosives and grenades; 5 = Mines; 6 = Containers; 7 = Cylinders; 8 = Barrels; 9 = Cans)





A1.6 One of the most heavily used areas for sea-dumping of munitions by the UK is the Beaufort’s Dyke, a 200 to 300 metre-deep trench located between Scotland and Northern Ireland. It has been estimated that well over one million tons of munitions have been dumped in the Beaufort’s Dyke since the early 1920s. The vast majority of the dumped munitions are conventional munitions but, in addition to the conventional munitions, some 14,500 tons of 5 inch artillery rockets filled with phosgene gas (a chemical weapon) were dumped in Beaufort’s Dyke in July 1945, see below.

A1.7 It is not possible to identify exactly what munitions have been dumped in the Beaufort’s Dyke. (We would emphasise that we believe that this is not because of any withholding of documents by any parties, but simply that many of the records have been destroyed due to the time-scale involved; and in any event it seems that detailed records were not always made of the exact types of the munitions involved and/or the exact locations.) Nevertheless, from the literature the munitions included:

> 29" Spigot mortar bombs; Smoke generators (Numbers 5, 8 and 14); Shrapnel mines; .303 Small arms ammunition (SAA) (incendiary); .50 Ammunition (incendiary); 3" Mortar bombs (smoke); 2" Mortar bomb (smoke); 40mm Light anti-aircraft (LAA) gun shells (Bofors); 20mm LAA shells; Percussion fuses percussion (Number 101E); Hand Grenades (Number 79: smoke); Instantaneous detonation fuses (Mk3); Rockets 'U': 3" (Type 'K': Anti-Aircraft with parachute and wire); Rockets 'U': 5" (Type 'G1': Phosgene); USAF 500lb HE bombs; RAF 9 lb bombs; RAF 500 lb cluster bombs (Number 17).

It is also possible that UK and captured German naval munitions such as torpedoes, machine gun rounds, etc. could also form part of the material in this area.

A1.8 Turning to the Atlantic, the dumping of chemical munitions in the Atlantic was a four-phase operation; as indicated in Tables A1 and A2. Phase 3 was designated Operation ‘Sandcastle’. Phase 1 scuttlings took place in the Atlantic Deep (NE end) and sites to the West of the Hebrides and to the West of Northern Ireland. Phase 2 dumpings took place at the NE end of the Atlantic Deep and Operation Sandcastle used the area to the West of Northern Ireland; Phase 4 probably took place close to here.

A1.9 Considering the types of chemical munitions, then Manley (1997) has stated:

> *"During World War II a number of chemical warfare agents were manufactured in the UK. These included mustard gas, phosgene, BBC, lewisite, diphenylamine chlorarsine, methyl dichloroarsine and KSK. However, of these only mustard gas and phosgene were manufactured and filled into munitions on a large scale. At the end of the war manufacture ceased and no CW agents were produced until the early 1950s, when a one tonne per week pilot plant was constructed to undertake process research to establish parameters for the production of GB. This plant was operated during the two-year period 1954-56. The GB produced during this period was stored in bulk containers and used solely for stability studies. No nerve agent was filled into munitions. In 1956 the United Kingdom took a unilateral decision to forgo renewal of its offensive CW capability and confine its future efforts solely to research into effective countermeasures against the CW threat. Since 1956 the preparation of CW agents in the UK has been limited to the small quantities necessary to support this research programme."*

A1.10 Further, Pluck (1996) states:

> *"Between 1945 and 1949 MoD disposed of approximately 120,000 tons of UK CW munitions, bombs and shells, filled with mustard and phosgene gas (but not nerve agent) by deep sea dumping at various positions in the Atlantic. The Ministry of Agriculture, Fisheries and Food was consulted over the selection of deep water disposal areas. The munitions were dumped in water up to 2000 metres deep, mostly sealed within redundant cargo vessels which were then scuttled. Residual UK munition stocks of mustard gas and confiscated German WWII aerial bombs containing the nerve agent Tabun were also sea dumped in the Atlantic between 1955 and 1957. Dump sites were located between 50 and 100 miles west of the Hebrides, 80 miles northwest of Northern Ireland, 250 miles southwest of Lands End in the Western Approaches and in Beaufort's Dyke."*

And from Hansard (15 November 1995) The Minister of State for the Armed Forces (Mr. Nicholas Soames) stated:

> *"Beaufort's Dyke was our main dumping site for surplus and redundant munitions for many years. It was probably first used as early as 1920. With the exception of one emergency operation in 1976, dumping there ceased in 1973. We estimate that more that 1 million tonnes were disposed of at the site.*
>
> *Surviving records confirm that between July and October 1945, some 14,600 tonnes of 5in artillery rockets filled with phosgene were disposed of in Beaufort's Dyke. There is, however, no evidence to suggest that any munitions containing nerve or biological warfare agents were dumped by my Department in Beaufort's Dyke, the Irish Sea or the North Channel and we did not dispose of radioactive waste in those areas."*

And from Hansard (23rd April 2002):

> *"**Dr. Moonie:** Detailed inventories of chemical weapons and other munitions disposed of in Beaufort's Dyke are no longer available; many records were destroyed after the disposals as a matter of routine custom and practice in view of the fact that sea dumping of munitions, including CW-filled items, was then an acceptable method of disposal. Where records of disposals do remain in existence, they have been released to the Public Record Office. From those existing records, it is known that some 14,500 tons of 5 inch artillery rockets filled with phosgene were dumped in Beaufort's Dyke in July 1945. There are no records which indicate that other chemical weapons, including mustard gas, have been disposed of to that dump site."*

A1.11 From the literature, apart from one emergency dumping of corroded ammunition in 1976, the use of Beaufort's Dyke, and other sites on the continental shelf around the UK, ceased in 1973 following the enactment of two global conventions covering dumping materials at sea. The sole, approved MoD site was then in the Atlantic Deep (site 42 in Figure 2) some 400 miles West of Lands End. Finally, all sea dumping of munitions ceased in October 1992, in line with the OSPAR Convention which came into force on 1st January 1993.

A1.12 Finally, it should be noted that all the sources for the above information essentially state:

> *"Disclaimer: These maps and tables show what is believed to be the best available information. The sites and data shown do not constitute an exhaustive description of the sites or what they may contain. No liability for the accuracy or completeness of this information is accepted by the OSPAR/Helsinki Commission or by the Governments of Contracting Parties to the Conventions."*

Table A1: Sites of UK-Dumped Chemical Munitions in the Atlantic

(Site Numbers refer to those in Figure A2)

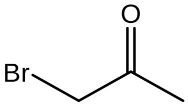
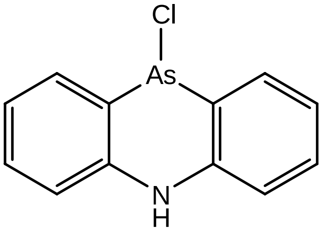
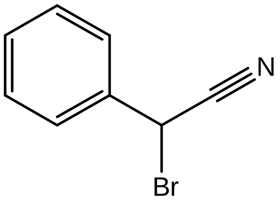
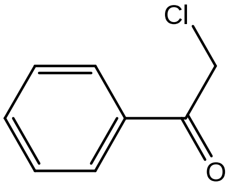
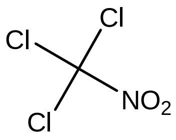
Site No.	Longitude	Latitude	Depth (m)	Comments
46	59°00’ N	07°40’ W	800	Empire Woodlark: Phase 1 scuttled on 02.11.46
49	58°00‘N	11°00’ W	2000	Empire Fal: Phase 1 scuttled on 02.07.45
51	56°30’ N	12°00’ W	2500	Empire Claire and Vogtland: Phase 3 (Operation ‘Sandcastle’) scuttled on 27.07.55 and 30.05.56 respectively
52	56°31’ N	12°05’ W	2500	Krotka: Phase 3 (Operation ‘Sandcastle’) scuttled on 23.07.56
53	56°22’ N	09°27’ W	1300	Leighton: Phase 1 scuttled on 09.08.47
54	56°00’ N	10°00’ W	2000	Possible site of Phase 4 scuttlings between June 1956 and September 1956 (ships unknown)
55	55°30’ N	11°00’ W	2500	Empire Simba, Empire Cormorant, Wairuna and Botlea: Phase 1 scuttled on 11.09.45, 01.10.45, 30.10.45 and 30.12.45 respectively
56	47°40’ N	09°22’ W	3500 to 4000	Dora Oldendorf: Phase 1 scuttled on 05.02.47
57	48°03’ N	08°09’ W	500	Empire Nutfield: Phase 1 scuttled on 03.09.46
58	48°00’ N	08°21’ W	800 to 900	Lanark: Phase 1 scuttled on 11.11.46
59	47°57’ N	08°33’ W	700 to 800	Empire Peacock: Phase 1 scuttled on 25.08.46
60	47°55’ N	08°58’ W	2500	Harm Freitzen: Phase 1 scuttled on 01.03.48
61	47°55’ N	08°17’ W	750 to 800	Empire Lark: Phase 1 scuttled on 27.07.47
62	47°54’ N	08°21’ W	1000	Kindersley: Phase 1 scuttled on 01.10.46
63	47°52’ N	08°51’ W	2000	Empire Connyngham: Phase 2 scuttled on 20.06.49
64	47°47’ N	08°21’ W	1500	Thorpe Bay: Phase 1 scuttled on 08.09.47
66	47°36’ N	09°31’ W	4100	Margo: Phase 1 scuttled on 03.11.47
67	47°23’ N	09°24’ W	4000	Miervaldis: Phase 1 scuttled on 22.09.48
68	47°16’ N	09°24’ W	4200	Empire Success: Phase 1 scuttled on 22.08.48

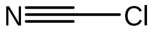
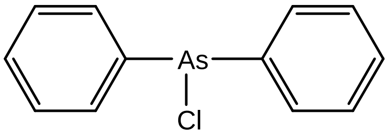
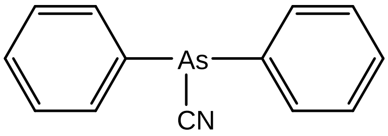
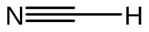
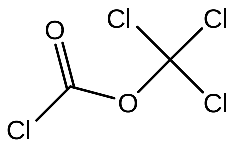
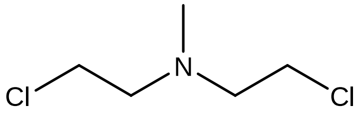
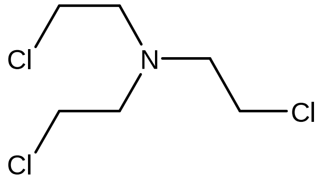
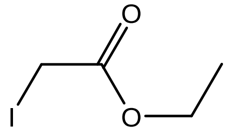
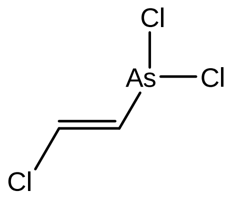
Table A2: Post War Atlantic Deep Sea Dumping. (Data source. T. Dixon, personal communication).

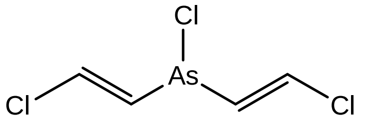
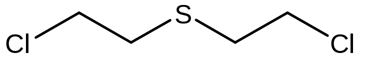
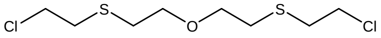
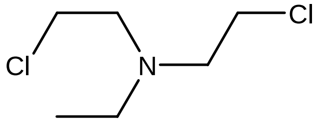
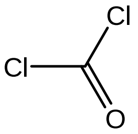
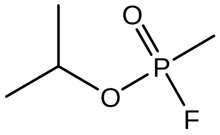
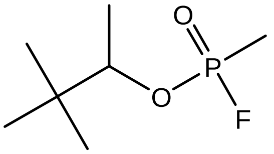
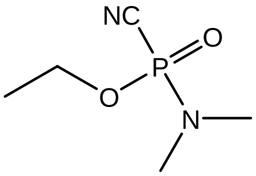
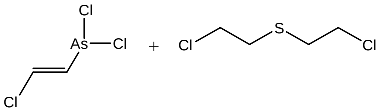
				Approx position		Depth (m)
Ship (scuttled)	**Munitions Cargo**	**Weight (Tons)**	**Date**	**N**	**W**	
Phase I :1945-1948	(Operation Sandcastle)					
Empire Pal	Defective bombs	Unknown	2.7.45	59 20	11 10	>1000
Empire Simba	Unknown	8032	11.9.45	55 20	12 05	>1000
Empire Cormorant	Unknown	8383	1.10.45	55 20	11 50	>1000
Wairuna	Unknown	8432	30.10.45	55 30	11 30	>1000
Botlea	Unknown	6152	30.12.45	55 40	11 00	>1000
Empire Peacock	Unknown	Unknown	25.8.46	47 40	8 10	>1000
Empire Nutfield	Unknown	Unknown	3.9.46	48 05	7 55	200-1000
Kindersley	Unknown	2074	1.10.46	47 20	7 55	>1000
Empire Woodlark	Unknown	4348	2.11.46	58 55	8 55	200-1000
Lanark	Unknown	Unknown	11.11.46	47 55	7 30	200-1000
Dora Oldendorf	Unknown	2507	5.2.47	47 10	8 40	>1000
Empire Lark	Unknown	7649	27.7.47	47 40	7 10	200-1000
Leighton	Unknown	Unknown	9.8.47	55 55	12 50	>1000
Thorpe Bay	Unknown	1933	8.9.47	46 50	8 50	>1000
Margo	Unknown	1259	3.11.47	47 40	8 50	>1000
Harm Frietzen	Unknown	7854	1.3.48	47 55	8 40	>1000
Empire Success	Unknown	9853	22.8.48	47 00	9 05	>1000
Miervaldis	Unknown	1880	22.9.48	47 00	8 05	>1000
Phase 2: 1949.						
Empire Connyngham	Unknown	Unknown	20.6.49	47 05	7 30	>1000
Phase 3: 1955-1956.						
Empire Claire	16,088 Aircraft bombs -nerve gas (Tabun)	3500	2.7.55	55 55	12 10	>1000
Vogtland	Approx 26,000 Aircraft bombs -nerve gas (Tabun)	Unknown	30.5.56	56 10	11 00	>1000
Kotka	Approx 26,000 Aircraft bombs -nerve gas (Tabun)	Unknown	23.7.56	56 50	12 30	>1000
Phase 4: 1956-1957.						
Jettisoned	Artillery shells 25pdr mustard & 1ton phosgene	271	?.6.56	56 00	10 00	200-1000
Jettisoned	Artillery shells 25pdr mustard & 5 tons phosgene	3200	6.9.56	55 30	9 30	<200

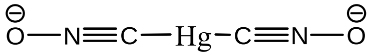
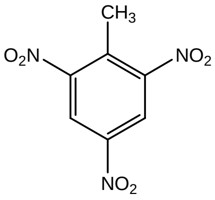
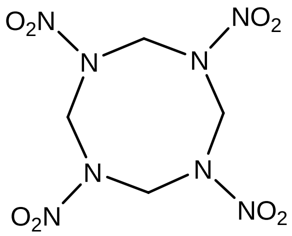
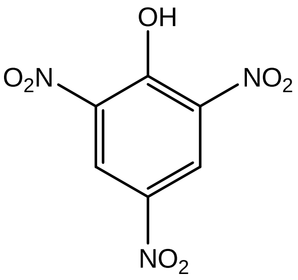
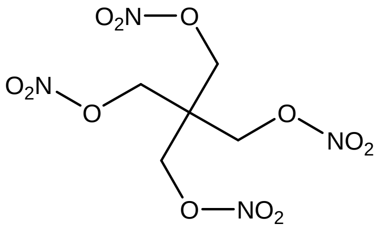
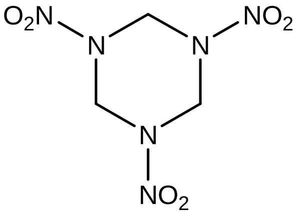
Appendix 2: Name and Structure of Chemical and Conventional Munitions

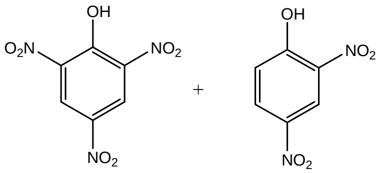
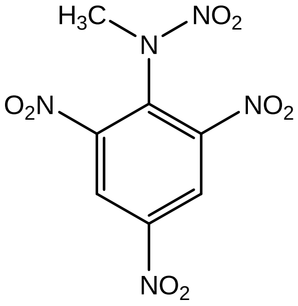
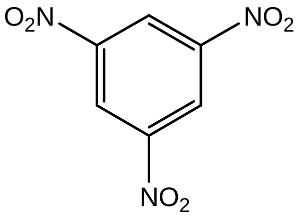
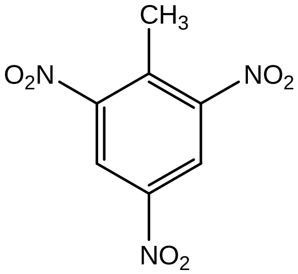
Sources for Chemical Munitions:
1: Mitretek Systems [http://www.mitretek.org/home.nsf]
2: By inference from the data on the individual components
3: Various sources
Sources for Conventional Munitions:
1: Wikipedia [http://en.wikipedia.org]
2: Accurate Energetic Systems [http://www.aesys.biz/MSDS.htm]
3: Segulab [http://www.segulab.com/]
4: Sigma-Aldrich
5: Various sources

Trivial Name	Chemical Name	Chemical Structure	Solubility in Water [g/l]
	Bromoacetone [CAS: 598-31-2]		Sparingly Soluble[1]
Adamsite [Agent DM, Sternite]	Diphenylaminechlorarsine, 10-chloro-5,10-dihydrophenarsazine [CAS: 578-94-9]		Practically Insoluble[1]
CA [BBC]	Bromobenzyl Cyanide [5798-79-8]		Practically Insoluble[1]
CAP	α-Chloroacetophenone [CAS: 532-27-4]		<1[1]
Chloropicrin	Trichloronitromethane [CAS: 76-06-2]		1.6[1] Slightly soluble: 1 - 5 at 22°C[3]

Trivial Name	Chemical Name	Chemical Structure	Solubility in Water [g/l]
CK	Cyanogen chloride [CAS: 506-77-4]		60 to 70[1] 158[3]
Clark I	Dipenylchlorarsine [CAS: 712-48-1]		2[1]
Clark II	Dipenylcyanorarsine [CAS: 23525-22-6]		2[1]
Cyclon-B	Hydrogen Cyanide [CAS: 74-90-8]		Miscible[1] 1500[3]
Diphosgene [Agent DP]	Trichloromethyl chloroformate [CAS: 503-38-8]		Nearly Insoluble[1]
HN-2	2,2'-Dichloro-N-methyldiethylamine [CAS: 51-75-2]		12[1] Sparingly soluble[3]
HN-3	Tris(2-chloroethyl)amine [CAS: 555-77-1]		0.16[1] Insoluble[3]
KSK [SK]	Ethyl Iodoacetate [623-48-3]		Insoluble
Lewisite I [Agent L]	2-Chlorovinyl dichlorarsine [CAS: 541-25-3]		0.5[1] Insoluble[3]

Trivial Name	Chemical Name	Chemical Structure	Solubility in Water [g/l]
Lewisite II	Bis(2-chlorovinyl)chlorarsine [CAS: 40334-69-8]		
Mustard Gas HD, [Yperite, Lost]	Bis-(dichloroethyl)-sulphide [CAS: 505-60-2]		0.8[1] 0 to 0.07[3]
Mustard Gas T [O-Mustard]	Bis(2-chloroethylthioethyl)ether [CAS: 63918-89-8]		
N-Mustard [N-Lost, HN-1]	N-ethyl-2,2-dichlorodiethylamine [CAS: 538-07-8]		Practically soluble[1]
Phosgene	Carbonyl dichloride [CAS: 75-44-5]		Decomposes 9[1] Very slightly soluble[3]
Sarin [Agent GB]	O-Isopropyl Methylphosphonofluoridate [CAS: 107-44-8]		Miscible[1]
Soman [Agent GD]	Pinacolyl methylphosphonofluoridate [CAS: 96-64-0]		15 to 34[1] <21[3]
Tabun [Agent GA]	Ethyl N,N-dimethylphosphoramidocyanidate [CAS: 77-81-6]		72[1] Miscible; 120[3]
'Winter Mustard'	Bis-(dichloroethyl)-sulphide [63%] and 2-Chlorovinyl dichlorarsine [37%] [CAS: 505-60-2 and CAS: 541-25-3]		<1[2]

Trivial Name	**Chemical Name**	**Chemical Structure**	**Solubility in Water [g/l]**
	Mercury fulminate [CAS: 628-86-4]	 $\overset{\ominus}{O}-N\equiv C-Hg-C\equiv N-\overset{\ominus}{O}$	Insoluble[1]
Amatol	2,4,6-Trinitrophenol plus Ammonium nitrate [CAS: 8006-19-7 ≡ CAS : 88-89-1 and CAS: 6484-52-2]	 + NH_4NO_3	14 and completely soluble[4]
HMX	Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine [CAS: 2691-41-0]		Insoluble[2] Negligible[5]
Lyddite	Picric Acid 2,4,6-Trinitrophenol [CAS: 88-89-1]		14[3]
PETN	Pentaerythritol tetranitrate [CAS: 78-11-5]		Very Slight[2] <1[5]
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine [CAS: 121-82-4]		Insoluble[2]

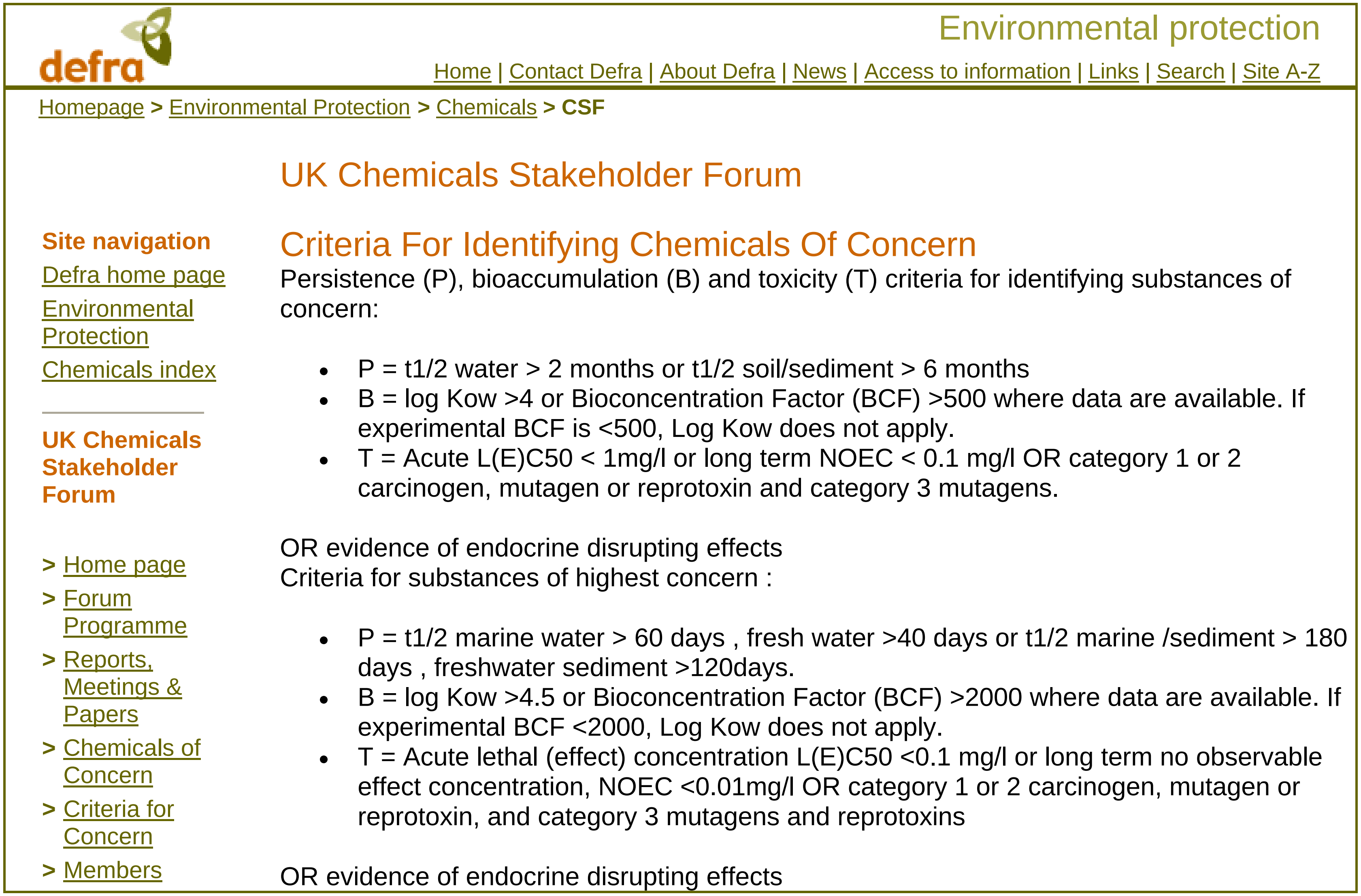
Trivial Name	Chemical Name	Chemical Structure	Solubility in Water [g/l]
Shellite	70% 2,4,6-Trinitrophenol + 30% 2,4-Dinitrophenol [CAS: 88-89-1 and CAS: 51-28-5]		14[3] and 2.8[4]
Tetryl	2,4,6-trinitrophenylmethyl nitramine [CAS: 479-45-8]		Insoluble[2] 0.2[5]
TNB	1,3,5-Trinitrobenzene [CAS: 99-35-4]		0.35[5]
TNT	2,4,6-Trinitrotoluene [CAS: 118-96-7]		0.1[2] Insoluble[5]

Appendix 3: PBT Criteria

Table 1. Comparison of Stakeholder Forum and EU PBT Criteria

	1.CSF PBT Criteria for Chemicals of Concern	2. CSF PBT Criteria for Chemicals of Highest Concern	3.EU/OSPAR Marine PBT	4. CSF and EU/OSPAR Marine vPvB
Chemicals captured from screen of IUCLID database				
Persistence	Halflife in water, 60 days Halflife in sediment, 180 days Halflife in soil, 180 days Screening criteria; lack of Achievement of pass level in ‘ready biodegradability’ or equivalent	Halflife in water, 60 days Halflife in sediment, 180 days Halflife in soil, 180 days Screening criteria; lack of achievement of pass level in ‘ready biodegradability’ or equivalent	Halflife in water; ***Freshwater – 40 days*** marine water – 60 days Halflife in sediment; ***Freshwater – 120 days*** marine water – 180 days Screening criteria; lack of Achievement of pass level In ‘ready biodegradability’ Or equivalent	Halflife in water, 60 days Halflife in sediment, 180 days Screening criteria; lack of achievement of pass level in ‘ready biodegradability’ or equivalent
Bioaccumulation	Bioconcentration factor (BCF) >500 Screening criteria; Log K_{ow} >4	Bioconcentration factor (BCF) >5000 Screening criteria; Log K_{ow} >5	Bioconcentration factor ***(BCF) >2000*** Screening criteria; ***Log K_{ow} >4.5***	Bioconcentration factor (BCF) >5000 Screening criteria; Log K_{ow} >5
Toxicity	Aquatic toxicity; Acute $L(E)C_{50}$ <1 mg/l chronic NOEC <0.1 mg/l Mammalian toxicity; CMR cat 1 and 2 Mutagenicity cat. 3	Aquatic toxicity; acute $L(E)C_{50}$ <1 mg/l chronic NOEC <0.1 mg/l Mammalian toxicity; CMR cat 1 and 2 Mutagenicity cat. 3	Aquatic toxicity; ***chronic NOEC <0.01 mg/l*** Mammalian toxicity; CMR cat 1 and 2 Mutagenicity and Reprotox cat. 3 Screening criteria; ***acute $L(E)C_{50}$ <0.1 mg/l***	Not applicable

Bold Italics used to highlight differences http://www.defra.gov.uk/environment/chemicals/csf/criteria/index.htm



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UK Chemicals Stakeholder Forum

Criteria For Identifying Chemicals Of Concern

Persistence (P), bioaccumulation (B) and toxicity (T) criteria for identifying substances of concern:

- P = t1/2 water > 2 months or t1/2 soil/sediment > 6 months
- B = log Kow >4 or Bioconcentration Factor (BCF) >500 where data are available. If experimental BCF is <500, Log Kow does not apply.
- T = Acute L(E)C50 < 1mg/l or long term NOEC < 0.1 mg/l OR category 1 or 2 carcinogen, mutagen or reprotoxin and category 3 mutagens.

OR evidence of endocrine disrupting effects
Criteria for substances of highest concern :

- P = t1/2 marine water > 60 days , fresh water >40 days or t1/2 marine /sediment > 180 days , freshwater sediment >120days.
- B = log Kow >4.5 or Bioconcentration Factor (BCF) >2000 where data are available. If experimental BCF <2000, Log Kow does not apply.
- T = Acute lethal (effect) concentration L(E)C50 <0.1 mg/l or long term no observable effect concentration, NOEC <0.01mg/l OR category 1 or 2 carcinogen, mutagen or reprotoxin, and category 3 mutagens and reprotoxins

OR evidence of endocrine disrupting effects

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Advisory Committee on Hazardous Substances (ACHS)

Safety net procedures

The Forum also has a safety net procedure for chemicals do not meet the PBT criteria but where there are reasons to believe that the chemicals raise equivalent concerns.

The Forum has been advised by the ACHS that the following types of organic substances or scenarios could be subject to the safety net procedure:

i. Substances that are very toxic (vT) to organisms in the aquatic or terrestrial compartments: for example, substances with acute toxicity L(E)C50<0.1 mg/L, NOEC <0.01 mg/L (L(E)D50<0.1 mg/Kg, NOED <0.01 mg/Kg). Such substances may not be sufficiently persistent or bioaccumulative to meet the PBT criteria, but due to their potent toxicity may still be a cause for concern, especially if they are continually released to the environment.

ii. Substances which are actually or potentially very bioaccumulative (vB) by whatever mechanism (not necessarily just lipophilic compounds, but also those that accumulate in bone, bind to proteins etc). These may include, for example, substances with a BCF>10,000 or substances with a log Kow>6, respectively. The committee noted that BCFs must be determined in typical environmental concentrations to give an accurate indication. Bioaccumulation factors should also be used where available. These substances (especially if actually found in biota) may be of concern due to their bioaccumulation, even if their persistence and toxicity do not meet the Stakeholder Forum's criteria. Substances with a very high log Kow, however, may have reduced bioavailability to organisms as they may sorb very strongly to soils and sediments, and may not be freely available in water. Substances which are both bioaccumulative and toxic (i.e. B and T) also may be a cause for concern, especially if the substances are released regularly (i.e. the input load is greater than the degradation removal).

iii. Organic substances that may persist in the environment for many years (t1/2>10 years), or for shorter periods where evidence suggests that adverse effects to the environment and human health may occur. Evidence of potential adverse effects may be identified by measurement via testing, by modelling predictions, or by monitoring. Adverse effects may include interference with biogeochemical cycles or toxicity to humans or other organisms (1). The ACHS will continue to examine this issue and will advise further.

iv. Substances that may cause adverse effects measured, or detected, as novel toxicity endpoints. Such substances may cause sub-lethal effects that might result in population level effects for exposed species, and could include endocrine-disrupting chemicals, for example. Further scrutiny on a case by case basis may be required to determine whether or not a particular substance should be included in the safety net.

v. The safety net will consider additional substances identified on other appropriate priority lists such as OSPAR, which apply to the UK as a consequence of our European and/or international commitments. If these substances comply with one or other of the proposed safety net criteria, they will be retained. If not, they will be considered further to determine if they require inclusion in the safety net due to some unforeseen potential hazard or whether they should not form part of the safety net list.

In December 2001 the ACHS advised that the following inorganic substances should be included in the safety net:

vi. Substances that are very toxic to organisms in either the aquatic or terrestrial compartments. Toxicity thresholds for inorganic substances could be those with acute toxicity of L(E)C50<0.1 mg/L(Kg), or point estimate (or NOEC/D) <0.01 mg/L(Kg); and/or

vii. Substances that are actually or potentially very bioaccumulative in organisms, by whatever mechanism. These may include, for example, substances with a BCF/BAF>5,000. Note that to eliminate the bioaccumulation concern BCF/BAF data should only be used if the experiments were conducted at environmentally relevant concentrations.

Substances identified under the safety net criteria would require case-by-case consideration by the ACHS prior to the Chemicals Stakeholder Forum's consideration for risk management.

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(1) The ACHS considered that dispersive uses of very persistent substances were in themselves a cause for concern, whether or not there was any evidence of harmful effects.

Page last modified: 3 December 2004
Page published 22 December 2000

Glossary to Appendix 3

ACHS	Advisory Committee on Hazardous Substances
BAF	Bioaccumulation factor. The ratio of a substance's concentration in an organism's tissue to its concentration in the water where the organism lives. BAFs measure a chemical’s potential to accumulate in tissue through exposure to both food and water.
BCF	Bioconcentration Factor. The ratio of a substance's concentration in tissue versus its concentration in water in situations where the organism is exposed through water only. BCF measures a chemical’s potential to accumulate in an organism’s tissue through direct uptake from water (excludes uptake from food).
CMR	Carcinogen, Mutagen or Reproductive toxin. There are 3 Carcinogen Categories: Category 1: substances known to be carcinogenic to man. There is sufficient evidence to establish a causal association between human exposure to a substance and the development of cancer. Category 2: substances which should be regarded as if they are carcinogenic to man. There is sufficient evidence to provide a strong presumption that human exposure to a substance may result in the development of cancer, generally on the basis of: - Appropriate long term animal studies - other relevant information Category 3: Substances which cause concern owing to possible carcinogenic effects but in respect of which the available information is not adequate for making a satisfactory assessment. There is some evidence from appropriate animal studies but this is insufficient to place the substance in Category 2.
CSF	Chemical Stakeholder Forum
LD_{50}	The median Lethal Dose. The median lethal dose that will kill 50% of a population. If a test is carried out where the end-point is an adverse response other than death, then an ED_{50} is determined.

log K_{ow}	Log Octanol-Water Partitioning Coefficient. The octanol-water partition coefficient (K_{ow}) is a measure of the equilibrium concentration of a compound between octanol and water that indicates the potential for partitioning into soil organic matter (i.e., a high K_{ow} indicates a compound which will preferentially partition into soil organic matter rather than water). K_{ow} is inversely related to the solubility of a compound in water. Log Kow is used in models to estimate plant and soil invertebrate bioaccumulation factors.
NOEC	No Observed Effect Concentration. The highest concentration of toxicant to which organisms are exposed in a full life-cycle or partial life-cycle (short-term) test, that causes no observable adverse effects on the test organisms (i.e., the highest concentration of toxicant in which the values for the observed responses are not statistically significantly different from the controls).
NOED	No Observed Effect Dose
PBT	Persistence, Bioaccumulation and Toxicity