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**Investigation into the Fate of Phosgene Contained
within Chemical Munitions Dumped into Beaufort's
Dyke**

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Executive summary

The UK was left with enormous quantities of munitions, including chemical munitions, after both world wars. These stockpiles were surplus to peacetime requirements and needed to be disposed of safely and quickly. When cost, as well as public and worker safety were taken into account, sea dumping of munitions was found to be the safest and most efficient method of disposal [1] and was authorised by the government in the period 1945 - 1947.

Beaufort's Dyke was one of the main dumpsites in British waters. It is situated in the North Channel and lies between Northern Ireland and the Rhins of Galloway in South West Scotland. It is a long narrow trench approximately 50 km long and is one of the deepest areas in the waters of the inner UK coastal shelf with a maximum charted depth of 315m [2].

Detailed inventories of all the munitions that were dumped in Beaufort's Dyke are not available, as many records have been destroyed. It is known, however, that a wide range of munition types were dumped and it has been estimated that over 1 million tonnes have been disposed to this location since the early 1920's [3]. Records from 1945-46 show that the munitions being dumped included an estimated 14,500 tonnes of 5 inch artillery rockets filled with phosgene gas [4]. However, the remaining records do not indicate that any other types of Chemical Warfare (CW) munitions were dumped in Beaufort's dyke.

No work has been found that specifically examines the fate of phosgene munitions in the sea although it is generally accepted [5 and 6] that leaking phosgene will rapidly hydrolyse to give essentially harmless products. This report provides the first detailed study of the likely outcome if phosgene were to be released from dumped munitions and concludes that phosgene released into seawater deeper than 3 metres, that does not exceed 15°C, will remain as a dense liquid on the seabed and not rise to the surface. Consequently, phosgene released to the sea bed due to the corrosion of munitions in Beaufort's Dyke (the main dump area is >100m with outliers estimated as >10m) should not cause any harm to people in vessels at the surface.

Any phosgene leaking from munitions is expected to dissolve slowly in the seawater and will then rapidly hydrolyse to harmless products (so contamination of the water does not occur). However, the rate of dissolution is not known and pools of liquid phosgene could persist for significant periods of time. Previous studies from around Beaufort's Dyke [6] have not identified any contamination from chemical warfare agents, including phosgene, in fish, shellfish or in the sediment of the seabed. However, any effects would be acute, local and probably short term, so it is likely that they would have been missed by infrequent sampling. More research would be needed to determine if phosgene is sufficiently persistent to cause harm to flora and fauna in the area immediately surrounding a leak from a munition on the seabed.

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1 Introduction

- 1.1 The UK was left with enormous quantities of munitions, including chemical munitions, after both World War I and II. It has been estimated that there were some 2,000,000 tonnes of army ammunition stored in the UK at the end of the World War II (WWII). These stockpiles of munitions were surplus to peacetime requirements and needed to be disposed of safely and quickly. Different disposal methods were considered but only three methods were practical at the time. They were; breaking down the munitions at a suitable factory; demolition and burning on land where safe to do so or; dumping at sea where the above two options were not deemed suitable. When cost as well as public and worker safety were taken into account, sea dumping of munitions was found to be the safest and most efficient method of disposal and was authorised by the government in the period 1945 - 1947.
- 1.2 Beaufort's Dyke (Figure 1) was one of the main dumpsites in British waters. It is situated in the North Channel, between Northern Ireland and the Rhins of Galloway in South West Scotland. It is a long narrow trench approximately 50 km long and is one of the deepest areas in the waters of the inner UK coastal shelf with a maximum charted depth of 315m [2]. Beaufort's Dyke became the United Kingdom's largest off-shore dump for conventional and chemical munitions.

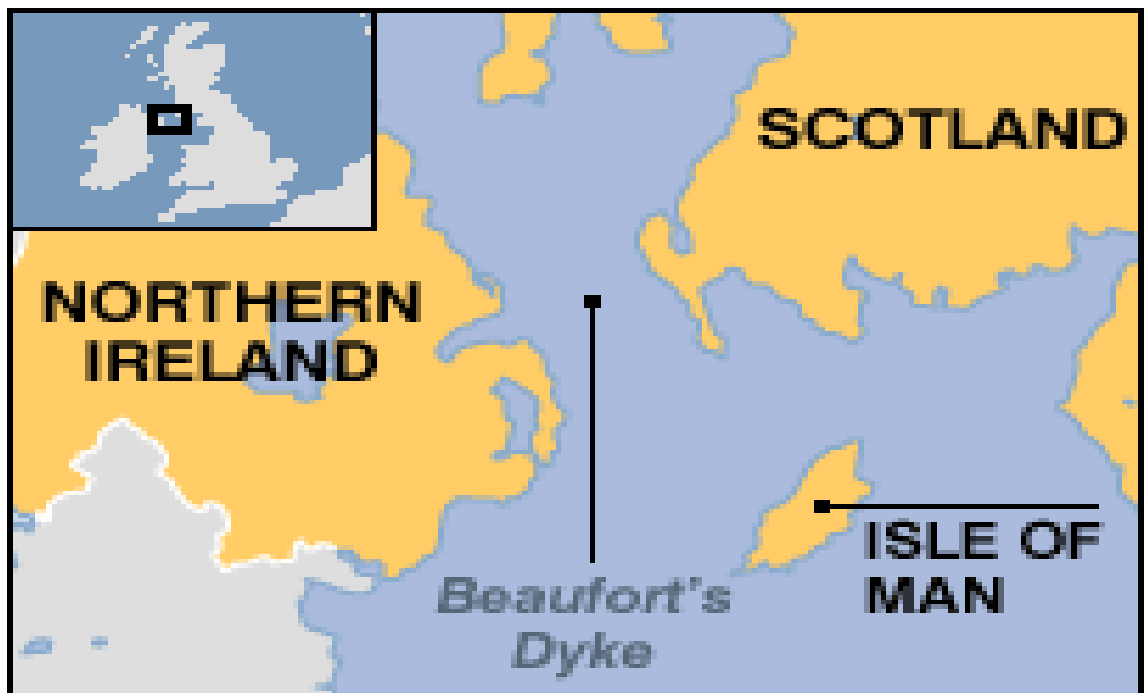


Figure 1 - Beaufort's Dyke located between Northern Ireland and Scotland.

- 1.3 Detailed inventories of all the munitions that were dumped in Beaufort's Dyke are not available, as many records have been destroyed. It is known, however, that a wide range of munition types were dumped and it has been estimated that over 1 million tonnes have been disposed to this location since the early 1920's [3]. Records from 1945-46 show that the munitions being dumped included an estimated 14,500 tons of 5 inch artillery

rockets ('U' 5" Type 'G1') filled with phosgene gas in July 1945 [4]. However, the remaining records do not indicate that any other types of Chemical Warfare (CW) munitions were dumped in Beaufort's dyke.

- 1.4 No reports have been found that examine the fate of phosgene munitions in the dump area although it is generally accepted [5 and 6] that leaking phosgene will react rapidly with sea water to give essentially harmless products.
- 1.5 This report aims to provide the first detailed study of the likely outcome if phosgene were to be released from dumped munitions into the Irish Sea at Beaufort's Dyke. A number of factors need to be considered including; the environmental conditions in Beaufort's Dyke, acute effects, if any, on the occupants of a vessel immediately above the release event, and any effects on marine flora and fauna.

2 Scope and limitations

- 2.1 This report investigates the fate of phosgene were it to leak into the sea in Beaufort's Dyke. It will consider the physicochemical properties of phosgene, including its solubility and hydrolysis rate in water, and the physical environment including the depth, pressure, and temperature of the water. Calculations, based on these factors, are undertaken to estimate the physical state of phosgene and its reaction rates with sea water. The implications of these findings are related to two hypothetical scenarios; a release of phosgene from a single munition and a release of phosgene from multiple munitions. This enables a prediction to be made of the likely outcome of a leak of phosgene on the seafloor in Beaufort's Dyke and tests the previous assertion that phosgene leaking into sea water will have little, if any, impact on the environment or man.
- 2.2 Factors that are not considered in this report are: corrosion rates of the munitions; munitions buried in the sea bed; or the consequences of munitions brought to the surface, (in, for example, fishing nets).

3 The physical environment of Beaufort's Dyke.

3.1 General

3.1.1 The physical environment of the seawater in Beaufort's Dyke has been reviewed to gain an understanding of the conditions where the munitions may have been dumped. The effects of density, depth, pressure and the temperature of the seawater have been taken into account.

3.2 Depth of seawater in the vicinity of Beaufort's Dyke

3.2.1 Beaufort's Dyke is marked on the admiralty chart (Figure 2) [2] and shows that the main depth contour line is at 200m with the deepest point recorded at 315m. Figure 2 shows the locations of the known Beaufort's Dyke explosives dumping areas. Although the majority of the designated dumping areas are below the 100m contour, there is anecdotal evidence that munitions were dumped by sailors on the way to the designated dumping ground. This statement is backed up from information on the Admiralty chart [2] (see Figure 2) which has specific areas, well outside the designated dumping area, marked as containing unexploded ordnance. These marked areas include the route of the gas pipeline (54°51'·3N, 5° 44'·9W to 54° 58'·9N, 5° 10'·8W) and also a few areas adjacent to the limits of the Beaufort's Dyke Explosives dumping ground (54° 43'·0N, 5° 12'·6W) as well as one area well to the North (55° 01'·5N, 5° 27'·0W).

3.2.2 The sea floor area surrounding Beaufort's Dyke slopes up to a shelf 50m deep that runs around the coast of Scotland and Ireland. The slope of the sea bed is greater up to the Scottish shore line than it is to the Irish shore line, because the dyke is slightly closer to the Scottish shore than the Irish shore. The 10m depth contour is never very far from the shore and in places extends to just 2.5m from land.

3.2.3 Even though there is some anecdotal evidence that munitions were not always dumped directly in the dyke, it is almost certain that none were dumped this close to the shore so all should be safely below the 10m contour.

3.2.4 The depths at which the munitions have been dumped are sufficient to mitigate any significant effects of wave action although it is possible that munitions at the minimum estimated depth of 10m could experience some water movement during severe storms.

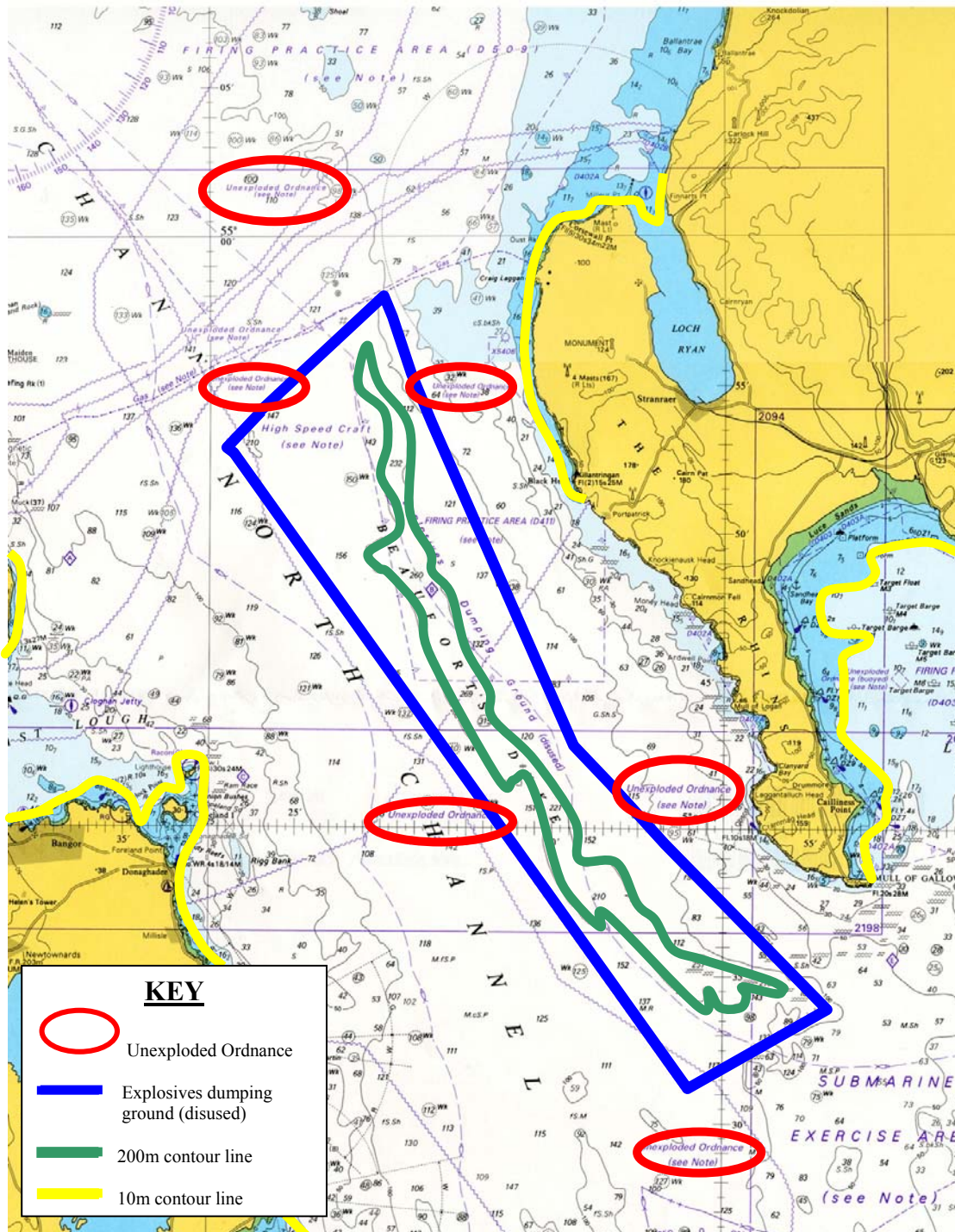


Figure 2 -Beaufort's Dyke showing the depth profile of the seabed.

3.3 Currents at the bottom of Beaufort's Dyke

- 3.3.1 The mean bottom ocean currents shown in Table 1 have been produced by the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) [7]. POLCOMS is a baroclinic three-dimensional model which runs daily predicting the mean ocean currents.

Month	Average Bottom Current cm s ⁻¹
January	10-20
April	0-5
May	0-15
June	0-10
July	0-10
August	0-5

Table 1 - The mean bottom currents for the Irish sea in the Beaufort's Dyke area

- 3.3.2 Although data is not available for all months of the year, it appears that some flow occurs (in the range 0-20 cm s⁻¹) throughout the year and this will help disperse phosgene as it dissolves and thus prevent the water from becoming saturated and inhibiting the reaction. These flow rates are not sufficient, however, to dislodge or move munitions or to cause scouring of sediments in which they may be buried.

3.4 Density of sea water

- 3.4.1 The density of water increases in direct proportion to the quantity of dissolved salts. Sea water will therefore be denser than fresh water because it contains a greater quantity of salts. The density of water also increases with depth and Figure 3 [8] shows the density of sea water with increasing depth. According to this the density at the surface is 1.025 g cm⁻³ and increases to 1.026 g cm⁻³ at a depth of 300m, the deepest parts of the trench. This change with depth is small in the context of the present study and has been ignored in the following calculations.

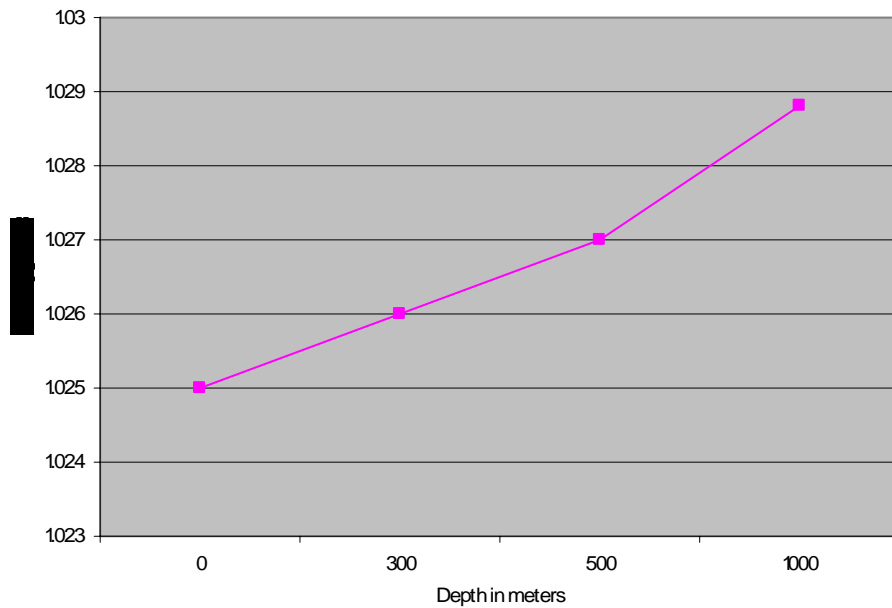


Figure 3 -Relationship between seawater density and depth.

3.5 Pressure

3.5.1 The munitions that have been dumped in Beaufort's Dyke will be subjected to pressure, not only from the overlying water column but also from atmospheric pressure. This environmental pressure is an important factor as it will determine whether the phosgene is present as a gas or liquid when it leaks from the munitions.

3.5.2 The pressure (P measured in Pa) that would be exerted on the submerged munitions is given by:

$$P = \rho \times g \times h + P_{at}$$

Where ρ is the density of the sea water, g the acceleration due to gravity (9.8 m s^{-2}), h the height in meters of sea water above the munition and P_{at} is atmospheric pressure (101 kPa). This equation has been used to calculate the pressure at various depths and the results are shown graphically in Figures 4 and 5.

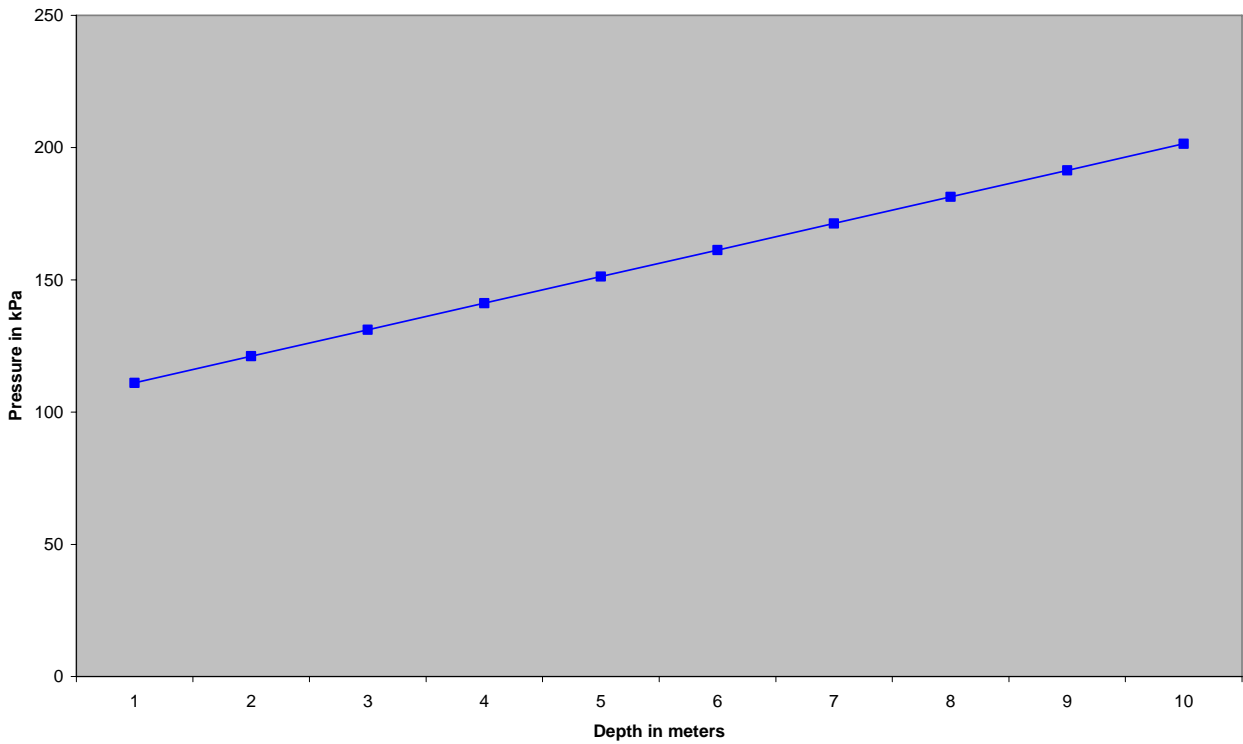


Figure 4 - Total pressures at depths between 1 and 10 meters.

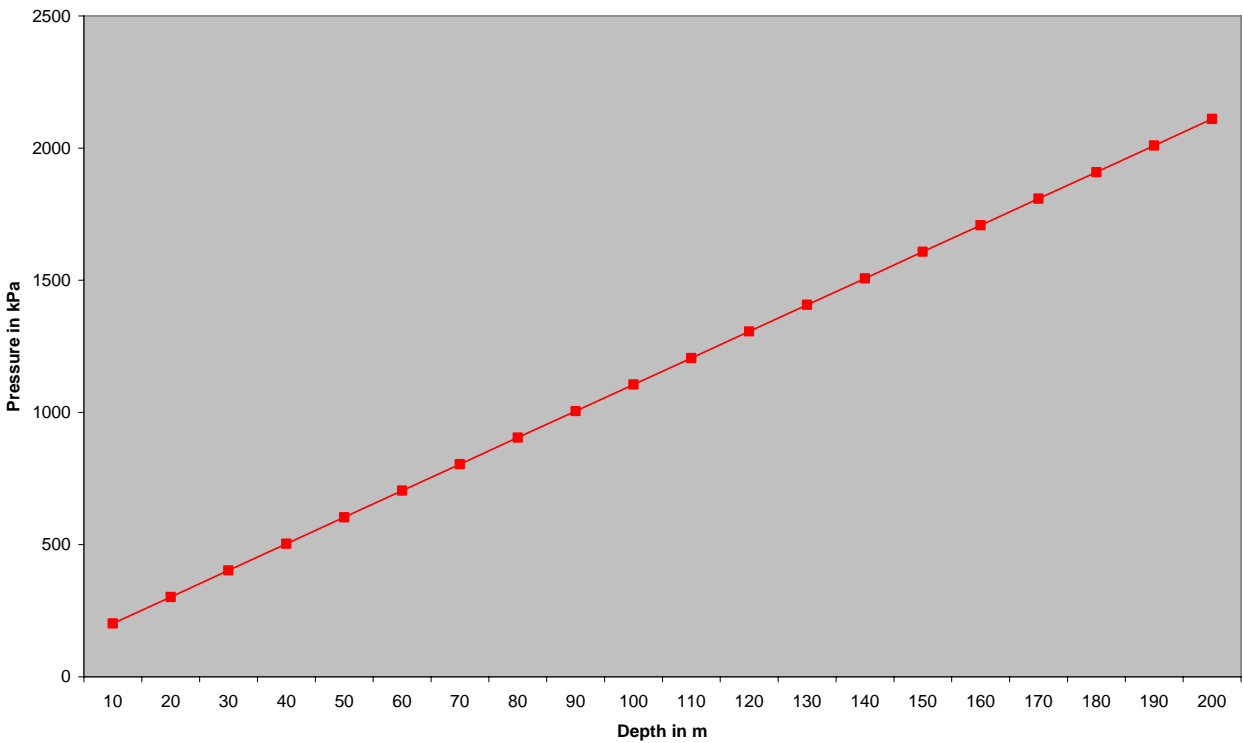


Figure 5 - Total pressures at depths between 10 and 200 meters

3.6 Temperature

- 3.6.1 The surface of the sea is warmed by the sun, but the sea bed is cooler as the warming rays of the sunlight do not penetrate to the sea bed and mixing effects are slow. The surface waters of Beaufort's Dyke reach approximately 14-15°C during the summer and 9.5-11°C during the winter. The temperatures on the sea bed in the Irish Sea can reach up to 10-12°C in the summer months and are approximately 7-9°C during the winter months [7].

4 The physicochemical and toxicological properties of phosgene

4.1 General

4.1.1 Phosgene (carbonyl chloride, COCl_2 , or military designation CG) is a corrosive, highly toxic and highly reactive gas or refrigerated liquid. It is a manufactured chemical, but can occur naturally in small quantities. It is formed by the thermal decomposition of chlorinated solvents such as carbon tetrachloride and chloroform and is also one of the combustion products of chlorinated plastics. Phosgene is an important industrial compound used in the preparation and manufacture of many organic chemicals. During 1997 it is estimated that about 3 million tonnes of phosgene were produced worldwide [9].

4.1.2 Phosgene at room temperature and pressure is a colourless gas, which is denser than air. When released into the air it may appear white or as a yellow/greenish haze and in low concentrations it has an odour of freshly mown hay. In higher concentrations it is highly toxic and suffocating.

4.2 Density

4.2.1 The density of phosgene will to a large extent determine its behaviour on release from a munition. A density of less than seawater will cause it to rise through the water column to the sea surface, whereas a density of greater than seawater will cause it to sink to the sea bed. Phosgene is a gas at atmospheric pressure and a temperature of 25°C and has a density of 3.4 times that of air. Hence, if it reaches the surface of the water, it would be likely to form a dense layer sitting on the surface of the seawater and present a significant hazard to people in vessels. At atmospheric pressure and a temperature of 0°C phosgene is a liquid with a density of 1.4 g cm^{-3} and so should sink to the seabed when released from a munition. (No data has been found on the effects of pressure on the density of phosgene but it will be small, i.e. anticipated to be similar to the response of sea water in Figure 4, and has therefore been ignored).

4.3 Vapour pressure

4.3.1 The boiling point of a liquid under a given applied pressure is the temperature at which the vapour pressure is just equal to the applied pressure [10]. The normal boiling point is the temperature at which the vapour pressure of a liquid is exactly equal to one atmosphere (101.33 kPa) pressure and is 7.6°C for phosgene. Therefore, liquid phosgene released from a munition at the sea surface (and atmospheric pressure) in the vicinity of Beaufort's Dyke would boil and release large amounts of vapour even at winter temperatures. However, at depth within Beaufort's Dyke pressures would be significantly higher and would limit the potential for liquid phosgene to change to a gaseous state. Figure 6 and Figure 7 give the vapour pressure of phosgene at various temperatures and the conversion of this to boiling point for various depths of submersion respectively.

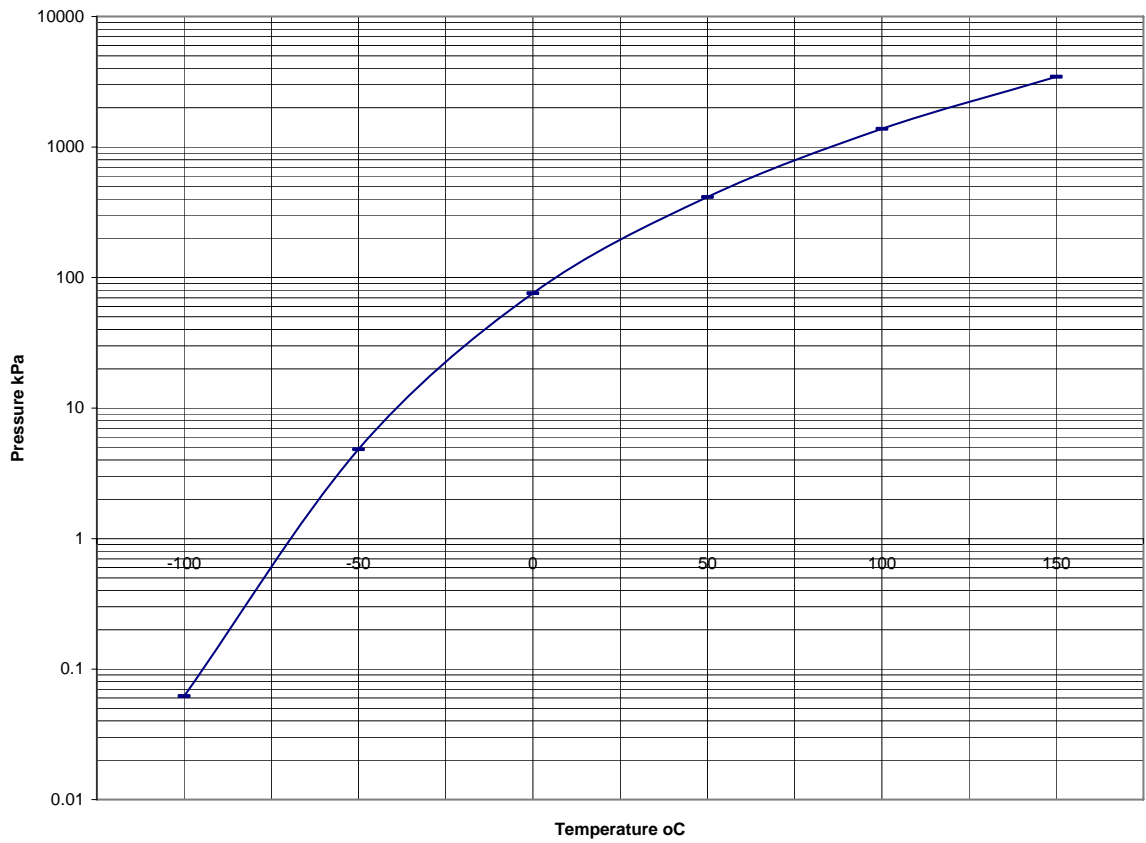


Figure 6 - Vapour Pressure curve for phosgene [11].

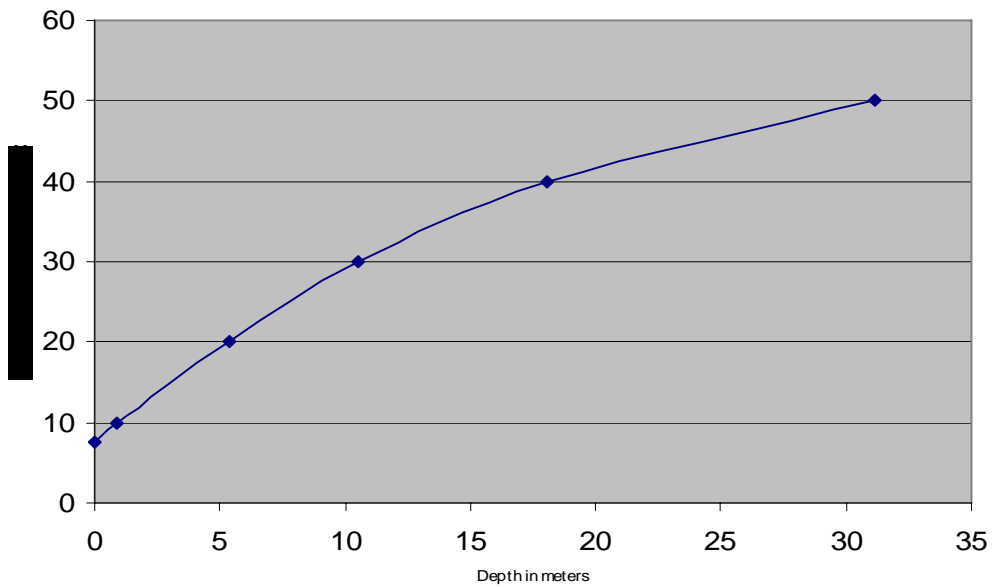


Figure 7 - Boiling point of phosgene at shallow depths of seawater

4.3.2 It is clear from Figure 7 that the boiling point of phosgene increases significantly at shallow depths of submersion. At a 10m depth of submersion the temperature would need to be approximately 29°C for the liquid phosgene to boil. The temperature of the seawater in the region of Beaufort's Dyke can rise to 14-15°C at the surface during the summer months and will be lower at depth. Hence, liquid phosgene submerged to 10m depth will not boil.

4.3.3 Given the above, any phosgene released from munitions on the sea bed of Beaufort's Dyke at depths greater than 10m will remain as a liquid until it reacts with the seawater. In addition, it will remain on the sea bed because its density is 1.4 times greater than water.

4.4 Solubility of phosgene in water

4.4.1 Figure 8 shows that the solubility of phosgene in deionised water increases with decreasing temperature [12]. The sea temperature at the bottom of Beaufort's Dyke ranges from 12°C summer maximum to 7°C winter minimum with corresponding solubility values for phosgene of 0.11 and 0.12 mole l⁻¹. However, for seawater, a reduction in solubility due to the salting out effect can be expected. Although no experimental data have been found for phosgene in seawater, this effect has been estimated [12] for solutions of phosgene in sodium hydroxide at 25 °C. These results show that phosgene dissolved in a solution of 0.6 molar sodium hydroxide (i.e. a concentration equivalent to the 35g kg⁻¹ of sodium chloride in seawater) would have its solubility reduced by a factor of 0.8. Assuming that the same factor applies at the temperatures found in the dyke (~10 °C), the solubility of phosgene in sea water becomes ~0.1 mole l⁻¹ which for all practical purposes is not significantly different from the solubility in fresh water but will be the value used in the discussion when considering the environmental impact of phosgene in seawater.

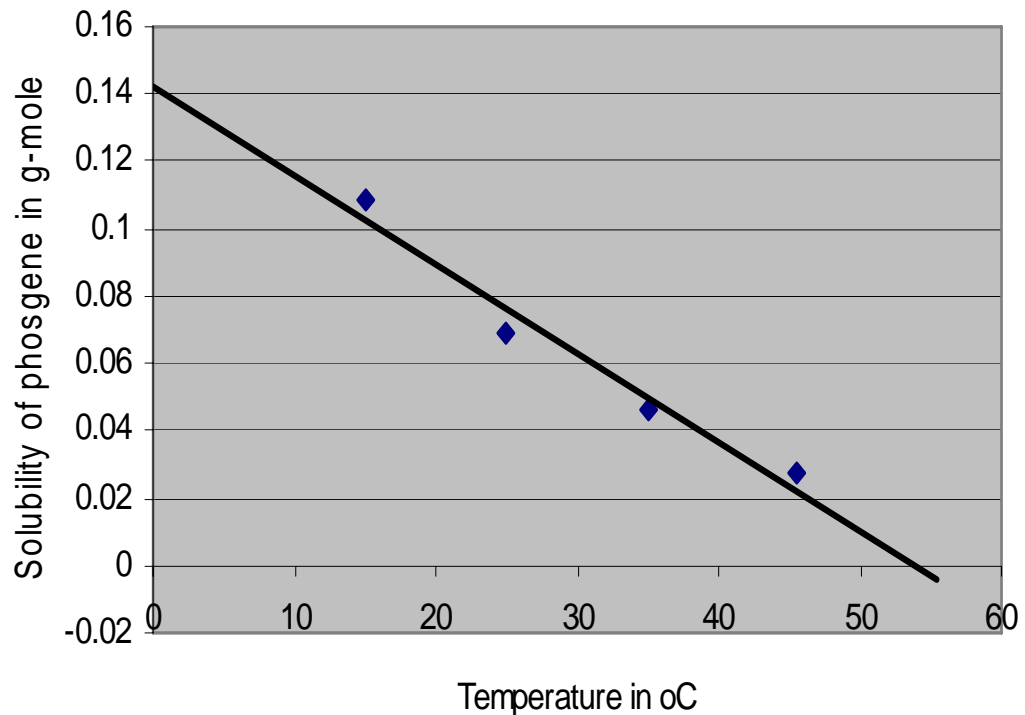
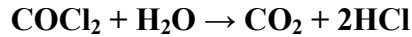


Figure 8 - Solubility of phosgene at different temperatures

- 4.4.2 The rate at which phosgene gas dissolves in water has been measured [12] but no experimental data have been found on the rate of dissolution of liquid phosgene. This is not surprising because most workers have been concerned with the properties of phosgene vapour released from detonating munitions due to industrial accidents. It is suspected from anecdotal evidence that liquid phosgene below its boiling point and water will coexist for some time as separate liquid phases. This suspicion is supported by the following unpublished account of a simple small scale experiment carried out at Porton [13] when neutralisation with sodium hydroxide was being developed as a disposal method for phosgene in munitions.
- 4.4.3 The experiment was performed at an ambient temperature of 22 °C. Phosgene (0.25ml) was placed in a glass tube and one drop of deionised water added. Poor miscibility was observed with reaction only occurring with shaking, which resulted in one bubble approximately every second for two seconds. A 0.5ml jet of water was then discharged at the phosgene using a syringe; no evidence of reaction occurred although the immiscible drop of phosgene disappeared. Finally sodium hydroxide solution was added with no evidence of reaction.
- 4.4.4 Although the above experiment made no attempt to measure the dissolution rate of phosgene into water it does show that the two liquids do not mix readily and that the overall reaction rate is slow. Indeed it required vigorous mixing for any reaction to be seen at all and, if left alone, the two liquids may well have remained separate for some time. It would be expected that a large mass of liquid phosgene would therefore take some time to dissolve.

4.5 Hydrolysis of phosgene in water

4.5.1 The hydrolysis reaction between water and phosgene gives carbon dioxide and hydrochloric acid, i.e.



4.5.2 Experiments have been carried out to determine the rate of the hydrolysis of phosgene in water. In many cases the reports only state that phosgene hydrolyses rapidly and no figure is given for the half life of the reaction. The examples below show some experimental values that have been reported for the break down of phosgene in water.

4.5.3 Hall, 1944 [14], carried out an investigation on the solubility and rate of hydrolysis of phosgene in water. A solution of phosgene in water was rapidly streamed along a tube, the phosgene concentration being measured at fixed distances down the tube. The relation between phosgene concentration and time of reaction was concluded to be pseudo first order. Hall found a value for the rate constant at 13°C of 2.8 s⁻¹.

4.5.4 Manogue and Pigford, 1960[12], carried out work on the kinetics of the absorption of phosgene into water and aqueous solutions, using short laminar jets of aqueous solutions to dissolve pure phosgene gas. They stated that the hydrolysis reaction rate is probably proportional to the phosgene concentration, water being in very large excess, so is pseudo first order. They reported that the rate constant at 15°C was 3 s⁻¹.

4.5.5 Both [14 and 12] of these researchers have produced pseudo first order rate constants for the hydrolysis of phosgene in water that are in remarkable agreement. The half life of the reaction can be calculated readily using the following equation.

$$t_{1/2} = \ln(2) / k$$

Using a rate constant of 3 s⁻¹ this gives a half life for phosgene in water at 15°C of 0.25s and this value has been used later in this report.

4.5.6 The Danish Environment Protection Agency [5] stated that phosgene is a very reactive compound which in seawater is broken down into carbon dioxide and hydrochloric acid. In slightly alkaline sea water (the pH of seawater ranges from 7.3 to 8.3, Figure 9 [15]), the hydrochloric acid is neutralised which will tend to help the hydrolysis reaction. The reaction occurs rapidly even at 0°C, with a 1% aqueous phosgene solution being completely decomposed after only 20s.

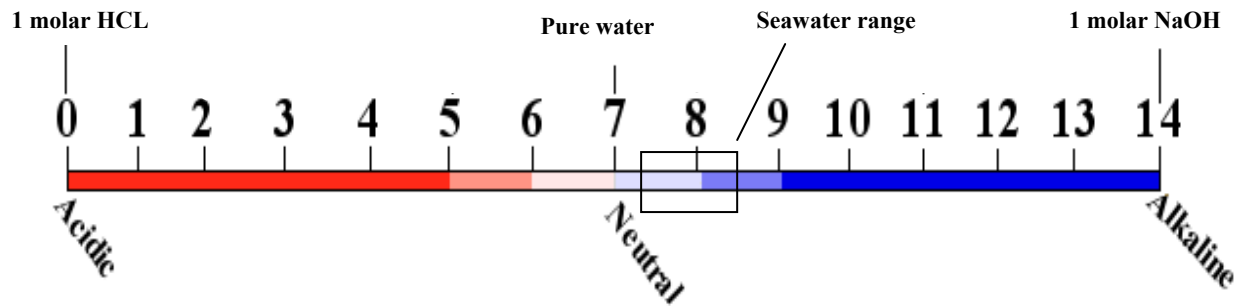


Figure 9 - pH range of seawater

4.6 The toxicity of phosgene

4.6.1.1 The primary route of phosgene entry into the body is by inhalation. Phosgene combines with water in the tissues of the respiratory tract to form hydrochloric acid. The acid then dissolves the membranes of the lungs. This causes the lungs to fill with fluid, resulting in death ('dryland drowning'). Phosgene is also a severe irritant of the eyes and skin. The toxic effects of phosgene are often delayed, in some cases up to 72 hours.

4.6.1.2 Due to these factors phosgene gas was used as a very effective CW agent during WWI and was stockpiled as the UK's principal lethal agent during WWII. It has been estimated that 80% of all of the chemical agent casualties during the First World War were due to phosgene [16].

4.6.2 Phosgene in the environment

4.6.2.1 There have been a number of studies carried out looking at contaminants in the marine environment of Beaufort's Dyke. The sediments and marine fauna of the area have been surveyed extensively by the Marine Laboratory, Aberdeen [6]. This report states that fish, shellfish and sediments sampled from around the dyke did not contain chemical warfare agents or contaminants associated with dumped munitions.

4.6.2.2 In 1994 HELCOM [5] released a report that stated 'sampling of the sediment and marine fauna that had been carried out [in the vicinity of Beaufort's Dyke] had not detected any traces of phosgene'. The report concluded that dumping of phosgene munitions does not pose a threat to marine flora and fauna.

4.6.2.3 In 2002, Howard & Meylan [17] studied the bioconcentration of phosgene to determine if it will accumulate in the tissues of flora and fauna. The study estimated a bioconcentration factor of 3 indicating that the potential for bioconcentration is low in aquatic organisms. The study also investigated the octanol-water partition coefficient ($\log K_{ow}$) of phosgene to indicate the potential for phosgene to partition into soil organic matter or water. A $\log K_{ow}$ of -0.71 was estimated, showing that phosgene will preferentially partition into water rather than soil organic matter.

5 Discussion

5.1 General

5.1.1 There are a number of factors that need to be taken into account when considering the possible impact of phosgene that has been dumped in Beaufort's Dyke. The relevant characteristics of phosgene and the environment of Beaufort's Dyke have been outlined in Sections 3 and 4 and these are discussed below in relation to each other and their effect on the possible human and environmental impacts of phosgene.

5.2 Physicochemical considerations

5.2.1 The high density of phosgene (1.4 g cm^{-3} compared to 1.025 g cm^{-3} for seawater) means that, provided it is below its boiling point, if it is released at depth it will settle to the lowest point on the sea bed. Phosgene filled munitions dumped at sea in will be subject to pressures above atmospheric pressure exerted by the depth of the overlying water. These increased pressures mean that any phosgene released from munitions at the possible depths of dumping (i.e. approximately 10m or greater) will not boil. Hence, it is highly unlikely that any phosgene released from munitions will form a gas and migrate to the sea surface. It is therefore not expected that phosgene released from munitions in Beaufort's Dyke could cause any harm to people in vessels on the sea surface.

5.2.2 The half life of phosgene in water has been shown to be approximately 0.25s so, once in solution, it will hydrolyse rapidly to give hydrochloric acid and carbon dioxide. Further, the slight alkalinity of seawater will neutralise the breakdown products as soon as they are formed and thus help maintain the rate of reaction. The salts formed by the neutralisation reaction are already present in seawater in large amounts so can be regarded as harmless. Phosgene is slightly soluble so it is expected to dissolve slowly into the seawater with the rate of dissolution expected to be the rate determining step of the destruction process.

5.2.3 Unfortunately, no experimental data have been found on the rate of dissolution of liquid phosgene into seawater but the following controlling physicochemical processes will apply. The rate of dissolution of liquid phosgene will be governed by the boundary layer of water saturated with phosgene close to the liquid interface. The thickness of this boundary layer, and hence the magnitude of its effect on the dissolution rate, will depend on the steepness of the concentration gradient of phosgene in solution. The steeper the concentration gradient, and the thinner the boundary layer, the faster phosgene will go into solution and be destroyed by hydrolysis. The steepness of the concentration gradient will be increased by the rapid removal of the hydrolysis products, as described above for neutralisation, but will also be affected by local movements in the water. In stagnant water the concentration of dissolved phosgene can only be reduced by diffusion of molecules out into the water and the boundary layer will be at its maximum. At the bottom of Beaufort's Dyke tidal currents move slowly (with an approximate maximum of 20 cm s^{-1}) (Table 1) which will help remove the hydrolysis products.

5.2.4 The ratio of volume to surface area will also be an important factor in determining the rate of dissolution of phosgene and for a given volume will depend very much on local factors such as the topography of the seabed, the presence of “containers” such as previously broken open munition parts or ammunition boxes, which may result in the released volume being split into separate smaller pools. The presence of deep sediment may also be a factor since it could be penetrated by pools of the dense liquid which would then be shielded from the scouring effect of water currents with a consequent reduction of the potential dissolution rate.

5.2.5 The rate of dissolution remains the greatest area of uncertainty. If it is judged necessary to study this in more detail, experiments should be undertaken to measure the dissolution rate of phosgene in sea water at temperatures and pressures equivalent to those expected in the vicinity of Beaufort’s Dyke. These experiments should also measure the effects of water currents since this may have a significant impact on the persistence of liquid phosgene. Persistence can also be expected to depend on the surface to volume ratio so the experiments will need to consider this factor also.

5.3 Environmental impact of liquid phosgene on the seabed

5.3.1 Research [17] has been carried out into the octanol-water partition coefficient of phosgene to determine the potential for phosgene to either adsorb to the sediment or remain in the water. The study shows that, although phosgene can adsorb to the sediment particles, it is more likely for it to partition into water and subsequently be hydrolysed. HELCOM and the Scottish Office [5 & 6] has carried out research to determine if the dumping of munitions has caused contamination of the seabed but no contamination from phosgene has been found. This could be due to a number of reasons:

- a. phosgene has leaked out of dumped munitions and has not spread widely enough to be identified in the surveys;
- b. there has not been a leak of phosgene; or
- c. when phosgene leaks out, it is broken down so quickly that it does not cause lasting contamination.

5.3.2 The studies showing that the sediment and aquatic organisms are not contaminated with chemical warfare agents have been carried out recently but the dumping of phosgene filled munitions was thought to have been carried out from 1945 to 1946. It is therefore possible that phosgene leaked out of the munitions many years ago and any evidence of contamination or toxic effects has long since disappeared. Even if this is not the case, and phosgene filled munitions remain, it is unlikely that any sampling should coincide with a recent release since the effects will necessarily be restricted to a very small area close to the point of origin. In addition, phosgene is not a persistent poison but, due to its corrosive nature, causes acute, possibly permanent, damage to the tissues with which it comes into contact. Any persistent evidence would therefore be restricted to dead plant or animal material, or possibly scarring on organisms not immediately killed. It is unlikely that samples of flora and fauna will be collected showing recent damage from phosgene.

5.3.3 From this it can be concluded that phosgene or its breakdown products may well cause acute damage to flora and fauna but it is unlikely that evidence will be found. It is possible that the flora and fauna that were surrounding the munitions when phosgene leaked out would be adversely affected. This could be primarily from the phosgene itself or from hydrochloric acid (the product of hydrolysis) although this is less likely as it would be rapidly neutralised by the alkaline seawater.

5.4 **The likely effects with two test scenarios.**

5.4.1 The best and worst case credible scenarios for a leakage of phosgene into the sea could be:

- Best case - Single munitions leaking over time as the walls of the warhead are corroded. Approximately 4.7kgs of phosgene would leak out.
- Worst case - Nearby detonation of a munition causing the breaching of a whole pallet load of phosgene munitions leading to the simultaneous release of the entire contents. It is estimated that the total pallet load could contain between 188kgs and 376kgs of phosgene depending on whether the pallet consists of warheads only or complete rounds (rockets and warheads). The figures are an educated guess as the numbers of munitions packed onto a single pallet are not known. Further information is included in Appendix A.

5.4.2 The first, and probably most important, thing that can be said is that the amount of phosgene released will not make any difference at the surface of the sea since, whatever the quantity, it will remain on the bottom until it has dissolved and hydrolysed. This means that whether one munition or a whole pallet load is breached there will be no hazard to humans at the surface. The main difference that can be expected between the two scenarios will be on the persistence of liquid phosgene on the seabed. Persistence is related to the surface area to volume ratio and, since there is a factor of 80 between mass of phosgene in a single munition compared to a complete pallet load, the larger amount would be expected to persist for significantly longer.

6 Conclusions

- 6.1 Phosgene released into seawater at depth consistent with dumping of munitions following WWII will remain a dense liquid that will stay on the seabed and not rise to the surface. It is therefore not expected that phosgene released from munitions in Beaufort's Dyke could cause any harm to people in vessels on the sea surface.
- 6.2 Phosgene leaking from munitions on the sea bed will slowly dissolve into the water where it will rapidly hydrolyse to harmless products. Contamination of the water will therefore not occur.
- 6.3 The rate of dissolution of liquid phosgene is not known and pools of corrosive liquid phosgene could persist for significant periods of time on the sea bed.
- 6.4 From past studies around Beaufort's Dyke [6] no contamination from chemical warfare agents, including phosgene, has been found in fish, shellfish or in the sediment of the seabed. However, any effects would be acute, local and probably short term so it is likely that they would have been missed by infrequent sampling.
- 6.5 More research would be needed to determine if phosgene is sufficiently persistent to cause significant harm to flora and fauna in the immediate area surrounding a leak from a munition on the seabed.

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APPENDIX A Deep Sea Dumping of 5 inch rockets at Beaufort's Dyke

A-1 Brief Description of Ammunition

A-1.1 The warhead of the 5 inch rocket was developed from the Light Cased (L.C.) 30lb Aircraft Bomb shown below in Figure A-1.



Figure A-1 - The 30lb Light cased aircraft Bomb.

- A-1.2 Although there were many variations and types of 30lb aircraft bomb the two primary chemical bombs were the Mk1 and Mk2. The Mk1 bomb employed a gunpowder burster in the nose that was designed to function on impact and thus produce an overpressure within the bomb body. The rear closure of the bomb was then ruptured by the overpressure which led to the ejection of the tail unit followed by the contents of the bomb.
- A-1.3 The Mk2 bomb was very similar in appearance to the Mk1 bomb but it did not possess any explosive components. The bomb was intended for use on hard targets and buildings and was designed to break up on impact.
- A-1.4 The 5-inch Unstabilised (U) Mk1 Rocket utilised the warhead of the 30lb aircraft bomb. In place of the bomb tail unit a cordite charged rocket motor was fitted. The warhead was also fitted with a high explosive impact fuze designed to detonate a burster fitted in the nose. Alternative sources describe the burster as either consisting of TNT or CE (known in the US as Tetryl). Photographs of the warhead and motor are shown below at Figure A-2.



Figure A-2 - The warhead and motor of the 5-inch Rocket

A-1.5 The weight of agent charged into the rockets varies depending on the information source however it is in the region of 4.7kgs of phosgene (CG) per rocket.

A-2 Method of Disposal

A-2.1 It is believed that 14,500 tons of 5-inch rockets were dumped in the sea at Beaufort’s Dyke in July 1945. A number of questions arise when discussing this figure. Mainly:

- Is this the all up weight of the munitions dumped including packaging? The practice when carrying out recent deep sea dumping in the late 1980s was to ensure that the mass of the package was heavier than the equivalent volume of water so that it was guaranteed to sink to the bottom. This often involved the weighting of packages with scrap metal, inert munitions or even small arms ammunition. The potential quantity of CG could be much reduced if this was the case.
- Were the warheads dumped with the rocket motors? It is not known whether rocket motors and warheads were supplied within the same package or whether they were mated at the firing point. This may affect the way that the munitions were destroyed. There are a number of scenarios that could result. Table 1 below briefly outlines a few scenarios.

Pack Option	Disposal Rocket	Disposal Warhead	Remarks	Likelihood
Packaged together in same box	Remove rocket and dispose of separately by alternative means.	Dump	1. Manpower intensive to un-package warheads and weight boxes. 2. Rockets would require further repackaging and disposal. 3. CG proportion of total mass dumped is increased.	Unlikely

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Pack Option	Disposal Rocket	Disposal Warhead	Remarks	Likelihood
Packaged together in same box.	Dump with rocket motor	Dumped with warhead	The quantity of CG as a percentage of the 14,500 tons may be greatly reduced, therefore the total mass of CG may be well under half of 14,500 tons.	Likely if rockets and warheads packaged together.
Packaged in separate boxes	Rockets disposed of separately by alternative means.	Dumped	1. Proportion of total mass of dumped material which is CG is increased significantly. 2. Increased manpower to mount a separate disposal operation.	Possible
Packaged in separate boxes	Rockets dumped at the same time	Dumped	The quantity of CG as a percentage of the 14,500 tons may be greatly reduced. Total mass of CG may be well under half of 14,500 tons. However the concentration of warheads in one pallet may be increased if the warheads were dumped then the rockets or vice versa.	Likely - It would be easier to dump the rocket motors at the same time even if they were in separate packages.

Table A-1 – Scenarios

A-2.2 The table above is not meant to be comprehensive and there are a number of other possible scenarios. It does, however, go some way to illustrate that it is likely that the rocket motors were dumped at the same time as the warheads and therefore the total amount of CG dumped may be considerably less than the 14,500 tons recorded.

A-2.3 It is also likely that munitions which were dumped from a moving vessel travelling along the trench. The most likely package to be dumped would be a pallet load as opposed to an individual box. This would mean that pallets of munitions would be scattered along the sea floor and not concentrated in a single area. An educated guess is that a pallet would contain about 40 complete rounds (both warhead and rocket motor) or 80 warheads. Over time the pallet bases and packages would decay leaving discrete piles of munitions, either with or without rocket motors.

A-3 Possible Pathways for CG Leaking into the Sea

A-3.1 The best and worst case credible scenarios for CG leakage into the sea would then be:

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- Best case - Single munitions leaking over time as the walls of the warhead are eroded. Approximately 4.7kgs of CG would leak out.
- Worst case - Nearby detonation of a munition causing the breaching of several munitions at once and leading to the simultaneous release of the contents of all of the CG from a pallet load of munition. The total pallet load would contain between 188kgs and 376kgs of CG depending on whether the pallet consists of warheads only or complete rounds. The figures are also an educated guess as the numbers of the numbers of munitions packed onto a single pallet are not known.

A-3.2 The warheads are constructed from thin sheet steel (approximately 4mm thick) which will undoubtedly corrode quite quickly over time. In general discussions with the Dstl CW munition disposal technicians it transpires that it is very rare (can't be remembered) to recover a CG filled 5'' warhead. Empty warheads are recovered from time to time which may have been CG filled. Therefore, without carrying out any further research into corrosion rates, the most likely case is as follows:

A-3.2.1 Rocket motors and warheads were dumped together and therefore the total amount of CG dumped is well under half of the 14,500kgs quoted.

A-3.2.2 The munitions were dumped in discrete piles as the ship travelled along the trench.

A-3.2.3 Munitions will leak individually and the contents slowly dissolve and hydrolyse.

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